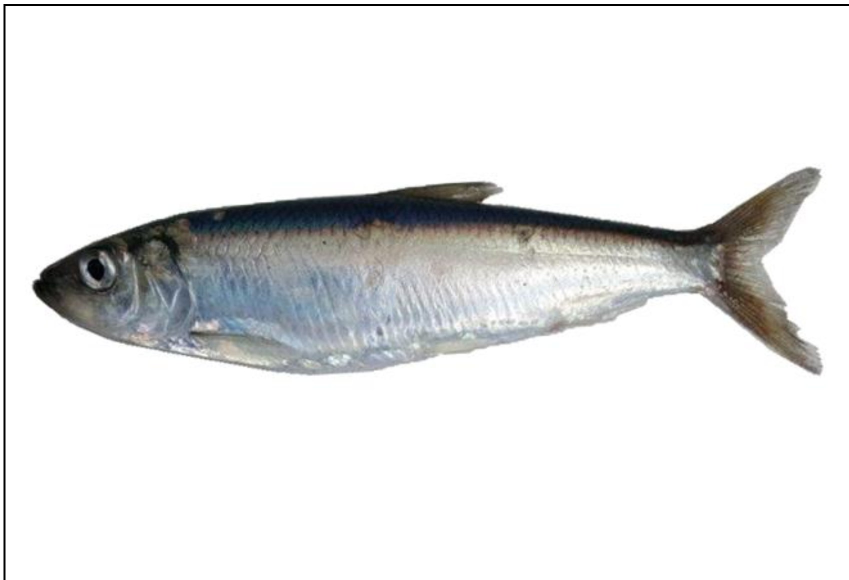
Draft California Pacific Herring Fishery Management Plan



Pacific Herring, *Clupea pallasii*.

Draft

August 08, 2019

California Department of Fish and Wildlife
Marine Region

Executive Summary

Pacific Herring (Herring), *Clupea pallasii*, support an important and historically significant commercial fishery in California. Four areas within the state have spawning stocks large enough to enable a fishery, including San Francisco Bay, Tomales Bay, Humboldt Bay, and Crescent City; however, over 90% of landings come from San Francisco Bay. Commercially, Herring are targeted for roe products, bait, and fresh fish. Since its onset in the winter of 1972, the sac-roe fishery (the eggs from gravid female Herring), has dominated landings, while landings in the whole fish sector are minor. A recreational Herring fishery also has taken place since at least the 1970s. The primary market for California's commercial Herring fishery is Japan, where Herring roe is considered a delicacy. Herring are also used as bait for salmon, *Oncorhynchus* spp., Pacific Halibut, *Hippoglossus stenolepis*, and Lingcod, *Ophiodon elongatus*, recreational anglers. Herring may also be smoked, pickled or canned for personal consumption.

The roe fishery was one of the most commercially valuable in California, reaching landings of more than 12,000 tons and an ex-vessel value of almost $20 million, but has since declined due to lower demand and competition from other Herring fisheries outside of California. Given the initial high value of sac-roe, high participation levels (more than 400 permits at its peak), and limited space in the San Francisco Bay, the Herring fishery benefitted from an intensive level of management.

Regulations changed annually as the fishery expanded, and many regulations were designed to address socio-economic rather than biological issues. Primary management measures used historically include but are not limited to limited entry, permits issued by lottery, individual vessel quotas, quota allocation by gear, a platoon system used to divide gill net vessels into groups, the transferability of fishery permits, and the conversion of permits between gear types. However, as the price and participation has continued to decline, particularly since the early 2000s, many of the regulations developed to manage a much larger fleet are outdated and no longer necessary. Additionally, despite concerns about an increasing level of take and potential for commercialization among the recreational Herring fishery, no restrictions on catch or effort for this sector have been established.

There were concerns about declining stock sizes in the late 1990s and early 2000s, and in response the Department began using more precautionary quota setting procedures. One of the primary goals of this Fishery Management Plan (FMP) was to further develop and codify this precautionary approach to ensure the sustainable management of California Herring into the future. In addition, Herring not only support commercial and recreational fisheries, but as forage fish they are a food source for many predatory fish, marine mammals, and seabirds within the California Current Ecosystem (CCE), providing an essential energetic link between primary producers and predators at the top of food chains. As such, a secondary goal was to develop a management approach that complies with the California Fish and Game Commission's (Commission) forage species policy, which seeks to recognize the importance of forage fish to the ecosystem and establishes goals intended to provide adequate protection to these species.

The overarching goal of this FMP is to ensure the long-term sustainable management of the Herring resource consistent with the requirements of the Marine Life Management Act (MLMA) and the Commission's forage species policy. In particular, it seeks to:

- provide a synthesis of relevant information on the species, its habitat, role in the ecosystem, and the fishery that targets it,
- integrate the perspectives and expertise of industry members and other stakeholders in the management process,
- identify environmental and ecosystem indicators that can inform management,
- provide an adaptive management framework that can detect and respond to changing levels of abundance and environmental conditions,
- specify criteria for identifying when a fishery is overfished,
- streamline the annual quota-setting process while ensuring that it is based on sound science,
- create an orderly fishery through an efficient permitting system,
- ensure that research efforts are strategic and targeted,
- use collaborative fisheries research to help fill data gaps,
- identify risks and minimize threats to habitat from fishing, and
- minimize bycatch to the extent practicable.

The MLMA requires that management changes be based on both the best available science as well as stakeholder input. Beginning in 2012, a Steering Committee (SC) including Herring fleet leaders, representatives from conservation non-governmental organizations (NGOs) and California Department of Fish and Wildlife (Department) staff evolved to develop a vision for the Herring FMP. This SC provided guidance throughout the FMP process and communicated the goals and strategies of the plan to their wider communities. In 2016 when the FMP development process was formally initiated, the scope of the FMP was presented to the California Fish and Game Commission (Commission) and refined via a public comment process. California Native American Tribes also were consulted. Permit holders were surveyed to gain input regarding potential regulatory changes. After the management strategy was developed, it was presented to the Commission and through other public meetings (both web-based and in-person) for stakeholder feedback.

Throughout the Herring FMP process, a number of scientific analyses, including a Management Strategy Evaluation (MSE) to develop and test a Harvest Control Rule (HCR), an analysis of correlations between herring productivity and environmental indicators, and a meta-analysis of dietary studies to better understand predator-prey relationships were conducted to ensure that the proposed management strategy had a solid scientific foundation. The management strategy was further refined based on the feedback of an external, independent peer review committee. While the Herring fishery is relatively data rich, a number of informational gaps were highlighted during this process, specifically related to the relationship between Herring, predator populations in the CCE, and alternative prey species. Additional information in these areas would allow the Department to more fully consider ecosystem impacts in future Herring management.

Management Strategy

This FMP proposes a management strategy that is based on an adaptive management framework that seeks to improve management of Herring in California through monitoring and evaluation, in order to better understand the interaction of different elements within marine systems. The management strategy consists of procedures to: 1) monitor Herring populations in the four management areas (San Francisco Bay, Tomales Bay, Humboldt Bay, and Crescent City Harbor), 2) analyze the data collected via the monitoring protocol to estimate Spawning Stock Biomass (SSB), 3) develop quotas based on current SSB using a HCR, 4) track indicators to monitor ecosystem conditions and adjust quotas as needed, and 5) additional management measures to regulate fishing.

The primary mechanism for ensuring stock sustainability in California's Herring management areas is to restrict harvest to a rate of no more than 10% of the estimated SSB by setting catch limits (quotas). This cap on the target harvest rate was agreed upon by a group of representatives from the fishing industry and conservation NGOs prior to beginning the development of this FMP as a means of continuing the precautionary management approach the Department has employed since 2004. Additional management measures are in place to ensure that harvest primarily targets age 4+ fish (mesh size restrictions), that spawning aggregations receive some temporal and spatial refuges from fishing (closed areas and weekend closures), and to minimize interactions between fishermen and concurrent users of the four management areas.

<u>Tiered Management Approach</u>

Implementing intensive surveys, like the annual spawn deposition surveys used to estimate the SSB in San Francisco Bay, in all four management areas is not feasible due to resource and staffing constraints. Thus, this FMP outlines a three-tiered management approach to help prioritize monitoring efforts and apply appropriate levels of management to fit the fishery activity level. Using this approach, each management area falls into one of three tiers based on the level of fishing occurring. Tier 3 has the highest level of fishing activity, Tier 2 is intermediate, and Tier 1 has the lowest level of fishing activity. The level of monitoring effort associated with each tier is dictated by the level of participation in the fishery. Quotas are determined based on the information available. As more information is available, higher harvest rates are available to participants, provided stock sizes can sustainably support higher levels of catch. When this FMP was first drafted, Tomales Bay, Humboldt Bay, and Crescent City Harbor were Tier 1 management areas, and the San Francisco Bay was the only Tier 3 management area.

Multi-Indicator Predictive Model to Estimate SSB

Setting quotas in Tier 3 management areas requires an estimate of the expected total SSB in the coming season in order to set a quota that will achieve the desired harvest rate. As part of the FMP development process, information on correlations between biological indicators of Herring stock health and environmental indicators were used to develop a predictive model to estimate the coming year's SSB. Although ecological indicators have been assessed yearly and presented as part of the annual season summary to the Director's Herring Advisory Committee (DHAC) for management recommendations and to provide context for the SSB estimate, they have not been used to quantitatively predict the SSB to set quotas prior to this FMP. The multi-indicator predictive model includes the following three indicators:

1. SSB_{year-1} – the observed spawn deposition from the previous season
2. YOY_{year-3} – the Catch Per Unit Effort (CPUE) of Young of the Year (YOY) Herring from April to October three years prior
3. $SST_{Jul-Sep}$ – The average Sea Surface Temperate (SST) between July and September prior to the upcoming season

The above-described model explains more variability, mechanistically supports what is known about Herring stocks, and reduces predictive error when compared to the current method. The synthesis of different environmental and ecosystem data into a multivariate forecasting equation may promote proactive, rather than reactive, management, and foster an interdisciplinary approach to ecosystem-based fisheries management. The currently used method is available as a backup should data be unavailable or should environmental changes compromise the predictive power of the model.

Harvest Control Rule

A key provision of this FMP is a HCR for California's Herring fishery to ensure that quotas are appropriate given the current SSB, and that intended harvest percentages (target harvest rates) are no more than 10 percent (%). The HCR developed for San Francisco Bay includes a SSB cutoff at 15,000 tons, below which no fishing can occur and the quota for the coming season will be zero. Developed in consultation with Department staff and stakeholders and tested using MSE, the HCR is used to set appropriate quotas in Tier 3 management areas. The HCR developed is based on the current precautionary management approach and provides a predetermined method for setting initial quotas each year based on SSB estimates.

Assessing Ecosystem Indicators

Given Herring's role as a forage species in the CCE, one of the primary goals of this FMP was to develop a transparent procedure for incorporating ecosystem considerations into Herring management. A set of ecosystem indicators was selected based on scientific analysis to provide a holistic view of predator-prey conditions in the system. These indicators are arranged in a decision tree to assist Department staff in determining whether additional quota adjustments are warranted. Additional environmental indicators were also chosen to provide information on the general health and productivity of the CCE, ensuring that decisions about the Herring stock are placed in the context of the larger ecosystem. The status of these additional indicators will be periodically described in an Enhanced Status Report.

Additional Management Measures

Existing management measures were evaluated during the FMP development process to ensure alignment with the overall management strategy proposed for California's Herring fishery. At this time, no changes are recommended for restrictions on catch, areas open to fishing, size, sex, or gear. Existing management measures to reduce impacts to habitat, as well as bycatch and discards were also found satisfactory.

Based on stakeholder input, this FMP institutes a single start (02 January) and end date (15 March) for all four management areas, compared to previously each had their own season dates.

Changes to streamline and modernize the regulations

The FMP development process provided an opportunity to modify existing Herring regulations for the gill net, Herring Eggs on Kelp (HEOK), and recreational fisheries. The goal of these changes was to meet the needs and capacity of the modern fleet, standardize and clarify the regulatory language across sectors and areas, and to make the regulations consistent with those used in other fisheries in California.

Gill net Fishery – The platoon system, and the complex permitting associated with that system, was developed for a much larger fleet and is no longer necessary in San Francisco Bay. To modernize the Herring gill net fishery regulations, the following regulatory changes will be made:

- convert all permit types to a single permit that allows holders to fish every week of the season in order to eliminate the platoon system in San Francisco Bay,
- establish a long-term capacity goal of 30 permits under the new permitting system,

- eliminate the paperwork associated with substitution by allowing anyone who possesses a valid California Commercial Fishing License to operate a Herring fishing vessel provided the permit is onboard and that vessel has been designated,
- require that gill nets be marked with the Fishing Vessel Number designated on the permit to track fishing activities,
- remove yearly quota specification from regulations, and instead set quotas via the HCR under the authority of the Director of the Department,
- reduce the permit cap from 35 to 15 in Tomales Bay,
- establish new conservative quotas for Tier 1 and 2 fisheries,
- adjust regulations to promote collaborative research between the Department and the fishing industry, and
- alter and update the permitting process.

HEOK – To streamline the HEOK fishery sector, the following regulations changes were determined via the FMP development process:

- restructure the permitting process such that HEOK permits are completely separate from the gill net permits,
- bring HEOK fees in line with those paid by the gill net sector,
- streamline notification requirements,
- require vessels, rafts and lines to display the Fishing Vessel Number designated on the permit to track fishing activities,
- require cork lines to be marked at each end with a contrasting-colored buoy for easier maneuverability.

Recreational Regulations – Prior to this FMP, there was no limit for the recreational take of Herring. To address this, the FMP recommends a range between 0 and 100 pounds, which is equivalent to up to 10 gallons (or two 5-gallon buckets), as a daily bag limit. This established bag limit is easily enforceable and provides for a satisfying recreational experience while deterring illegal commercialization of the fishery.

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List of Acronyms

APA	Administrative Procedure Act
BL	Body length
CCE	California Current Ecosystem
CCIEA	California Current Integrated Ecosystem Assessment
CCR	California Code of Regulations
Cefas	Centre for Environment, Fisheries and Aquaculture Science
CEQA	California Environmental Quality Act
CESA	California Endangered Species Act
CDFW	California Department of Fish and Wildlife
CI	Condition Index
Commission	California Fish and Game Commission
CPUE	Catch per Unit Effort
CRFS	California Recreational Fisheries Survey
DED	Draft Environmental Document
Department	Department of Fish and Wildlife
DHAC	Director's Herring Advisory Committee
ED	Environmental Document
EFI	Essential Fishery Information
EIR	Environmental Impact Report
ENSO	El Niño Southern Oscillation cycle
ESA	Federal Endangered Species Act
ESU	Evolutionarily Significant Units
FED	Final Environmental Document
FGC	Fish and Game Code
FMP	Fishery Management Plan
GOF	Gulf of the Farallones
HEOK	Herring Eggs on Kelp
HCR	Harvest Control Rule
Legislature	California State Legislature
LTMS	Long Term Management Strategy
M	Mortality, often reported as an instantaneous natural mortality
MEI	Multivariate ENSO Index
MLMA	Marine Life Management Act
MLLW	Mean Lower Low Water
MOCI	Multivariate Ocean Climate Indicators
MSE	Management Strategy Evaluation
NDBC	National Data Buoy Center
NOAA	National Oceanic and Atmospheric Administration
NOP	Notice of Preparation
NPGO	North Pacific Gyre Oscillation
PAHs	poly-aromatic hydrocarbons
PDO	Pacific Decadal Oscillation

PRC	Public Resources Code
SFBHRA	San Francisco Bay Herring Research Association
SSB	Spawning Stock Biomass
SST	Sea Surface Temperature
YOY	Young of the Year

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Acknowledgements

The California Pacific Herring (Herring) Fishery Management Plan (FMP) is the result of collaboration among many individuals and organizations. The Steering Committee, a group of stakeholders representing the Herring fleet (represented by Nick Sohrakoff and Harold Janiro), conservation groups (represented by Anna Weinstein and Geoff Shester), and Department of Fish and Wildlife (Department) staff, including retired Environmental Program Manager, Tom Barnes, Environmental Program Manager, Kirsten Ramey, and Environmental Scientist, Ryan Bartling, provided input throughout the FMP process, secured funding and contractors, and communicated the goals and strategies of the plan to their wider communities. The Director's Herring Advisory Committee have worked collaboratively over the years with the Department and were instrumental in the development of the permit consolidation proposal. The San Francisco Bay Herring Research Association provided funding to the Center for Environment, Fisheries and Aquaculture Science for development of a stock assessment model for the San Francisco Bay Herring stock. Thank you to Dr. Harold Geiger, Dr. Nathan Taylor, and Jake Schweigert for providing an independent review of the stock assessment model, which ultimately informed the Management Strategy Evaluation for this FMP. The Farallon Institute provided work on trophic interactions affecting the Herring stock in San Francisco Bay and development of a model to predict spawning stock abundance each year. Independent peer review greatly improved the FMP and we thank the organizers of that effort, Ocean Science Trust, and the scientific experts including Dr. Elliott Hazen, Dr. Dan Okamoto, Dr. Rebecca Selden and Dr. Cody Szuwalski. Finally, the National Fish and Wildlife Foundation provided the necessary funding to support the Project Management Team, composed of Dr. Sarah Valencia, Huff McGonigal, and David Crabbe. The Ocean Protection Council supported the FMP peer review process and funds for this FMP were administered by the California Wildlife Foundation.

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Chapter 1. Introduction

The Marine Life Management Act (MLMA) is California's primary fisheries management law. It directs the Department of Fish and Wildlife (Department) to ensure the sustainable use of the state's living marine resources (Fish and Game Code [FGC] §7050(b)). The MLMA also identifies Fishery Management Plans (FMPs) as the primary tool for achieving this goal (FGC §7072). FMPs are comprehensive planning documents that outline what is known about a species, the characteristics and impacts of the fishery that targets it, and how that fishery is to be managed and monitored once the FMP is implemented. The Department is responsible for drafting FMPs and presenting them to the California Fish and Game Commission (Commission) for adoption. New regulations required to implement a FMP are promulgated through a separate Commission rulemaking process, and are codified in Title 14 of the California Code of Regulations (CCR).

This FMP for Pacific Herring (Herring), *Clupea pallasii*, was first presented to the Commission in June 2019 and was adopted in October of 2019. Its goals, development process, and contents are described below.

1.1 Goal and Principal Strategies

Herring have supported commercial and recreational fisheries in California for more than one hundred years. They are also an important forage species in the California Current Ecosystem (CCE). The overarching goal of this FMP is to promote the long-term sustainable management of the Herring resource consistent with the requirements of the MLMA and the Commission's policy on forage fish. In particular, it seeks to:

- provide a synthesis of relevant information on the species, its habitat, role in the ecosystem, and the fishery that targets it;
- integrate the perspectives and expertise of industry members and other stakeholders in the management process;
- identify environmental and ecosystem indicators that can inform management;
- provide an adaptive management framework that can quickly detect and respond to changing levels of abundance and environmental conditions;
- specify criteria for identifying when a fishery is overfished;
- streamline the annual quota-setting process while ensuring that it is based on sound science;
- create an orderly fishery through an efficient permitting system;
- ensure that research efforts are strategic and targeted;
- use collaborative fisheries research to help fill data gaps;
- identify risks and minimize threats to habitat from fishing; and
- minimize bycatch to the extent practicable.

Specific strategies for achieving these goals are identified and described in the relevant chapters of the FMP.

1.2 Collaborative Development Process

A barrier often facing FMP development in California has been the significant financial and staff resources required for their preparation. These resource constraints have translated to relatively few FMPs being developed since the MLMA was enacted in 1999. To help overcome this challenge, beginning in 2012, Herring fleet leaders, representatives from conservation non-governmental organizations (NGOs), and Department staff began a discussion group to develop a vision for a Herring FMP. Through regular meetings over a four-year period, the discussion group identified a new, more collaborative approach to FMP development that preserved Department control while utilizing outside resources and expertise. The resulting process for FMP development is intended to be used as a test case and a potential model for future FMPs for other fisheries.

The MLMA places great emphasis on constituent involvement in decisions regarding marine resources, as well as collaboration among stakeholders. This Herring FMP has sought to incorporate stakeholder feedback throughout its development process and has done so in a number of ways. Prior to initiation of the Herring FMP, the discussion group worked to develop a "blueprint" outlining the broad scope and goals for the FMP development process, as well as the scientific analyses required to meet those goals. Industry and conservation stakeholders agreed to a broad outline for a Harvest Control Rule (HCR) to set yearly quotas, namely, that it would emulate the Department's precautionary management approach by capping target harvest rates at 10 percent (%) of the most recently estimated biomass, and include ecosystem indicators to further inform management. This agreement helped to reduce conflict between stakeholder groups and helped to focus scientific efforts. The discussion group evolved into a more formalized Steering Committee (SC) in 2016. The SC provided feedback and guidance throughout the FMP development process, and helped communicate the goals, objectives, and strategies of the FMP to their wider constituencies. Results of research conducted as part of FMP development were also shared with the SC iteratively throughout the process, and as a result the management strategy in this FMP reflects both the best available science as well as a high degree of stakeholder involvement.

Once the FMP development process was formally initiated in April of 2016, the scope of the FMP was presented to the Commission, and was further refined via the public scoping process, as well as through Tribal consultation. In addition, a survey of all Herring permit holders was conducted to understand the desire and need for regulatory changes, and the results of this survey were used to develop regulatory proposals. Once a management strategy was developed, it was presented to the Commission through the Marine Resources Committee. It was also presented at other public meetings (both web-based and in-person), and feedback from stakeholders was solicited and incorporated.

1.3 Fishery Management Plan Contents

Sections 7080-7088 of the MLMA describe in detail the required contents of FMPs and the Department's 2018 Master Plan for Fisheries includes guidance regarding how specific issues should be addressed. The structure and content of this FMP are based on the direction they provide.

The FMP first provides an overview of what is known about the natural history of the species and its role in the ecosystem (Chapters 1-3). It then describes the Herring fishery and the history of its management and monitoring (Chapters 4-6). The core of the FMP is Chapter 7, which outlines an integrated approach to monitoring, assessment, and management of the fishery moving forward. Chapter 7 includes a discussion of measures to promote sustainability of the stock and management of bycatch and habitat impacts. The FMP includes a chapter on alternative projects considered during FMP development. The FMP also includes a chapter focused on future research and management needs (Chapter 8), a chapter that describes what actions can be taken through rulemaking under the FMP and those that require a FMP amendment (Chapter 9), a chapter that includes an analysis of alternative management actions (Chapter 10) and a final chapter that includes literature cited (Chapter 11). The appendices provide additional detail on the FMP's development history, monitoring efforts, and modeling approaches and outcomes (Appendices A-P). Under Section 7088 of the MLMA, FMPs have the ability to render conflicting statutory law inoperative once adopted by the Commission. The FMP contains a list of these conflicting statutory provisions that will be made inoperative in Chapter 9.

1.4 Environmental Document under the California Fish and Game Commission's Certified Regulatory Program

This document is also intended to fulfill the Commission's obligation to comply with the California Environmental Quality Act (CEQA) [Public Resources Code (PRC) §21000 et seq.] in considering and adopting an FMP, and associated implementing regulations. In general, public agencies in California must comply with CEQA whenever they propose to approve or carry out a discretionary project that may have a potentially significant adverse impact on the environment. Where approval of such a project may result in such an impact, CEQA generally requires the lead public agency to prepare an Environmental Impact Report (EIR). In contrast, where no potentially significant impacts could result with project approval, a lead agency may prepare what is commonly known as a negative declaration. Where an EIR is required, however, the document must identify all reasonably foreseeable, potentially significant, adverse environmental impacts that may result from approval of the proposed project, as well as potentially feasible mitigation measures and alternatives to reduce or avoid such impacts. Because the lead agency must also subject the EIR to public review and comment, and because the agency must respond in writing to any public comments raising significant environmental issues, compliance with CEQA serves to protect the environment and to foster informed public decision-making.

CEQA also provides an alternative to preparation of an EIR or negative declaration in limited circumstances. Under CEQA, the Secretary of Resources is authorized to certify that a state regulatory program meeting certain environmental standards provides a functionally equivalent environmental review to that required by CEQA [PRC §21080.5; see also CEQA Guidelines, CCR Title 14 §15250- 15253]. As noted by the California Supreme Court, "[c]ertain state agencies, operating under their own regulatory programs, generate a plan or other environmental review document that serves as the functional equivalent of an EIR. Because the plan or document is generally narrower in scope than an EIR, environmental review can be completed more expeditiously. To qualify, the agency's regulatory program must be certified by the Secretary of the Resources Agency. An agency operating pursuant to a certified regulatory program must comply with all of CEQA's other requirements" [*Mountain Lion Foundation v. Fish and Game Comm.* (1997) 16 Cal.4th 105, 113-114 (internal citations omitted)].

The Commission's CEQA compliance with respect to the Herring FMP and associated regulations is governed by a certified regulatory program [CEQA Guidelines, CCR Title 14 §15251, subd. (b)]. The specific requirements of the program are set forth in CCR Title 14 in the section governing the Commission's adoption of new or amended regulations, as recommended by the Department (CCR Title 14 §781.5). Pursuant to CCR Title 14 §781.5, this Environmental Document (ED) contains and addresses the proposed Herring FMP and associated implementing regulations, and reasonable alternatives to the proposed Herring FMP. In so doing, the ED is intended to serve as the functional equivalent of an EIR under CEQA. As noted above, however, preparation of the ED is not a "blanket exemption" from all of CEQA's requirements [*Environmental Protection Information Center v. Johnson* (1985) 170 Cal.App.3d 604, 616-618; see also *Wildlife Alive v. Chickering* (1976) 18 Cal.3d 190]. Instead, the Commission must adhere to and comply with the requirements of its certified program, as well as "those provisions of CEQA from which it has not been specifically exempted by the Legislature" [*Sierra Club v. State Board of Forestry* (1994) 7 Cal.4th 1215, 1228].

1.4.1 Proposed Action

For purposes of CEQA and this ED, the proposed action consists of the adoption of the Herring FMP and its associated implementing regulations that govern Herring fishing activities in California, as outlined in Chapter 7. The various management tools and alternatives available will be described including the stated policies, goals, and objectives of FMPs under the MLMA. The Herring FMP will continue to be managed through ongoing oversight and management of the fishery by the Commission.

1.4.2 Scoping Process

As discussed above, the MLMA calls for meaningful constituent involvement in the development of each FMP. In addition, CEQA requires public consultation during lead agency review of all proposed projects subject to a certified regulatory program [See PRC §21080.5 (d)(2); see also CCR Title 14 §781.5). The adoption of the Herring FMP and its associated implementing regulations is such a project under CEQA. In addition to the requirements of the MLMA, CEQA requires public consultation on all environmental projects. The Department accomplishes this through a public comment period, scoping sessions within the communities involved, or at least two Commission meetings. As outlined above in Section 1.2, the Department went through a multi-phased iterative process with stakeholder groups as well as the SC in development of this FMP.

In August 2018, the Commission, with support from the Department, prepared and filed a Notice of Preparation (NOP) with the State Clearinghouse for distribution to appropriate responsible and trustee agencies for their input and comments. Further, the notice was provided to individuals and organizations that had expressed prior interest in regulatory actions regarding Herring. On behalf of the Commission, the Department held a scoping meeting on August 25, 2018. Appendix Q contains a copy of the notices as well as a summary of all comments received during the scoping period

1.4.3 Tribal Consultation

Pursuant to CEQA §21080.3.1, as well as the Department's Tribal Communication and Consultation Policy, the Department and Commission provided a joint notification to tribes in California. The letters to the individual tribes were mailed on August 1, 2018. The Commission received a response confirming that the proposed project is outside of the Aboriginal Territory Stewarts Point Rancheria Kashia Band of Pomo Indians. The Indian Canyon Band of Costanoan Ohlone People requested a Native American Monitor and an Archaeologist be present on site at all times if there is to be any earth movement within a quarter of a mile of any culturally sensitives sites. The Department confirmed the project does not involve any earth movement within a quarter mile of any culturally sensitive sites.

The Department initially informed tribes that a FMP for Herring was being developed in a letter dated July 5, 2016. As a follow-up to the initial introduction by mail, Department staff met with Graton Rancheria staff per requested on September 20, 2016 to provide additional details on the FMP process and scope. A subsequent letter soliciting tribal input on the management objectives outlined in the FMP was mailed to tribes on March 28, 2018. Appendix Q contains copies of the tribal notification letters.

1.4.4 Public Review and Certification of the Environmental Document

The Commission's certified regulatory program and CEQA itself require that the Draft ED (DED) be made available for public review and comment (CCR Title 14 §781.5(f); PRC §21091). Consistent with these requirements, and upon the filing with the Commission of the draft Herring FMP and implementing regulations proposed by the Department, as well as the filing of the same documents with the State Clearinghouse at the governor's Office of Planning and Research, the DED will be made available for public review and comment for no less than 45 days. During this review period, the public is encouraged to provide written comments regarding the DED to the Commission at the following address:

California Fish and Game Commission
P.O. Box 944209
Sacramento, California 94244-2090

Additionally, oral testimony regarding the proposed Herring FMP and DED will be accepted by the Commission at the public meetings announced under a separate cover. Public notice of the Commission meeting will be provided as required by the FGC.

The Department is required by law to prepare written responses to all comments on the DED and proposed Herring FMP received during the public review period that raise significant environmental issues (CCR Title 14 §781.5(h); see also PRC §21092.5). In some instances, written responses to comments may require or take the form of revisions to the DED or the proposed Herring FMP, or both. Any such revisions, along with the Department's written responses to comments raising significant environmental issues shall constitute the Final ED (FED). The Commission will consider the FED and the proposed Herring FMP at a public hearing scheduled to be held in San Diego on October 9-10, 2019. Public notice of the Commission meeting will be provided as required by CEQA and the FGC. Notice of any final decision by the Commission regarding the FED and Herring FMP will be provided to the extent required by law.

Chapter 2. Biology of the Species

This chapter describes what is known about the natural history and population dynamics of Herring stocks in California. When information is unavailable for California stocks, information from other Herring stocks along the coast of North America is summarized. This chapter is intended to be a resource for understanding the biology of the stock as it pertains to management.

2.1 Natural History of the Species

The Herring is a member of the family Clupeidae, which also includes the Pacific Sardine, *Sardinops sagax caeruleus*, and American Shad, *Alosa sapidissima*. Historically, Herring were thought to be a subspecies of Atlantic Herring (*C. harengus*) (Blaxter, 1985). However, recent taxonomic literature has designated the Herring a separate species (Grant, 1986; Robins and others, 1991). *C. pallasii* is thought to have diverged from Atlantic Herring soon after the opening of the Bering Strait about 3.5 million years ago (Grant, 1986; Liu and others, 2011). Herring have persisted through many climatic fluctuations, such as the glacial-interglacial cycles of the Pleistocene epoch, though their range has shifted over time in response to oceanic cooling and warming cycles (Liu and others, 2011).

Herring are dark blue to olive green on their backs and silver on their sides and belly (Figure 2-1) and this coloration helps reduce predation in a visual environment (National Oceanic and Atmospheric Administration, 2014b; Sigler and Csepp, 2007). Herring can grow up to 46 centimeters (18 inches (in)) in the northern parts of their range (National Oceanic and Atmospheric Administration, 2014b). The body is elongate with a deeply forked caudal fin, and a lateral line on each side of the fish (Hourston and Haegele, 1980; Lassuy and Moran, 1989). The mouth is terminal, moderate in size, without teeth, and directed moderately upward, with a protruding lower jaw (Hourston and Haegele, 1980; Lassuy and Moran, 1989). This allows adult and juvenile Herring to switch between particulate feeding and filter-feeding modes depending on prey size (Blaxter, 1985). Like all clupeids, Herring are physostomous, meaning that the swim bladder is connected to the gut and thus allows the fish to actively control its buoyancy (Blaxter, 1985; Carls and others, 2008b).

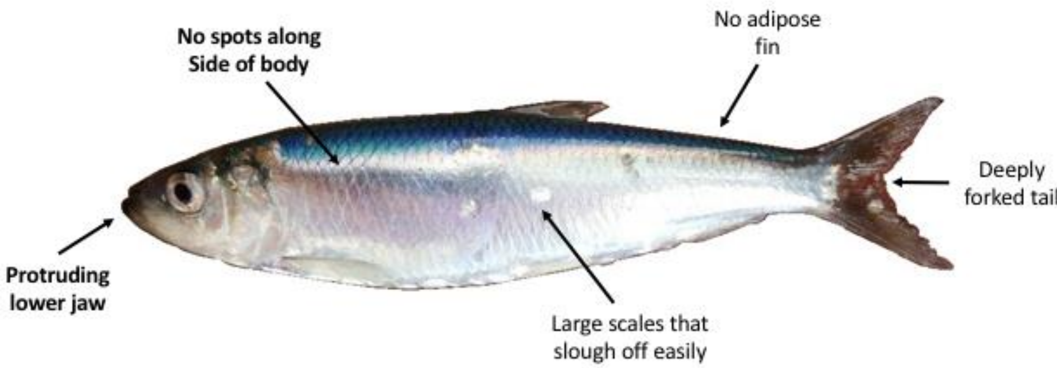

Figure 2-1. Herring, with identifying features noted.

2.2 Distribution of Herring

Herring are found throughout the coastal zone from Baja California to Alaska and across the north Pacific to Japan (Figure 2-2) (Spratt, 1981). A deep genetic division occurs between western and eastern Pacific populations (Hay and others, 2008; Liu and others, 2011). In the northeastern Pacific, it is thought that Herring exhibit three different life history forms: 1) a long-lived, migratory ocean form; 2) a coastal form that migrates short distances or not at all; and 3) a resident form that spends its life in low salinity estuarine systems (Beacham and others, 2008; Carls and others, 2008b). Herring distribution is heavily influenced by these differing life history strategies.

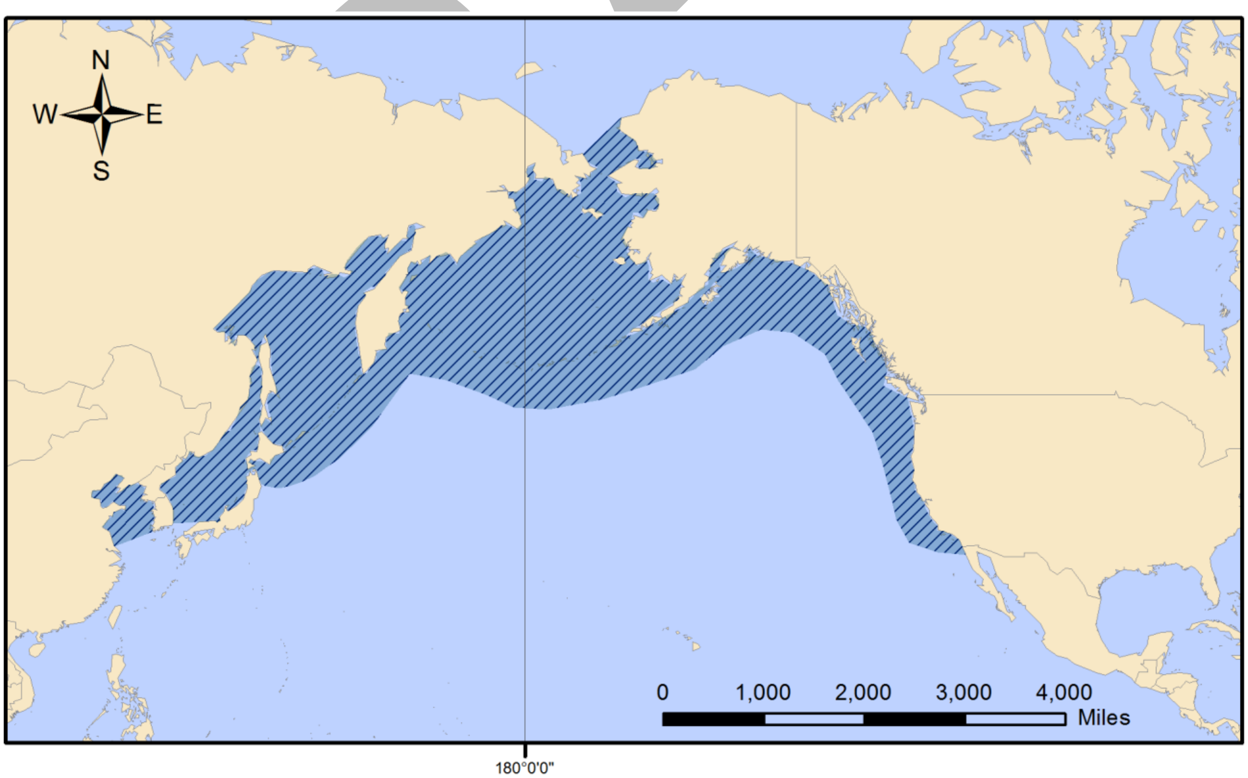

Figure 2-2. Approximate distribution of Herring throughout the northern Pacific.

2.3 Reproduction and Life Cycle

Herring spawn once per year in the winter (Hay and others, 2001; Watters and others, 2004). During the spawning season, Herring congregate in dense schools in the deep-water channels of bays while their gonads mature for up to two weeks, then gradually move inshore to intertidal and shallow subtidal areas of bays and estuaries (Californa Department of Fish and Game, 2015; Spratt, 1981). Spawning may be triggered by nighttime high tides (Spratt, 1981), neap tides (Hay, 1990), temperature (Hay, 1985), or lowered salinity due to fresh water inputs, though the mechanisms are not well understood. A homing instinct has been demonstrated in Canada (Tester, 1937) and it is possible that each spawning ground supports a stock that is distinct to some degree from adjacent stocks. However, the fluctuations in observed spawning locations in San Francisco Bay (Spratt, 1992; Watters and others, 2004) (Section 3.4, and Appendix D) suggest that other factors may influence choice of spawning location from year to year.

Herring display coordinated sexual behavior, in which a few sperm-releasing males can induce spawning behavior in a large number of fish (Hay, 1985; Rounsefell, 1930; Stacey and Hourston, 1982). During spawning, males release milt into the water column while females extrude adhesive eggs onto available substrate (Figure 2-3). Herring in California have been known to spawn on subtidal vegetation, such as eelgrass, *Zostera marina,* and red algae, *Gracilaria* spp., as well as rocks, shell fragments, and man-made structures, such as pier pilings, riprap, and boat hulls (Californa Department of Fish and Game, 2015). Sediment on the substrate may inhibit spawning (Stacey and Hourston, 1982). Spawn density varies from an egg or two per square meter of substrate to complete coverage in layers up to eight eggs thick (Spratt, 1981), and up to 16 eggs thick in San Francisco Bay.

Figure 2-3. Herring eggs on eelgrass.

Embryos (fertilized eggs) hatch in 8-14 days, determined mainly by water temperature (Californa Department of Fish and Game, 2015; Vines and others, 2000), producing slender, transparent larvae about 6-8 millimeter (mm) (0.2-0.3 in) long (Spratt, 1981). Warmer temperatures may lead to smaller egg size and earlier hatches. Incubation time was 6-10 days in water temperatures of 8-10 degrees Celsius (°C) (46-50 degrees Fahrenheit (°F)) in Tomales Bay (Miller and Schmidtke, 1956) and 10.5 days at an average water temperature of 10°C (50°F) in San Francisco Bay (Eldridge and Kaill, 1973). Larvae have a yolksac and limited swimming ability immediately after hatching. Their distribution is clumped, controlled largely by tidal factors (Henri and others, 1985). The duration of the yolksac stage is dependent on the amount of yolk present and temperature (Fossum, 1996).

The spawning season is followed by increasing temperature and productivity in San Francisco Bay, providing food for young Herring (Watters and others, 2004). At about three months of age and 38 mm (1.5 in) in length, Herring metamorphose into their adult form and coloration (Spratt, 1981). In San Francisco Bay, juvenile Herring typically stay in the bay through summer, and then most migrate out to sea (Californa Department of Fish and Game, 2015). They mature and spawn in their second or third year. Little is known about Herring from the time they leave inshore waters until they are recruited into the adult population at age two or three.

2.4 Spawning Season

In California, schools of adult Herring migrate inshore to bays and estuaries to spawn, beginning as early as October and continuing as late as April (Californa Department of Fish and Game, 2015). In San Francisco Bay, the spawning period is typically from November to March, with peak levels of spawning occurring most often from December through February (Watters and others, 2004).

Spawning becomes progressively later for stocks further north (Table 2-1). In Humboldt Bay and Crescent City Harbor spawns typically begin later compared to San Francisco Bay. The largest fish typically spawn early in the season and smaller fish spawn in subsequent waves (Reilly and Moore, 1985; Ware and Tanasichuk, 1989).

Table 2-1. Timing of Herring spawning season along the West coast of North America.

Location	**Spawning Season**
Gulf of Alaska and the southeast Bering Sea	March through May
British Columbia	January through May
Washington	Mid-January through early June
California	November through March

Figure 2-4 shows the magnitude and timing of all spawns observed in San Francisco Bay since 1973. Throughout the history of the fishery, 65% of observed spawns have been in areas around the Marin shoreline (Table 2-2), suggesting that the spawning grounds in and around Richardson Bay provide critical spawning habitat for the San Francisco Bay Herring population. The locations of spawns have changed over time. Some locations are used for several consecutive years and then abandoned. For example, Marin was the primary spawning area in the majority of seasons in the 1970s, but after a large storm in 1982-83 the San Francisco Waterfront became the dominant spawning location until the mid-90s (Spratt, 1992). Since the 2008-09 season, Point Richmond, in the North East Bay, has become an important spawning ground despite not being a historically important spawning ground.

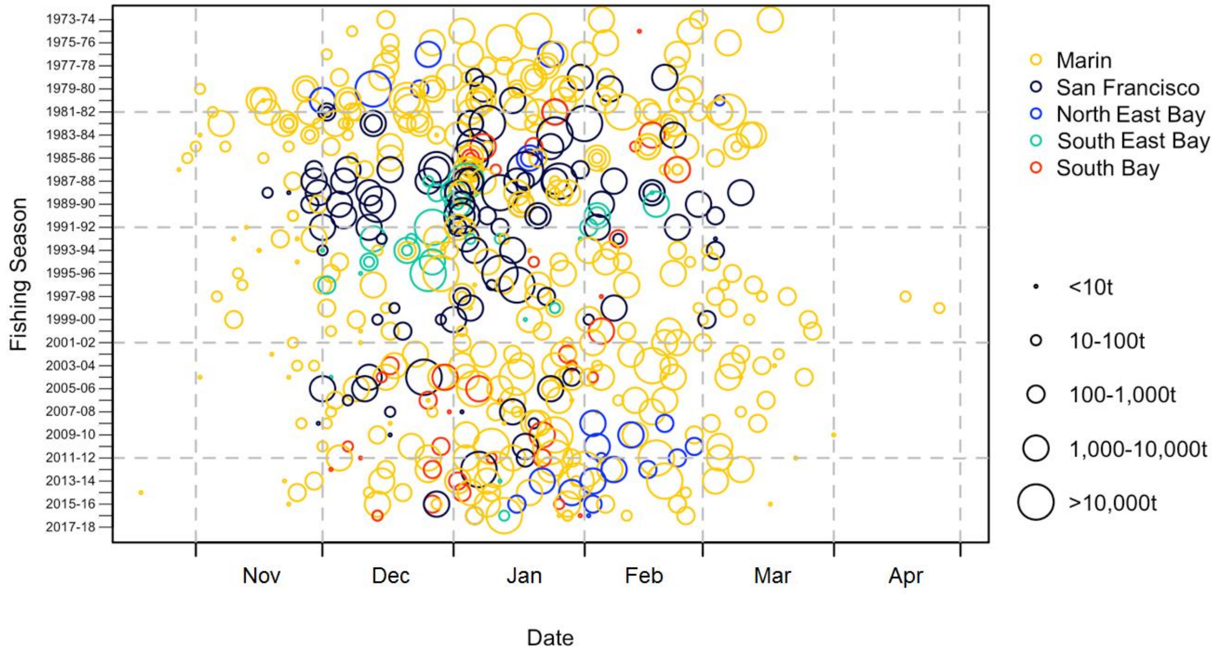

Figure 2-4. Distribution of dates (x-axis), magnitudes, and locations of observed spawns in San Francisco Bay from 1973-17 fishing seasons (y--axis). See Figure 2-12 for a map of these locations.

Table 2-2. Summary of observed spawns in five regions in San Francisco Bay. For a map of these locations see Figure 2-12.

Spawn Area	**Percent of Observed Spawns (1973-74 to 2016-17)**	**Average number of Spawns per year**	**Earliest date observed**	**Latest Date observed**	**Peak Month**
Marin	65.3	9	Oct 19 (2014)	Apr 26 (1999)	Jan
San Francisco	18.5	2.5	Nov 18 (1988)	Mar 10 (1989)	Jan
North East Bay	4.3	0.6	Dec 1 (1980)	Mar 5 (1981)	Feb
South East Bay	5.6	0.8	Dec 1 (1993)	Feb 18 (1990)	Dec
South Bay	6.3	0.9	Dec 3 (2015)	Feb 23 (1987)	Jan

2.5 Movement

Adult Herring move between spawning areas in the winter and feeding areas in the summer (Kvamme and others, 2000; Sigler and Csepp, 2007). During the spawning season (i.e., November through March in California), Herring congregate in dense schools and migrate inshore to intertidal and shallow subtidal areas of bays and estuaries (Moser and Hsieh, 1992; Spratt, 1981). During spring and summer months, Herring move offshore to feed, forming dense pelagic schools (Californa Department of Fish and Game, 2015; Carls and others, 2008b; Sigler and Csepp, 2007). Generally, they school close to the seafloor in continental shelf waters less than 200 meter (m) (656 feet (ft)) deep (Hay and McCarter, 1997) and at dusk they move towards the surface and feeding activity increases (Blaxter, 1985). The specific oceanic distribution of California's Herring stocks is unknown. The availability of suitable prey is likely the determining factor in Herring's migration pattern and behavior in the feeding period (Kvamme and others, 2000).

Most of what we know about Herring movement in California comes from observations of their behavior in bays during the spawning season (Section 2.2.3). Herring typically hold in deep water (>18 m) (>59 ft) for several days as they ripen for spawning (Watters and T. Oda, 2002), before moving in to intertidal and shallow subtidal areas to spawn (Watters and others, 2004). Spent Herring leave the bay soon after spawning and may travel over 150 kilometers (km)/week (93 miles (mi)/week) (Carls and others, 2008b; Watters and others, 2004). Many Young of the Year (YOY) Herring remain in the bay until summer and emigrate offshore between June and October (Fleming, 1999; Watters and others, 2004).

Little is known about the offshore movement of Herring in California. However, Herring have been collected in trawls in the Gulf of the Farallones (GOF) (Reilly and Moore, 1985) and landed commercially during summer months in Monterey Bay fishing port areas. There is also evidence that the Tomales Bay population moves offshore during the nonbreeding season while the San Francisco population remains onshore, moving down the coast to Monterey Bay (Moser and Hsieh, 1992). This is consistent with the thought that Herring in the northeastern Pacific exhibit a number of different life history strategies. Some Herring populations (i.e., Northern Bristol Bay Herring) are known to migrate as far as 2,100 km (1,304 mi) (Tojo and others, 2007), while others display more resident behavior (Beacham and others, 2008).

2.6 Diet and Feeding Behavior

Diet study data for Herring in California are incomplete, though studies have been conducted for other populations. In San Francisco Bay, a large portion of larval Herring diet is composed of tintinnids, a single-celled microzooplankton (Bollens and Sanders, 2004). Juvenile Herring feed on a variety of micro-plankton (diatoms, protozoans, bivalve veligers, and copepod eggs, nauplii, and copepodites) (Purcell and Grover, 1990). Juvenile Herring in shallow subtidal areas feed primarily on zooplankton (copepods and crab larvae) (Fresh and others, 1981).

Herring continue to feed on plankton throughout their life cycle, relying heavily on visual cues in feeding (Blaxter and Holliday, 1963). During the feeding season Herring also move diurnally to maximize access to prey, conserve energy, and avoid predation (Carls and others, 2008b). Adult Herring schools spend the day near the seafloor and move toward the surface at dusk, where feeding activity increases and fish scatter as light decreases (Blaxter, 1985). Herring may release gas from their swim bladders as they ascend (Thorne and Thomas, 1990). As light increases again at dawn, the school reforms and moves back into deeper water (Blaxter, 1985). This diel vertical migration cycle may be an adaptation for optimal feeding or to reduce predation (Blaxter, 1985).

Herring diet changes as a function of size, time of year, and habitat, and there may be very little direct competition for food between age classes (Californa Department of Fish and Game, 2015; Hay, 2002). Adult Herring in Alaska are known to feed on a variety of organisms, from euphausiids (krill) and copepods to salmon fry (Stokesbury and others, 1998). Adults will switch feeding forms (filter or particulate feeding) based on food concentration and size to maximize number of prey (Blaxter, 1985; Boehlert and Yoklavich, 1984; Gibson and Ezzi, 1985).

2.7 Natural Mortality

2.7.1 Annual Mortality Rates and Sources

Natural mortality is defined as all the sources of death for a fish population other than fishing (Ricker, 1975). Sources and annual rates of natural mortality for Herring differ at various life stages, with mortality typically being greatest during the first year of life (Table 2-3, Appendix A). Survival of eggs is highly variable, and thus a large number of eggs laid in a given year does not necessarily correlate with a strong year class (Watters and others, 2004). Larval survival is likely the major determinant of year class strength (Carls and others, 2008b), and a study in San Francisco Bay found the Catch Per Unit Effort (CPUE) of juvenile Herring in the bay (~3-8 months old) to be correlated with spawning biomass three years later (Sydeman and others, 2018). Once juveniles leave the bay (August-October) they begin to school to minimize predation risk (Carls and others, 2008b). Mortality rates for adult Herring worldwide are between 30 and 40% (Stick and others, 2014), though higher (and increasing) mortality rates have been documented in some Herring stocks.

Table 2-3. Summary of estimated natural mortality rates and sources for Herring at different life stages.

Life Stage	Mortality Rate	Sources of Mortality	Reference
Egg	66–100%	Wave action, predation, smothering by dense egg deposits, hypoxia, desiccation, temperature, and microorganism invasions	(Rooper and others, 1999)
Larvae - Post Hatch	0–50%	Physiological abnormalities, such as underdeveloped jaws, which leads to starvation	(Norcross and Brown, 2001)
Larvae - Dispersal Period	93–99%	Starvation or predation	(Norcross and Brown, 2001; Purcell and Grover, 1990)
Juveniles	1–98%	Starvation, competition, predation, and disease	(Norcross and Brown, 2001)
Adults	30 and 40% (with some estimates as high as 60%)	Predation, disease, starvation, competition, or senescence, and observed increases in mortality could also be caused by pollution or climatic shifts	(Bargmann, 1998; Gustafson and others, 2006; Stick and others, 2014)

2.7.2 Estimates for Instantaneous Mortality Rates

Mortality for fish is often reported as an instantaneous natural mortality (M) and is one of the most important and uncertain life history parameters in fishery management. In Herring populations estimates of M have varied substantially over time and life history stage (Cleary and others, 2017; Stokesbury and others, 2002). In British Columbia, M was found to increase with age from 0.21 to 0.67 between ages four and eight and was greater than 0.99 for older ages (Tanasichuk, 2000). In addition to varying with age, M has been found to vary over time, suggesting that it likely fluctuates in response to environmental conditions (Fisheries and Oceans Canada, 2016).

An age-structured stock assessment model commissioned for the San Francisco Bay Herring stock by the Centre for Environment, Fisheries and Aquaculture Science (Cefas) had difficulty estimating M for the San Francisco Bay Herring stock (Appendix B). Instead, values ranging from 0.27 to 0.61 (corresponding to annual mortality rates of 23-45%) were explored. In addition, this assessment explored increasing M in older (age six and older) Herring because it improved fits to the available data.

2.8 Maximum Age and Age Structure of the Population

Herring in California are considered a short-lived species and generally, few fish live longer than 9 years (yr), though longevity may exceed 15 yr (Ware, 1985). Maximum age of Herring increases with latitude (Carls and others, 2008b; Hay and others, 2008), with fish in northern populations living up to age 19 and fish in extreme southern populations typically living only 6 or 7 yr (Hay and others, 2008). The San Francisco population is towards the southern end of Herring's range and fish older than 7 yr do not form a large component of this stock.

Herring scales and otoliths can be used to determine the age of individual Herring. The Department has collected otoliths from the Herring research catch during each winter spawning season since 1982-83 to track the stock's age structure in San Francisco Bay (Figure 2-5). The age composition of spawning populations is influenced by dominant year classes and can vary considerably. For example, a strong recruitment event in 2009-10 was observed, but since then the proportion of age two fish observed in the research catch has declined, which may be attributed to unprecedented warm water and drought conditions from 2014-16, driven in part by the North Pacific Marine Heatwave (Chapter 3.2).

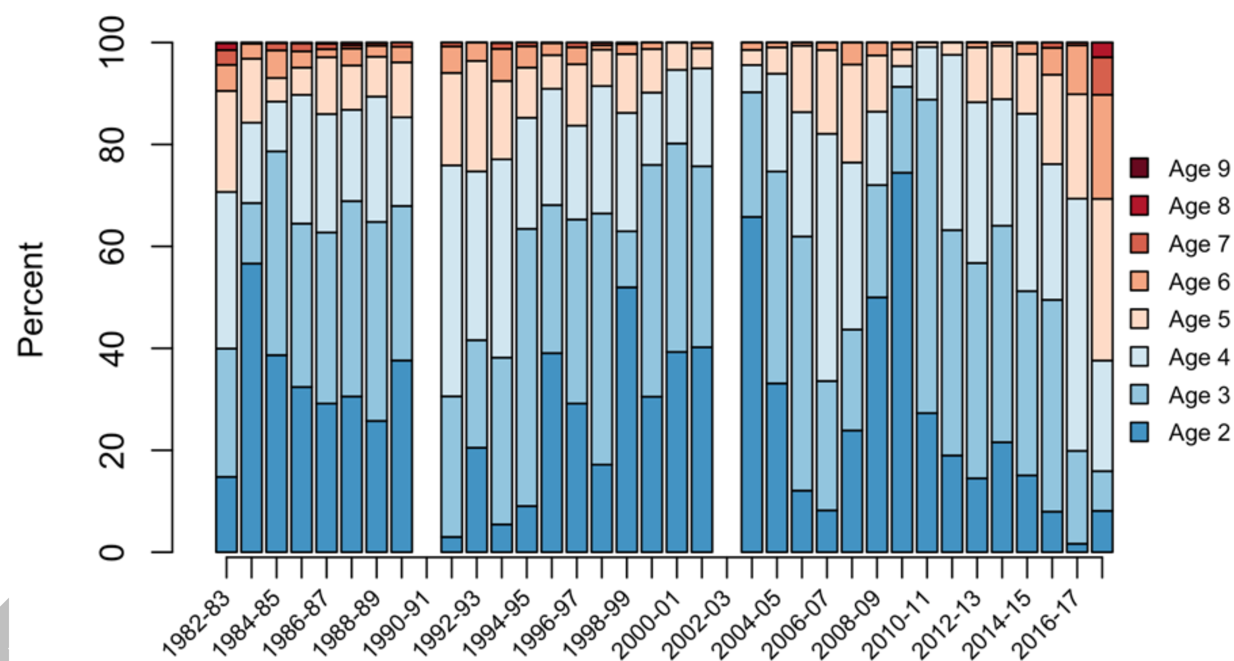

Figure 2-5. Observed age distribution of the research catch in San Francisco Bay, 1982-83 through 2017-18 seasons. Note that no sampling was conducted in the 1990-91 and 2002-03 seasons.

In the late 1990s and 2000s, a truncation in the age structure was observed, with few fish over age six recorded. This led to concerns that the harvest rate was negatively impacting the age structure of the stock, and fishing pressure was reduced due to lower harvest rates from 2004 onward. In recent years Department staff have observed an increase in older fish (age six and older) in their samples, indicating that 6 and 7 yr old Herring are once again present in the San Francisco stock.

Age structure data for the Humboldt Bay population were collected during the 1974-75 and 1975-76 season and provides information on the age structure of the stock when it was lightly fished (Table 2-4). The maximum age observed was 11, and almost 20% of the stock was over age eight. There are no recent data on the age structure from Humboldt Bay.

Table 2-4. Observed age composition in the Humboldt Bay stock between 1974-76 (Rabin and Barnhart, 1986).

Age	1974-75		1975-76	
	Number Sampled	**Percent**	**Number Sampled**	**Percent**
2	75	29.6	97	33.6
3	42	16.6	68	23.5
4	41	16.2	33	11.4
5	19	7.5	28	9.7
6	11	4.3	14	4.8
7	19	7.5	10	3.5
8	30	11.9	25	8.7
9	11	4.4	10	3.5
10	3	1.2	3	1
11	2	0.8	1	0.3
Total	**253**	**100**	**289**	**100**

2.9 Growth Information

2.9.1 Larval Growth

At the time of hatching, Herring larvae are approximately 7.5–9.0 mm (0.30-0.35 in) in length (Carls and others, 2008b; Hart, 1973; Hourston and Haegele, 1980). A growth rate of 0.48–0.52 mm/day (0.019-0.020 in/day) was estimated for larvae during the first 15 days of life (Alderdice and Hourston, 1985; Carls and others, 2008b). The body begins to change over the next five weeks as it deepens and forms rudimentary fins, and by week ten, with a length of approximately 25 mm (0.98 in), larvae begin to metamorphose into juveniles, taking on the general appearance of adults and begin developing scales (Carls and others, 2008b; Hourston and Haegele, 1980). After about three more weeks, metamorphosis is complete and juveniles are approximately 35 mm (1.4 in) long (Hourston and Haegele, 1980). Growth over the summer is quick, and juveniles typically reach a length of 100 mm (3.93 in) by fall, whereas little growth occurs during the winter (Hourston and Haegele, 1980). Herring in San Francisco Bay reach approximately 100 mm (3.9 in) in average length by age one.

2.9.2 Length at Age

Adult Herring typically range from 130–260 mm (5-10 in) in total length depending on the region, though larger Herring have been observed in Alaska (Emmett and others, 1991; Hart, 1973; Miller and Lea, 1972). Herring in the San

Francisco Bay spawning population range in size from approximately 100-240 mm (4-9 in) in body length (BL).

A comparison of growth curves from Herring sampling in San Francisco Bay in the 1970s (Spratt, 1981) and more recent years (1998-17) suggests that the length at age has been declining (Figure 2-6). Growth is highly variable from year to year due to variations in parental/adult biomass, initial larval mass, fish abundance, sea temperature, salinity, or other oceanographic factors (Tanasichuk, 1997). The Spratt (1981) growth curve may therefore reflect a time period of better growth conditions, however, the lower length at age in the more recent years may also reflect a long-term change in size at age attributed to either selective fishing pressure or changing climatic conditions, as has been documented in other Herring stocks (Fisheries and Oceans Canada, 2016; Wheeler and others, 2009), and appears to be the case with other size metrics for San Francisco Bay Herring.

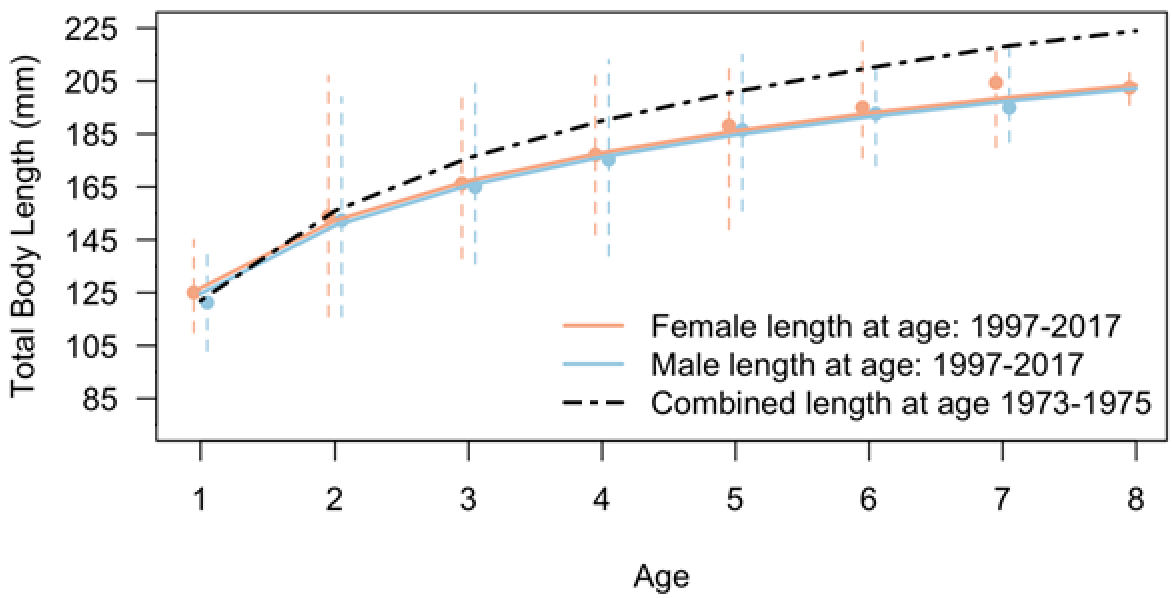

Figure 2-6. Mean length at age (dots), observed length distribution at age (dashed vertical lines), and modeled length at age for male (blue) and female (pink) Herring in San Francisco Bay between 1998-17 is contrasted with the modeled length-at-age for San Francisco Bay Herring from 1973-75 (black dot and dash line, sexes combined) (Spratt, 1981).

In addition to temporal variability, Herring also show a great deal of spatial variability in growth. San Francisco Bay Herring are near the southern end of their range and thus have smaller maximum sizes (Schweigert and others, 2002). Spratt (1987) found that Tomales Bay Herring are 1–10 mm (0.03-0.40 in) larger at each age than San Francisco Bay Herring. This latitudinal cline does not always hold, however, as environmental factors or life history strategies can have stronger effects on growth. Data on growth and size at age are lacking for Humboldt Bay and Crescent City Harbor stocks.

The Department has collected weight and length data as part of its ongoing sampling program since 1973. The data collected between the 1998 and 2017 seasons are summarized in Figure 2-7. Females are slightly heavier at age than males at larger sizes.

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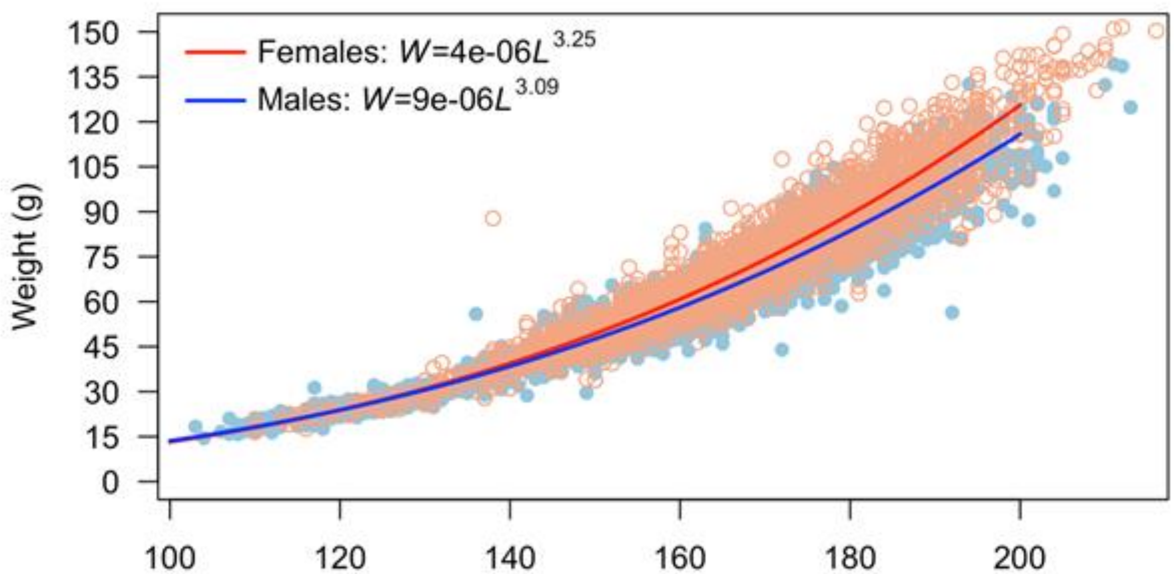

Figure 2-7. Length-weight relationship for mature, unspent San Francisco Bay Herring between 1998 and 2017 (n= 6296, 54% males).

The Department has tracked mean weight at age of San Francisco Bay Herring since 1983 (Figure 2-8). The 1982-83 season corresponded with an El Niño event, and weight at age increased in following years. However, since the mid-1980s there has been a substantial decrease in the weight at age of fish ages five and older. The weight at age of fish ages two to four remain variable but stable through the 1990s but has declined since the early 2000s despite reduced fishing pressure. A similar decline in weight at age has been seen in Herring stocks in British Columbia (Fisheries and Oceans Canada, 2016).

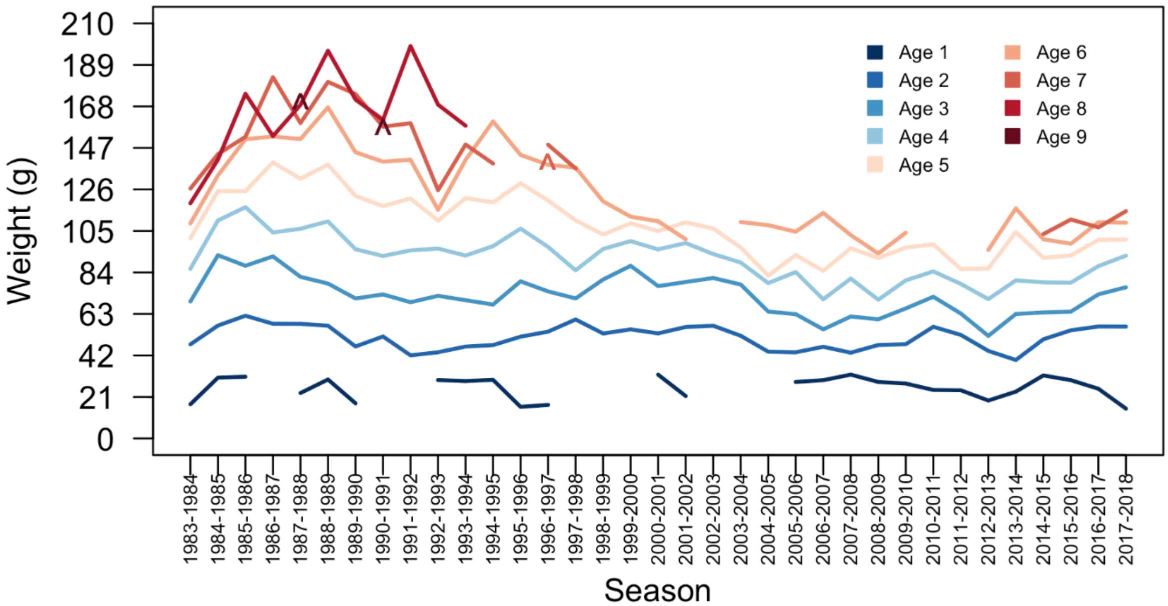

Figure 2-8. Mean weight at age observed in the research catch between the 1982-83 and 2017-18 seasons. Mean weight at age fluctuates from year to year but has declined for age three and older Herring.

2.9.3 Body Condition

Since 1979, each year the observed lengths and weights for mature Herring are used to develop a Condition Index (CI), which is derived from a fish's weight divided by the cube of its length. High condition indices have been associated with increased reproductive capacity and fish survival (Schloesser and Fabrizio, 2017). The average San Francisco Bay Herring CI for mature males and females are shown in Figure 2-9. The CI may be higher in some cool years, and can drop during or shortly after warmer years (Spratt, 1987). Increases may reflect the increased productivity of the CCE during cooler years. The largest reductions in CI were observed during the strong El Niño events in 1982-83 and 1997-98. Despite a recent increase, the long-term CI trend is decreasing, though the underlying cause of that decrease is unknown.

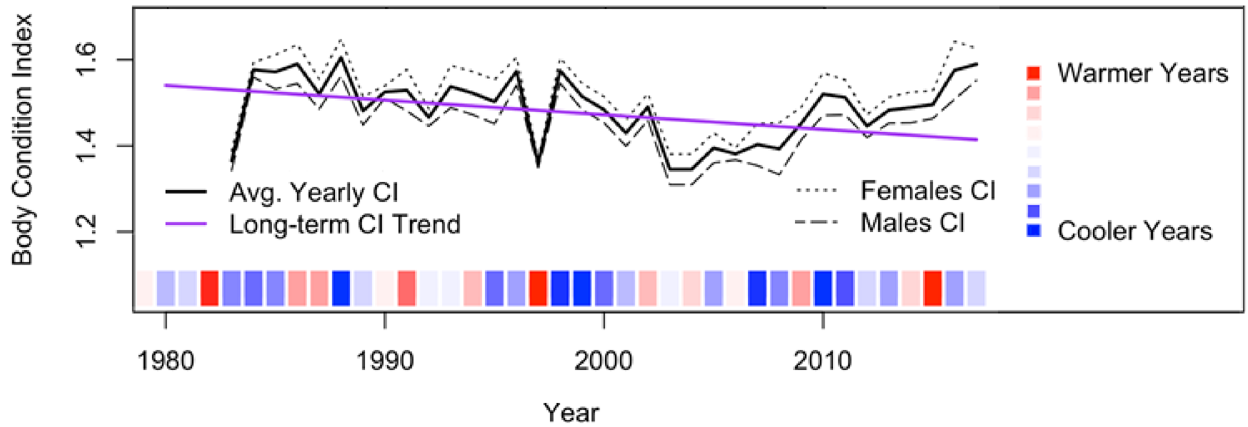

Figure 2-9. Yearly condition index for San Francisco Bay Herring and average SST anomaly[1] in the Eastern Pacific between 1980 and 2018.

2.10 Size and Age at Maturity

Herring are thought to enter the spawning population at age two and by age three all Herring are mature (Spratt, 1981). Some 1 yr old Herring occasionally spawn. In San Francisco Bay, there is a shift in the age and size structure of spawning runs as the season progresses. Early runs tend to be composed of a low percentage of age 2 and 3 yr Herring. These younger Herring mature later in the season and represent a high percentage of late season spawning runs. During years of poor recruitment, when age two and three and older fish appear in low numbers, spawning may cease prior to March. When recruitment of age 2 and 3 yr old fish is high, spawning may continue through March. A broad age structure can enhance the resilience of a stock by averaging out the effects of age on reproduction (Lambert, 1987).

Age at maturity varies spatially and increases with latitude and colder temperatures (Hay, 1985). For instance, Herring mature at 2 to 3 yr in California, 3 to 4 yr in Washington and British Columbia (Outram and Humphreys, 1974), and up to 8 yr in the Bering Sea (Carls and others, 2008b; Emmett and others, 1991; Spratt, 1981). Age at maturity also differs between sexes. Males begin to mature earlier and develop faster than females (Hay and Outram, 1981; Lassuy and Moran, 1989; Ware and Tanasichuk, 1989). Age at maturity is likely related to environmental conditions or cues and fluctuates from year class to year class.

2.11 Fecundity

Various researchers have estimated fecundity of Herring using fish length, weight (e.g., gonadosomatic index), or age (Lassuy and Moran, 1989). Length-specific fecundity has been widely reported to decrease with increasing latitude (Hay, 1985; Lassuy and Moran, 1989; Paulson and Smith, 1977). However, since fecundity increases with body size, mean and maximum fecundities of all

[1] SST Anomaly for the Nino 3.4 Index, averaged for the year. Retrieved on November 12, 2017 from https://www.esrl.noaa.gov/psd/gcos_wgsp/Timeseries/Nino34/

spawners actually increase with latitude as well (Carls and others, 2008b; Hart, 1973; Lassuy and Moran, 1989; Paulson and Smith, 1977). Since 1973, seven fecundity estimates have been generated for California Herring stocks in Humboldt Bay, Tomales Bay, and San Francisco Bay (Table 2-5). The range of average fecundity estimates for female Herring from different California Herring stocks is approximately 210-228 eggs per gram (g) of body weight. For females in San Francisco Bay, the most recent estimate of average fecundity is 210 eggs/g (Table 2-5).

Estimated fecundity is used to calculate annual Spawning Stock Biomass (SSB) from the number of eggs observed in spawn surveys. Because the fecundity of the stock can vary with environmental conditions, as well as among fish of different size class, and because using outdated or poor estimates of fecundity can bias the SSB estimate (Appendix O), fecundity should be estimated frequently, ideally by size class within a stock. However, fecundity measurements are resource intensive, therefore the Department only measures fecundity periodically (approximately once a decade). The Department will continue to estimate fecundity as necessary to determine SSB accurately as staff time allows.

Table 2-5. Summary of fecundity estimates for California Herring stocks.

Reference	Eggs/g Female Body Weight (Average)	Range	Sample Size
Tomales Bay - Hardwick (1973)	228	--	--
Tomales Bay - Kaill (unpublished data) in Spratt (1981)	216	--	--
Tomales Bay – Reilly and Moore (1984)	220	--	--
San Francisco Bay – Reilly and Moore (1986)	226.4		n=96
San Francisco Bay - Ray unpublished data (2014-15)	210	201 - 219	n=30
Humboldt Bay - Rabin and Barnhardt (1977)	220	185 - 255	n=37
Humboldt Bay - Ray unpublished data (2014-15)	228	218 - 238	n=20

2.12 Abundance Estimates

Herring abundance generally increases with latitude. Population size likely depends on the amount of summer feeding habitat (i.e., coastal shelf waters) as well as the presence of suitable spawning habitat, with the largest populations occurring off British Columbia and Alaska (Hay and McCarter, 1997).

Short-lived pelagic fish, such as Herring, can exhibit wide fluctuations in abundance. Herring are highly sensitive to environmental conditions that affect oceanic productivity and can experience large dips in population size even in the absence of fishing. The San Francisco Bay Herring population has shown an increased level of variation in population sizes since 1992, likely driven by increased variation in oceanographic conditions over that time period (Sydeman and others, 2018). However, Herring are highly fecund, and populations in California have increased rapidly following periods of decline.

Because of these dynamics, frequent short-term assessments are valuable for tracking the population status.

Yearly surveys have been the primary assessment method used to manage the Herring stock in San Francisco Bay (Chapter 4). Biomass estimates for the San Francisco stock increased as survey methodologies were refined during the 1970s (Section 6.1.2). Abundance surveys were also conducted yearly in Tomales Bay until the 2005-06 season and have been conducted intermittently in Humboldt Bay (Figure 2-10). Department biomass estimates are derived from egg deposition surveys and total commercial catch data, and may underestimate the true size of the mature stock (also known as the Spawning Stock Biomass, or SSB).

While management has primarily relied on survey-based estimates of abundance, two stock assessments have been conducted to provide modeled estimates of Herring abundance in San Francisco Bay, as well as to estimate other important life history parameters. In 2003 an age structured stock assessment model (Appendix C) was applied to a time series of catch-at-age, SSB estimates from Department surveys, and biological parameters. That study concluded that the while the stock abundance had remained high through the 1970s and 80s, a combination of lower recruitment (likely due to poor environmental conditions) and high exploitation rates in the late 1980s and 90s had lowered stock sizes to 20-25% of those from the early years of the fishery. The Coleraine model suggested that the most significant period of decline was after the strong El Niño in 1997-98 (Appendix C). More recently, in 2011, a second stock assessment model was commissioned for the San Francisco Bay Herring stock by the San Francisco Bay Herring Research Association (SFBHRA), and completed by Cefas in 2017. An age-structured population model was developed, and reference points were estimated using the model (Appendix B). However, due to an inability to fit a stock recruitment relationship and other uncertainties in the model, an independent peer review panel recommended that the stock assessment not be used to estimate SSB or make management decisions until additional analysis was completed (Appendix B).

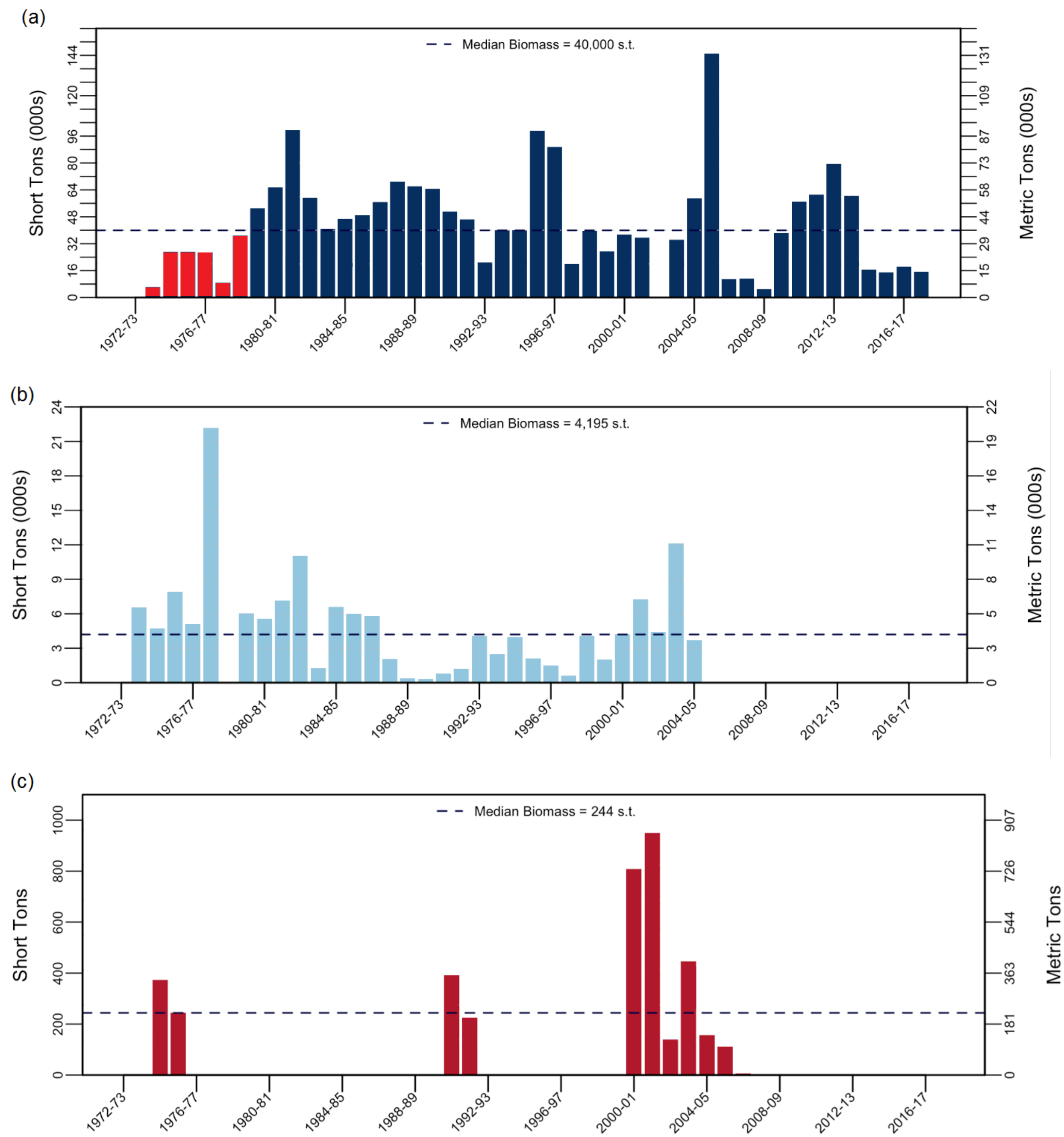

Figure 2-10. Reported estimates of SSB (including catch) for San Francisco Bay (a), Tomales Bay (b), and Humboldt Bay (c) for all seasons in which surveys were conducted. In San Francisco Bay, biomass estimates for seasons prior to 1979-80 represent intertidal spawns only. Note the y-axes scale differs among (a) – (c).

2.13 Habitat

2.13.1 Habitat Needs for Each Life Stage

2.13.1.1 Spawning Habitat

Herring in California spawn primarily in areas that are sheltered from the ocean surf, such as in bays, estuaries, and harbors. Herring have also been reported to spawn in unprotected near-shore coastal waters, though this has not been well studied in California. Spawning may take place in the intertidal zone, defined as the regions that lie between low and high tides, or in subtidal areas, which are always submerged. Herring eggs become sticky after fertilization and adhere to a variety of substrates, rather than float in the water column.

The predominant spawning habitat for Herring in California are beds of submerged aquatic vegetation, both in rocky intertidal areas, and in shallow subtidal areas with substrates composed of combinations of mud, silt, clay, sand, and pebbles/cobbles. Eelgrass is a native marine vascular plant that often forms dense beds that serve as one of the primary subtidal vegetation habitats on which Herring spawn. Eelgrass beds are structurally complex and highly productive habitats which provide refuge, foraging, breeding, or nursery functions for a variety of fishes, including Herring, invertebrates, and birds (Phillips, 1984). Eelgrass beds also enhance stability and prevent shore erosion through wave attenuation, provide nutrient transport, sequester carbon, and improve water quality by filtering organic matter and sediment.

Gracilaria spp. co-occurs with eelgrass in many shallow subtidal areas with soft sediment substrate, and over time vegetation beds in an area can fluctuate between being dominated by one species versus the other (California Department of Fish and Game, 1998; Spratt, 1981). Herring have also been observed to spawn on various other genera of subtidal and intertidal algae, including *Fucus*, *Ulva*, *Macrocystis*, *Laminaria* and *Sargassum*. Bed locations and sizes of submerged vegetation areas are determined by water depth and turbidity, which control light availability, as well as temperature, salinity and storm action. Eelgrass abundance and density is dynamic and beds expand and contract in response to changes in their environment (Section 2.13.3). It is not known how these fluctuations may impact the reproductive success of Herring.

Herring also spawn on natural hard substrates such as boulders, rock face outcrops, and low relief rock, as well as man-made hard substrate including submerged concrete breakwaters, bulkheads, vessel structures, pilings, riprap, and pipelines. These substrates are often covered with multiple species of animals including barnacles, chitons, limpets, anemones, bryozoans, tunicates, oysters, and mussels, as well as green, red, and brown algae. The San Francisco Bay Waterfront has been used consistently as spawning habitat, and in Crescent City Harbor Herring spawns occur on various man-made structures. However, the antifouling agents used in these areas may reduce the survival of Herring embryos and larvae (Vines and others, 2000).

2.13.1.2 Nursery Areas

After hatching, Herring spend 5-9 months in nursery habitats within estuarine ecosystems and utilize a variety of behaviors to adjust their position in the water column. During the summer and fall juveniles begin to leave these protected waters to school in the open ocean. There is limited information on how habitat factors affect the distribution or survival of Herring during these stages, and estuarine ecosystems are highly dynamic, unique, and variable, driven largely by oceanographic, watershed, and geomorphological conditions (i.e. salinity, degree of freshwater input, physical characteristics) (Griffin and others, 2004; Griffin and others, 1998; Haegele and Schweigert, 1985; Hay, 1985; Kimmerer, 2002a; Kimmerer, 2002b; Vines and others, 2000). Mortality at the larval and juvenile larval stages can be high (Hardwick, 1973; Outram, 1958), and may be a primary determinant of Herring year class strength.

Data on the distribution of larval and juvenile Herring within San Francisco Bay is provided by the Department's Bay Study Program (Baxter and others, 1999) using trawl, egg and larval net, and beach seine gear (Section 6.1.2.5). This survey began in 1980 and provides information on the distribution of YOY Herring within San Francisco Bay. Analysis of this dataset indicates that, in years when Delta outflow is lower than normal (as in dry years), more YOY Herring are found at upstream survey stations, with YOY observed in Suisun Bay and the West Delta. In years characterized by high Delta outflow, Herring YOY are found to the west, with YOY observed primarily in Central and South San Francisco Bay. This suggests that fluctuations in outflow and salinity in the Delta each year may determine where viable nursery habitat for Herring YOY occurs.

2.13.1.3 Pelagic Feeding and Schooling Grounds

After Herring move out of their nursery ground and into the open ocean, they inhabit coastal pelagic zones. Adult Herring spend most of their adult life in the open ocean but return to bays and estuaries each winter to spawn. The exact distribution of these schools in terms of their range, depth, and migratory patterns has not been well studied. However, Monterey Bay has been identified as a summer feeding ground for Herring, and based on similarities in parasitic infections, this is likely the same stock that spawns in San Francisco Bay (Moser and Hsieh, 1992). The same study indicated that the Tomales Bay stock had a different suite of parasites, which are more likely to be found offshore, suggesting that the Tomales stock may feed each summer in deeper waters.

2.13.2 Identified Herring Spawning Habitat in California

Herring roe fisheries, which target Herring in harbors and bays during the spawning season, occur in four separate management areas within California (Figure 2-11). The available Herring spawning habitat in these areas has been fairly well studied, and is described below and depicted in Appendix D. Only San Francisco Bay and Tomales Bay have Herring populations large enough to support major fisheries, though small fisheries have occurred historically in Humboldt Bay and Crescent City Harbor. The populations in each of these bays are managed as separate stocks because Herring are thought to return to areas that they were born when they reach spawning maturity.

Herring also spawn in other locations outside the four management areas. For example, Herring have been observed to spawn in San Diego Bay, San Luis River, Morro Bay, Elkhorn Slough, Bodega Bay, Russian River, Noyo River, and Shelter Cove (Figure 2-11) (Spratt, 1981). In 2016-17 a spawning event was documented for the first time in Trinidad Bay, located about 32 km (20 mi) north of Humboldt Bay. Spawning in these areas are thought to be minor and may not occur every year.

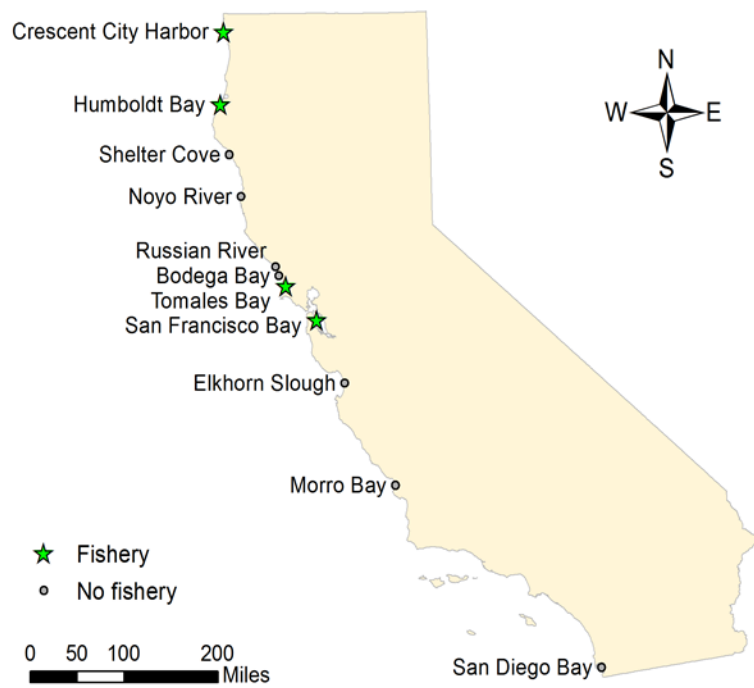

Figure 2-11. Map of observed Herring spawning locations and fisheries in California.

2.13.2.1 San Francisco Bay

The San Francisco Bay estuary, with a surface area of 1,240 km (478 mi), is the largest coastal embayment on the Pacific coast of the United States. San Francisco Bay is a broad, shallow, turbid estuary, with an average depth of 6 m (20 ft) at Mean Lower Low Water (MLLW). The bay is characterized by broad shallows that are incised by narrow channels that are typically 10 m (33 ft) deep, though some are much deeper. Ocean water enters the bay on the tidal cycle and flows up to 60 km (37 mi) from the bay’s entrance at the Golden Gate, while fresh water flows into the bay from the Sacramento-San Joaquin drainage basin as well as local streams. Inflow is highly seasonal, and is composed of rainfall runoff during winter and snowmelt runoff during spring and early summer.

In San Francisco Bay, Herring spawn in both the intertidal zone and immediately adjacent subtidal areas as well as in submerged vegetation beds (primarily eelgrass and *Gracilaria* spp.). Habitat types used for spawning include the rocky intertidal and subtidal shoreline of the Golden Gate, rocky intertidal and subtidal shoreline inside the bay, and protected bays and coves with subtidal vegetation, and man-made substrates such as the riprap, pilings, and boat hulls found in marinas or along piers and jetties. The only areas not utilized are mud flats with no vegetation. Figure 2-12 shows the areas where spawning has been observed since spawn surveys began in 1973.

Since the Department began monitoring Herring in San Francisco Bay, the majority of spawns have occurred in Richardson Bay (Section 2.4), where there is a large eelgrass bed of approximately 675 acres (273 hectares) (Merkel and Associates, 2014). This area is closed to gill net fishing for Herring (Section 5.5). Herring also frequently utilize the eelgrass beds along the southern shoreline of the Tiburon Peninsula, including Belvedere and Kiel Coves, as well as those along the East Bay shoreline, from Point San Pablo to Bay Farm Island (Appendix D). The largest eelgrass bed in the estuary is located between Point Pinole and Point San Pablo in San Pablo Bay. This bed was approximately 1,530 acres (619 hectares) during 2014 and composed almost 55% of the total eelgrass coverage in San Francisco Bay at that time (Merkel and Associates, 2014). However, despite its size, there is no Department record of Herring ever utilizing this bed as spawning substrate. In recent years, the waterfront area of Point Richmond, near the Richmond San Rafael Bridge, has become an important spawning habitat for the San Francisco Bay stock.

The vegetation bed areas in San Francisco Bay tend to expand and contract in response to conditions in the bay. Recent mapping efforts showed an increase in eelgrass coverage from 2,700 acres (1,092 hectares) in 2003 to 3,700 acres (1,497 hectares) in 2009, and then a contraction back down to 2,700 acres (1,092 hectares) in 2014 (Merkel and Associates, 2014). These changes in coverage are primarily attributed to changes in temperature and light availability due to turbidity in the water column, which increases during years with high runoff or increased storm action (Sections 2.13.1.1 and 2.13.1.2). In favorable conditions, eelgrass is able to recolonize areas that have lost coverage. Figures 2-13 and 2-14 show the persistence of these beds in the northern and southern portions of San Francisco Bay, respectively. Frequency is defined as the number of survey years (2003, 2009, and 2014) in which eelgrass was observed in each location.

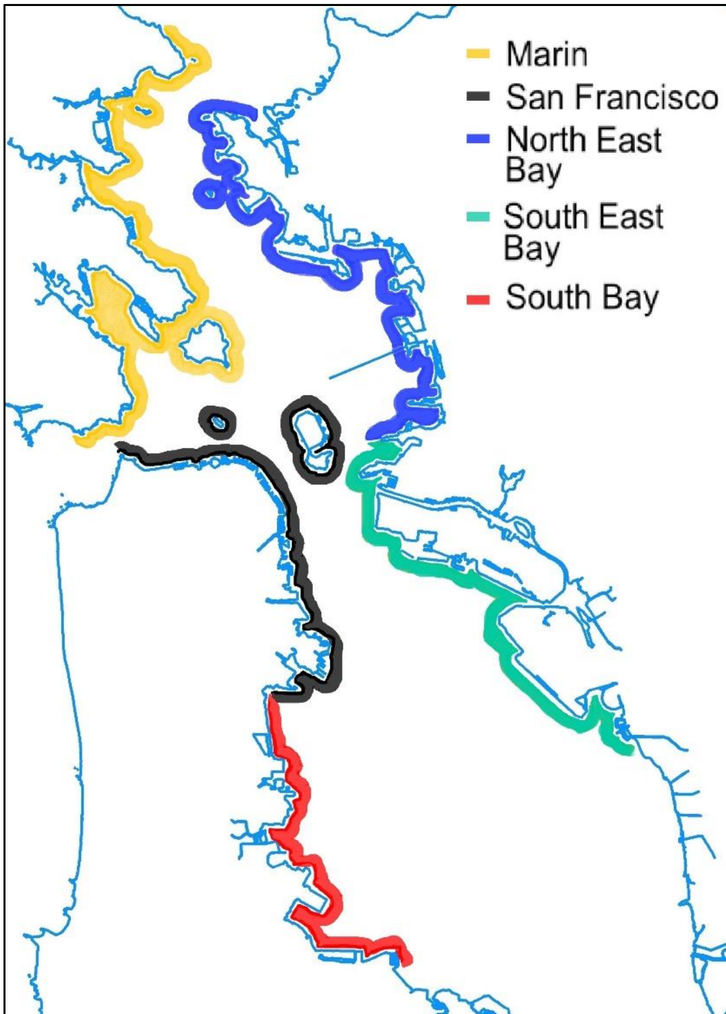

Figure 2-12. Observed spawning locations in San Francisco Bay from 1973 to 2019.

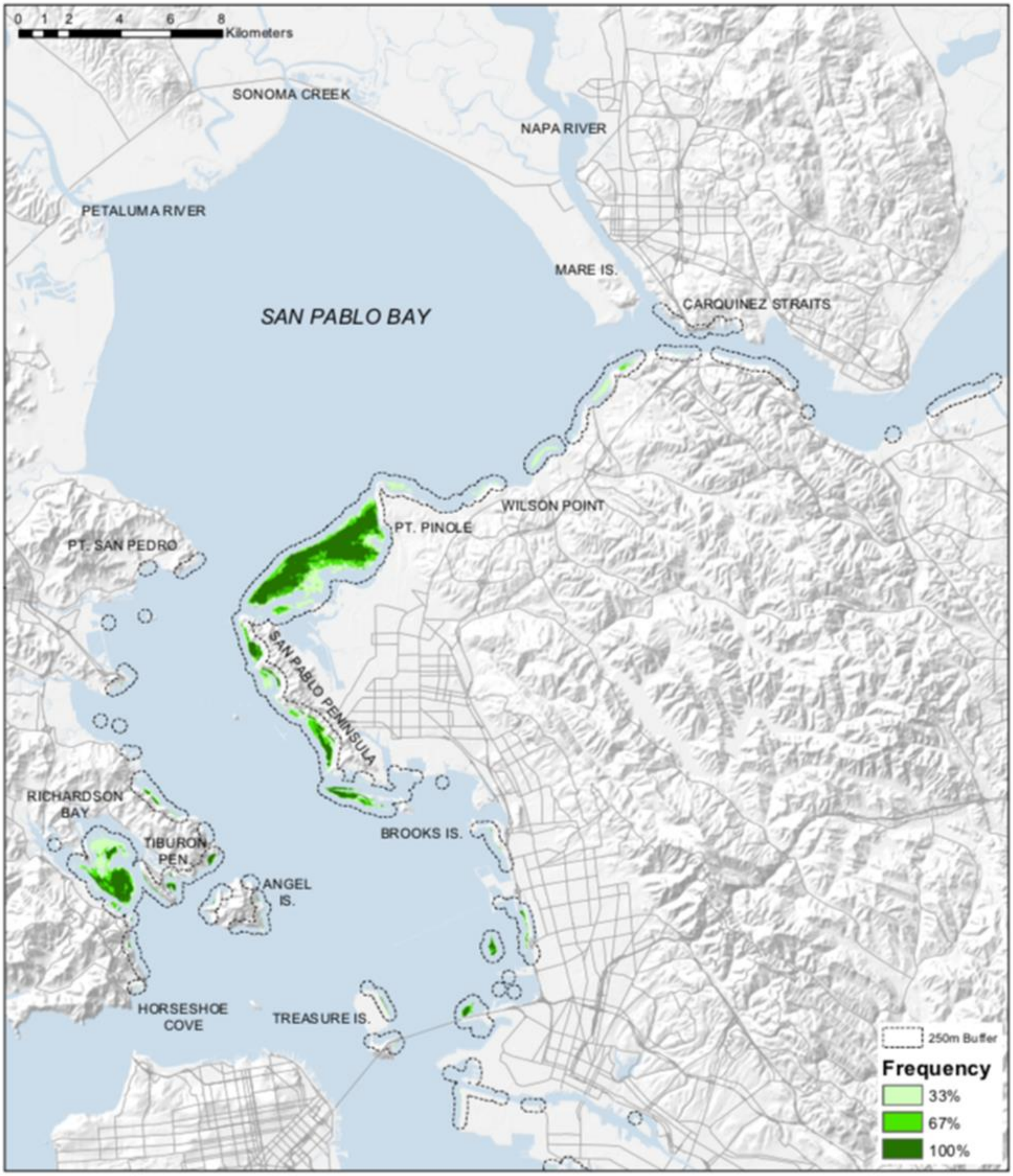

Figure 2-13. Eelgrass distribution and persistence in the northern portion of San Francisco Bay (Reproduced from Merkel and Associates (2014)).

Figure 2-14. Eelgrass distribution and persistence in the southern portion of San Francisco Bay (Reproduced from Merkel and Associates (2014)).

2.13.2.2 Tomales Bay

Tomales Bay lies in Marin County, approximately 48 km (30 mi) north of San Francisco Bay. It is 20 km (12.5 mi) long and averages nearly 1.6 km (1 mi) wide. The bay is completely sheltered from the open ocean, and considerable freshwater runoff enters the bay from numerous streams in the area. Submerged aquatic vegetation beds in Tomales Bay include eelgrass and various species of benthic macroalgae, as well as widgeongrass, *Ruppia maritima,* in the southern-most extent of the bay. Eelgrass is the dominant marine flora in Tomales Bay (Hardwick, 1973; Merkel and Associates, 2017) and the primary spawning habitat for Herring there. In the northern half of Tomales Bay, eelgrass beds are present on shallow, subtidal sand bars, while in the southern half of the bay, they are mostly restricted to narrow bands along the shore at depths no greater than 3.6 m (12 ft) below the MLLW line (Spratt, 1986). Portions of the eelgrass beds are intertidal, becoming completely exposed during lower-low tides. Eelgrass distribution in Tomales Bay is relatively stable from year to year. A 2013 Department mapping effort identified 1,288 acres (521 hectares) of eelgrass habitat in Tomales Bay, while 2017 effort identified 1,527 acres (618 hectares) (Merkel and Associates, 2017). While the overall distribution of eelgrass habitat is relatively stable in Tomales Bay, bed densities are variable and can fluctuate seasonally, as is typical for the species.

2.13.2.3 Humboldt Bay

Humboldt Bay is located approximately 488 km (260 mi) north of San Francisco and is California's second largest estuary. The bay is 23 km (14 mi) long, 7 km (4.5 mi) wide at its widest point, and approximately 65 km^2 (25 mi^2) in size excluding its tributaries and sloughs. Humboldt Bay consists of three main areas, known as North Bay (or Arcata Bay), South Bay, and Entrance Bay. North Bay and South Bay are large shallow basins with extensive intertidal flats that are fully exposed during minus tides. Entrance Bay is composed of a large deep-water channel that connects North and South Bays to the Pacific Ocean. Entrance Bay is periodically dredged to allow for large vessel traffic and has a highly developed shoreline that supports commercial activities.

Eelgrass is the dominant vegetation type in Humboldt Bay, and is the primary spawning habitat for Herring. Eelgrass distribution has been mapped several times in Humboldt Bay between 1959 (Keller, 1963) and 2009 (Schlosser and Eicher, 2012), with estimates of total eelgrass acreage ranging widely during this time. While some of this variation likely reflects actual changes in eelgrass area, primarily in North Bay, due to freshwater inflows, thermal stress, and changes in the intensity of historic shellfish bottom culture practices, some of the variation may also be a function of different survey methods (Merkel and Associates, 2017; Schlosser and Eicher, 2012). At the bay-wide scale, eelgrass extent is generally considered relatively stable through recent time; however, at finer scales, eelgrass in Humboldt Bay is recognized as being fairly dynamic (Merkel and Associates, 2017). Based on data in Schlosser and Eicher (2012), Merkel and Associates (2017) estimate approximately 4,700 acres (1,902 hectares) of continuous eelgrass habitat in Humboldt Bay.

Herring spawning occurs in both North and South Bays, although North Bay typically receives the majority of spawning activity. Spawning has occurred every year in North Bay since the fishery began during the 1973-74 season.

2.13.2.4 Crescent City Harbor

Crescent City is located approximately 560 km (350 mi) north of San Francisco and approximately 24 km (15 mi) south of the Oregon-California border. The majority of Herring spawning events take place in Crescent City Harbor. This makes Crescent City somewhat unique, because the primary spawning habitat is the harbor breakwater and all rocky areas and kelp beds near the harbor, rather than shallow mudflats. It is possible that Herring spawn in areas outside of the harbor, but these areas have not been surveyed by Department staff.

2.13.3 Threats to Herring Habitat

There are a number of threats to Herring habitat from both fishing and non-fishing sources. The Department has direct jurisdiction over and ability to mitigate threats stemming from fishing activities, and does this by restricting the types of fishing gears allowed, requiring gear modifications, or restricting the locations or times of year when fishing activities can occur. The Department considers the threats from fishing activity to Herring spawning habitat in San Francisco Bay to be low. Richardson Bay is closed to Herring gill net fishing, and this provides protection to the eelgrass habitat in this area. However, portions of vegetation beds in areas open to gill netting may be disturbed by gill nets and Herring boat anchors during fishing activities. The habitat impacts from the fishery are short in duration and primarily over muddy habitat in areas that are routinely subjected to disturbance from tides and currents that suspend and deposit material. Potential adverse impacts include scouring of soft-bottom sediments by propeller wash in shallow water areas and disruption of sediments while setting and pulling fishing gear (nets or anchors dragging along the bottom). However, the fine-grained muds found in most fishing areas within the bay are constantly being re-suspended, transported and re-deposited by water movement. The dynamic nature of fine-grained sediment deposition suggests that no significant short-term or long-term impacts to the San Francisco Bay bottom are likely (California Department of Fish and Game, 1998).

Given the unique life history of Herring, the majority of habitat threats in shallow, coastal spawning/nursery ground habitat are from non-fishery sources, such as construction, shoreline development, pile driving, dredging, urban runoff, invasive species, freshwater diversion, vessel traffic, and pollutants. The impacts of each of these threats are described in detail in Table 2-6.

In San Francisco Bay, many of these activities are particularly intense along the San Francisco Waterfront, Port of Oakland, San Francisco–Oakland Bay Bridge, and the Richmond–San Rafael Bridge. In addition, these threats tend to be cumulative, with both direct and secondary impacts on Herring stocks and their habitat. The primary threats to eelgrass and spawning habitats in Tomales and Humboldt Bays include aquaculture practices and damage from vessel mooring. In Tomales Bay, the threat associated with moorings has been mitigated via the adoption of the Tomales Bay Mooring Program in 2017, which prohibits vessels from mooring in seagrass beds. In harbors and marinas such as in Crescent City and along working waterfront areas in San Francisco Bay, the use of antifouling agents also presents a threat to the development of Herring larvae. Crescent City Harbor has also undergone a large amount of construction to repair the harbor after the 2011 tsunami.

Herring spawning habitats in California, particularly eelgrass beds, also face threats from climate change. The distribution of California's eelgrass beds are a function of water temperatures, light availability, and salinity, all of which are variable (Sections 2.13.1.1 and 2.13.1.2). For example, the depth to which eelgrass beds can grow is a function of light penetration, which may be impacted by sea level rise or increased turbidity from storms (Short and Neckles 1999). The intrusion of ocean water into formerly fresh or brackish water areas may cause eelgrass beds to move farther inland (Short and Neckles, 1999). Warmer Sea Surface Temperatures (SST) or greater fluctuations in temperature may also increase the frequency and extent of seasonal die offs (Carr and others, 2012). Warmer temperatures can also increase the incidence of eelgrass wasting disease, which is caused by infection from the opportunist pathogen *Labyrinthula zosterae* and can cause rapid population declines of eelgrass beds (Short and others, 1987). Disease occurred more rapidly and with higher severity in seedlings and at high and fluctuating temperatures (Groner and others, 2016). Changes in the pH of sea water associated with ocean acidification may also impact eelgrass distribution. Increases in the dissolved carbon dioxide content may result in increased productivity in eelgrass beds due to greater carbon availability (Palacios and Zimmerman, 2007), but may also increase rates of grazing on these marine plants due to reduced production of the chemicals that deter predators (Arnold and others, 2012). The cumulative and dynamic nature of these various factors make it difficult to predict how eelgrass beds will be affected by climate change.

Table 2-6. Summary of some threats to Herring habitat and the effects of those impacts on Herring at various life stages.			
Threat	**Physical Impacts on Habitat**	**Effects on Herring**	**References**
Dredging	Dredging can increase suspended sediment concentrations, release sediment-bound contaminants such as chemicals or heavy metals into the water column, reduce dissolved oxygen levels, bury submerged vegetation, increase turbidity, and increase noise in localized areas.	Adult Herring may exhibit an avoidance response in the presence of suspended sediments in the vicinity of their intended spawning site. Sediment on vegetation beds may interfere with the ability of Herring eggs to adhere to the substrate. Suspended sediments can settle onto the eggs interfering with fertilization or by preventing oxygen exchange, and smothering the embryos. The larval fish life stage may be the most sensitive to suspended sediments, and effects include increased precocious larval hatch, higher percentages of abnormal larvae, and increased larval mortality.	(Alderdice and Hourston, 1985; Boehlert and others, 1983; Messieh and others, 1981; Ogle, 2005; Phillips, 1978; Thayer and others, 1975)
Noise	Construction, dredging, and pile driving can produce underwater noise. High intensity noise can be generated by pile driving activities, especially of steel piles. Dredging operations produce lower intensity but continuous noise. Noise in busy coastal harbors generally reaches about 100 dB, peaking at 150 dB in major ports; marine engine noise is in a frequency band of 10-00 Hz.	High intensity noises (> 187 dB) can damage the soft tissues of fish such as gas bladders or eyes, and have been shown to result in mortality of YOY Herring. Lower intensity but continuous noise may cause an avoidance response in adult Herring. Herring have been observed to avoid sounds ranging from 1600-3000 Hz, corresponding to the presence of large vessels.	(Blaxter and Hoss, 1981; Connor and others; Schwarz and Greer, 1984)

Storms	Large storms may cause increased runoff, which can reduce the salinity in estuarine systems during crucial life history periods. Storms can also increase turbidity and wave action, which can negatively affect both intertidal and subtidal vegetation beds. Storm water runoff or storm surge introduce or re-suspend chemicals and heavy metals.	Large winter storms, such as those that occur during El Niño years, have been observed to remove vegetation beds used for spawning. *Gracilaria* spp. are especially vulnerable to storms, and storms were hypothesized to have altered vegetation beds in Richardson Bay in the early 1980s.	(Alderdice and Velsen, 1971; Bird and McLlachlan, 1992; Costello and C. Gamble, 1992; Griffin and others, 1998; Spratt, 1992)
Changes in Water Outflow	Changes in water flow into the estuaries where Herring spawn, including either very high flows or very low flows, as may occur in drought years or when water is diverted, can impact salinity or water turbidity. These can impact the survival of eelgrass beds, which has an optimal salinity of 10-30 parts per thousand (ppt).	Adult Herring have a wide range of salinity tolerance (4-45 ppt), and can move to achieve their preferred salinity range. However, sudden changes in salinity may cause changes in Herring spawning behavior. The optimal range for fertilization is 12-24 ppt, and embryos and larvae can tolerate a narrower salinity range (8-28 ppt).	(Alderdice and Velsen, 1971; Kikuchi and Peres, 1977; Nejrup and Pedersen, 2008; Phillips, 1984)

Pollutants and Contaminants	Contamination of Herring spawning substrates from antifouling agents or oil spills can reduce survival. Oil contamination can also occur through seawater when no visible oil is present. Substrates can also be contaminated by water-born chemicals, pesticides, and heavy metals.	Exposure to oil can result in decreased survival and hatching success in late stage embryos as well as lower growth rates and increase the probability of deformities in larvae. Embryos that adhere to surfaces with antifouling agents, such as creosote-treated pilings, exhibit morphological deformities, reduced heart rates and reduced hatching rates. Exposure to heavy metals, pesticides, and other pollutants have been shown to reduce egg fertilization and embryo survival by up to 80%.	(Carls and others, 2008a; Carls and others, 2002; Hose and others, 1996; Incardona and others, 2004; Incardona and others, 2012; McGurk and Brown, 1996; Norcross and others, 1996; Vines and others, 2000; Von Westernhagen, 1988)
Boating Activities	Docks and piers can shade submerged areas and cause light-limiting conditions for marine plants or other species. Improper moorings can disturb eelgrass beds, creating barren patches ranging from 3-300 m^2 in eelgrass beds. Boat propellers, anchors and anchor chains can damage vegetation beds.	Boating activities may directly reduce the vegetation beds that are the preferred spawning habitat of Herring stocks in some locations.	(Burdick and Short, 1999)
Aquaculture	The infrastructure and activities associated with oyster cultivation has been shown to reduce the density of eelgrass in known Herring spawning areas. In addition, eggs may be deposited on aquaculture gear.	The impacts of reduced density in eelgrass beds means less spawning habitat is available. Eggs deposited on aquaculture gear may be at greater risk of desiccation or exposure to toxic compounds, depending on how the gear is treated.	(Rooper and others, 1999; Rumrill and Poulton, 2004; Schlosser and Eicher, 2012; Steinfeld, 1971)

Chapter 3. Ecosystem Considerations

3.1 Forage Role of Herring

California policy considers small pelagic fish such as Herring to be "forage fish" because they provide an important food source for upper- and mid-trophic level predatory fish, marine mammals, and seabirds. Typically, forage fish feed near the base of the food chain, often on plankton. By serving as forage for higher trophic levels they provide an energetic link between primary producers and predators at the tops of food chains.

In the greater CCE, Herring, along with juvenile rockfishes; Northern Anchovy, *Engraulis mordax*; krill; and Market Squid, *Doryteuthis opalescens* are forage species with the highest number of documented predators (Szoboszlai and others, 2015). The CCE is an eastern boundary current upwelling system off the West Coast of the United States, extending from the Straight of Juan de Fuca in the north to the Mexican border in the south. The magnitude of Herring's role as forage in the central CCE, which spans roughly from Crescent City Harbor to Point Conception, and is near the southern end of their eastern-Pacific range, is less clear. Herring from San Francisco Bay are thought to migrate to Monterey Bay during the summer (Moser and Hsieh, 1992), and this area provides a feeding ground for a number of predators, including Humpback Whales and Harbor Seals (Calambokidis and others, 2000; Eguchi and Harvey, 2005). Spawning aggregations, however, are likely to provide a seasonally important pulse for local predators, and the accumulated herring and their eggs have been shown to provide important feeding grounds for migratory birds (Bishop and Green, 2001; Lok and others, 2008).

Herring's high fecundity and fast growth rate allows the species to take advantage of favorable oceanographic conditions, and stocks may exhibit large cyclical fluctuations in abundance, with stock sizes changing by orders of magnitude. While oceanographic conditions affect this variability, and forage fish stocks are generally able to recover rapidly when environmental conditions improve (Beverton, 1990), fishing can potentially exacerbate natural declines (Essington and others, 2015).

Because of the key role forage stocks play in transferring energy up the food chain, overfishing during declines has ecological implications beyond the sustainability of the target stock (Bakun and others, 2009). Decreases in forage fish populations have been identified as drivers of diet shifts and reduced productivity in predator populations, particularly seabirds (Becker and Beissinger, 2006; Crawford and others, 2007; Sunada and others, 1981). Ecosystem modeling has shown that the CCE is relatively more resilient to the effects of harvest on forage species than other upwelling systems due the presence of additional species that provide forage at some point in their life cycle (Smith and others, 2011). However, management safeguards may be needed to reduce the impacts of fishing on the ecosystem during periods of low productivity (Chapter 7, Appendix F).

3.2 Oceanic and Environmental Processes

Within the CCE, variability in several oceanographic processes can affect coastal and nearshore productivity, and in turn California's Herring spawning and rearing areas. For example, oceanic temperature and effects from regional climate processes co-vary with local conditions within San Francisco Bay to affect Herring spawning biomass negatively during warmer ocean periods (Sydeman and others, 2018). Herring biomass is thought to be positively correlated with upwelling (Reum and others, 2011), in which deep, cold, nutrient-rich water is brought to the surface by Ekman transport, which results from the strong, northerly winds that occur during late spring and early summer in the CCE. This nutrient-laden water results in increased plankton, which fuels production in coastal pelagic ecosystems (Rykaczewski and Checkley, 2008). Large-scale oceanographic processes in the Pacific Ocean such as the El Niño Southern Oscillation (ENSO) cycle, the North Pacific Gyre Oscillation (NPGO), and the Pacific Decadal Oscillation (PDO) can affect the extent, timing, and nutrient content of upwelled water (Chavez and others, 2002; Checkley and Barth, 2009).

3.2.1 Pacific Decadal Oscillation

The PDO reflects periodic changes in North Pacific SST that occur at longer temporal scales (~25 years). PDO values fluctuate between positive values, which suggest warmer, less productive conditions, and negative values, which indicate cooler, more productive conditions in the North Pacific (Figure 3-1). The PDO index was primarily positive ("warm") between 1977 and 1998, but switched to a negative ("cool") cycle in the late 1990s, which lasted through 2014. Shifts in PDO may provide some explanation for the cyclical patterns of Herring abundance observed in British Columbia over the last seven decades (Thompson and others, 2017).

3.2.2 North Pacific Gyre Oscillation

The NPGO signals fluctuation in sea surface height associated with changes in the circulation of the North Pacific Subtropical and Alaskan Gyres. NPGO has been found to correlate with fluctuations in salinity, nutrients, chlorophyll, and variety of zooplankton taxa, all of which are known to affect Herring productivity (Di Lorenzo and others, 2008). Fluctuations in the NPGO are driven by regional and basin-scale variations in wind-driven upwelling and advection, which control salinity and nutrient concentrations. Nutrient fluctuations drive planktonic ecosystem dynamics, and this is likely to affect species at higher trophic levels (Black and others, 2010). A positive NPGO index (Figure 3-1) is correlated with upwelling that begins earlier in the season in central California, which leads to a more productive planktonic ecosystem throughout the spring and summer and likely improves the survival of larval Herring.

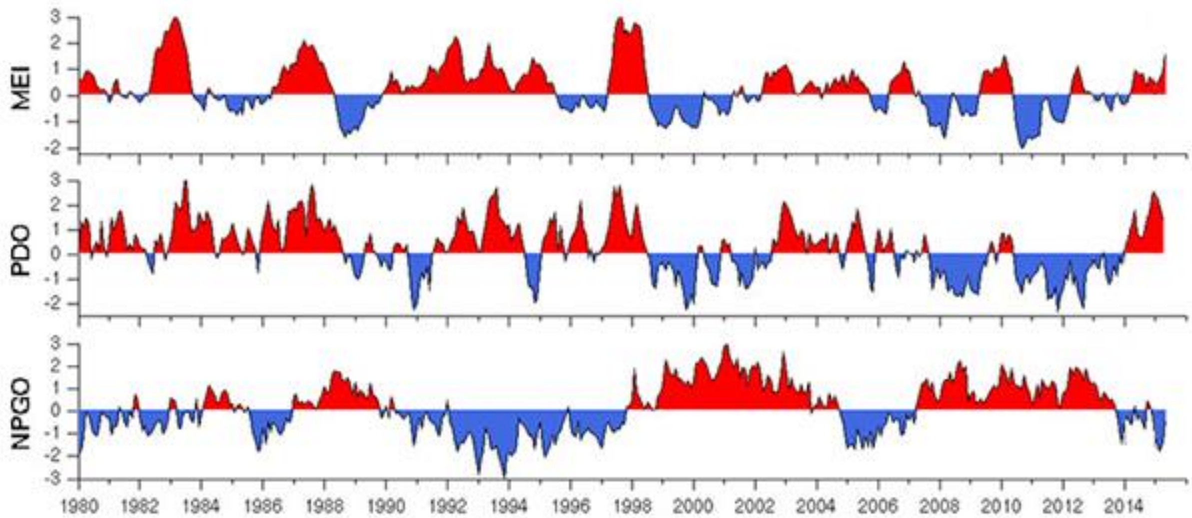

Figure 3-1. The Multivariate ENSO Index (MEI), PDO index, and NPGO between 1980 and 2016. Red MEI values denote El Niño (warm, low productivity) conditions and blue values denote La Niña (cool, more productive) conditions. Red PDO values are associated with warm regimes and blue values are associated with cold regimes. Red NPGO values are linked to earlier/greater upwelling, while blue values denote periods of lower/later upwelling.

3.2.3 El Niño Southern Oscillation Cycle and Herring Stocks

The ENSO cycle, which is measured using the Multivariate ENSO Index (MEI) (Figure 3-1), is the major mode of climate variability in the equatorial Pacific and can have major impacts throughout the Pacific Basin and the CCE. Strong El Niño events occurred in 1982-83, 1992–94, 1997–98, and 2015-16 (Jacox and others, 2016), and had noticeable negative impacts on the San Francisco Bay Herring population. For example, estimates of stock abundances have dropped sharply during or just after those events. Strong El Niño conditions result in warmer and more nutrient-poor conditions, which in turn reduces oceanic productivity and prey availability and reduces survival rates, growth rates, and the condition factor of Herring, as demonstrated by below-normal weight and condition factor indices for San Francisco Bay Herring in those years (Section 2.9.4). Warmer local oceanic conditions in the fall (i.e. just prior to spawning season) may affect the timing and/or magnitude of spawning migrations into San Francisco Bay, resulting in lower biomass estimates from spawning surveys (Sydeman and others, 2018) (Section 3.2.4). During the 1997-98 El Niño, it was noted that many females were reabsorbing their eggs rather than spawning that season (California Department of Fish and Game, 1998). El Niño events may also affect the survival of eggs, larvae, or YOY Herring.

3.2.4 Understanding Local and Regional Environmental Indicators of Herring Productivity

It can be difficult to assess how the variation in Herring production is driven by large-scale oceanic conditions relative to local effects at spawning grounds

(Reum and others, 2011; Siple and Francis, 2016). A study examining correlations between environmental indicators at various scales and metrics of San Francisco Bay Herring population health (such as SSB, age structure, and condition index) was commissioned as part of the development of this FMP (Sydeman and others, 2018) (Appendix E). In addition to the large-scale MEI, NPGO, and PDO indices, a composite index known as the Multivariate Ocean Climate Indicators (MOCI) (García-Reyes and Sydeman, 2017), which couples the shared variation in basin-scale drivers with regional processes such as upwelling and local oceanic responses (e.g., temperature and winds), was also tested. Additional indicators include regional metrics of SST and salinity, as well as delta outflow.

Correlations between these indicators and the observed SSB were tested over two-time periods: (1) the entire period of data availability (1979-2016) and (2) the time period corresponding with an increase in the variance of Herring SSB (1991-2016). While none of the indices had significant correlations with SSB for the entire period, many were significantly correlated with SSB in the later period (Table 3-1). All significant indicators were correlated with the observed SSB three years later (lag 3), except NPGO, which was also correlated at a lag of 2 years. The variance explained in correlations between SSB and environmental indicators increased after 1990, suggesting that Herring became more sensitive to environmental variability after the 1990s, which corresponds with a regime shift that was observed in CCE at that time (Hare and Mantua, 2000).

Of the large-scale oceanographic indicators, all significantly correlated with SSB except MEI, suggesting that, while strong El Niño events have had severe impacts on Herring stocks, the index does not correlate with overall stock abundance over the long term. The correlations of SSB with the other indices suggest that, as expected, oceanic conditions that result in more upwelling, cooler water, and higher nutrient levels result in higher observed SSB two to three years later.

Table 3-1. Correlation between SSB and environmental indices from 1991-2016. Indicator months and lag in years, if applicable, are shown in parentheses. Only nominally significant correlations ($p < 0.05$) are shown (adapted from Sydeman and others (2018)).

Indicator (1991-15)	**Spearman Rank Correlation (ρ) Between Indicator and Observed SSB**
Midwater trawls temperature (Trawl T)	-
Midwater trawls salinity (Trawl S)	**ρ** = 0.48 (Aug-Oct, yr-3)
Sacramento River Delta outflow (Outflow)	**ρ** = -0.59 (Jul-Sep, yr-3)
Farallon Islands sea surface salinity (Far-SSS)	-
Buoy N26 SST (N26-SST)	**ρ** = -0.41 (May-Jul, yr-3)
MEI	-
PDO	**ρ** = -0.46 (Apr-Jun, yr-3)
NPGO	**ρ** = 0.45 (July-Sept, yr-2, yr-3)
MOCI	**ρ** = -0.46 (Jul-Sep, yr-3)

Some conditions, such as temperature, showed different significance patterns between the ocean and bay. This analysis found that the Trawl-T index collected as part of the Department's Bay Study Program (Chapter 6) was not significantly correlated with SSB, but SST at Buoy N26 (near the Farallon Islands) was. SST at the Farallon Islands is influenced by large-scale oceanographic processes and is representative of nearshore oceanic conditions in the central CCE, while the Trawl-T index is more reflective of local conditions and processes within the bay and greater estuary area.

In contrast, salinity in the San Francisco Bay (from the Trawl S index) was significantly correlated with SSB, while salinity at the Farallon Islands was not. This suggests that salinity within the bay (which is primarily affected by Delta outflows and runoff) may influence spawning behavior of adults or larval survival. Laboratory studies indicate higher survival of larvae at lower levels of salinity (Griffin and others, 1998). Delta outflow at a three-year lag was also significantly correlated with SSB, but the time of year (summer) and flow direction (negative) makes it difficult to interpret any ecological mechanism behind this correlation.

3.2.5 Anticipated Effects of Changing Oceanic Conditions on Herring

The MLMA directs FMPs to describe the likely effects of changing oceanic conditions on the target species. The CCE is already a highly variable marine ecosystem, and Herring are sensitive to these environmental changes. This section describes some of the likely impacts of climate change on Herring stocks in California, however, this list is by no means exhaustive.

3.2.5.1 Increased Variability

Changes in atmospheric and oceanographic forcing may alter the length of warm or cool states, and these changes may be most apparent at the southern end of a species' range (Di Lorenzo and Mantua, 2016; Walther and others, 2002). Since the early 1990s, environmental conditions off the coast of California have been more variable than in previous decades, with more rapid shifts between warm and cool conditions. This oceanographic variability has been reflected in the increasing variance of the spawning biomass of the San Francisco Bay Herring stock: the inter-annual coefficient of variation of the SSB was 30% between 1980–1989 versus 97% after 1990 (Sydeman and others, 2018). Oregon and Washington Herring stocks also experienced increased variability over this time period, though northern stocks in British Columbia and Alaska exhibited either stable or decreasing variability (Thompson and others, 2017).

3.2.5.2 Range Shifts

Gradual change in SST is expected to drive long-term, directional changes in species distributions, and thus, species abundance and community composition in any given location (Walther and others, 2002). Species that favor cool conditions, such as Herring, may experience range contractions as SST increases and the ecosystem shifts into a less productive warm regime (Cochrane and others, 2009). A shift in species distribution may also reduce fishing opportunities in San Francisco Bay, which has historically supported a large fishery.

3.2.5.3 Increased Storm Action

Climate change may result in increased frequency and intensity of large storm events, which may impact spawning habitat for Herring. For example, a large storm event in 1981 damaged subtidal vegetation beds in Richardson Bay. Prior to that, Richardson Bay was the primary spawning location in San Francisco Bay, but after 1981 the San Francisco Waterfront became the primary spawning area for over 10 years (Spratt, 1992).

3.2.5.4 Changes in Physical Traits

Changes in temperature may drive changes in phenotypic expression (physical traits) of fishes and invertebrates, with faster growth and younger age at maturity more commonly observed in warmer waters (Crozier and Hutchings, 2014; Gienapp and others, 2008). Herring stocks in colder climes exhibit larger body sizes, slower maturation, and higher maximum ages (Schweigert and others, 2002). Herring stocks in California may see increases in growth rate and corresponding decreases in maximum size and life span. These changes would have far-reaching implications for our ability to assess the health of the stock, which is largely done via comparisons to historical metrics. In addition to observing a loss of older age classes of fish and a reduction in size at age (both metrics that usually indicate overfishing), the SSB at a given abundance would be lower due to the smaller size and lower fecundity of each fish. Additionally, the current mesh size of gill nets is regulated to select Herring of a specific size, age, and maturity level, so fishermen may see reductions in catch rates if Herring size decreases.

3.2.5.5 Changes in Seasonal Timing

Climate change may influence the seasonal timing of processes that affect Herring biology. The timing of spawning varies with winter temperatures, with spawning occurring earlier in warmer areas (Haegele and Schweigert, 1985). In addition, changes in the NPGO can alter the timing of spring upwelling (Chenillat and others, 2012). Delays in upwelling can affect the timing and magnitude of spring plankton blooms and the subsequent food availability for larval and YOY Herring.

3.3 Ecological Interactions

3.3.1 Herring Prey Sources and Competition

During all life stages, Herring primarily feed on small planktonic organisms (Section 2.6). Juvenile Herring in shallow subtidal areas feed primarily on zooplankton (Fresh, 1981). In San Francisco Bay, tintinnids, which are single-celled microzooplankton, compose a large portion of larval Herring diet (Bollens and Sanders, 2004). Larval copepods have been found in the stomach contents of larval Herring, and juvenile Herring feed on a variety of micro-plankton (diatoms, protozoans, bivalve veligers, and copepod eggs, nauplii, and copepodites) (Purcell and Grover, 1990). Increased concentrations of copepods have been shown to increase the growth rates of Atlantic Herring (Kiørboe and Munk, 1986).

Herring continue to feed on plankton throughout their life cycle, relying on visual cues in feeding (Blaxter and Holliday, 1963). Prey items selected by Herring change with their growth and geographic distribution. Krill become the primary food item for adult Herring as they move into offshore pelagic habitats. Foraging can have strong local effects on zooplankton community structure (Blaxter and Hunter, 1982).

Herring compete with a number of organisms for food during their life cycle. Although this has not been extensively studied, some data are available. Herring and Pacific Sardine share many of the same feeding grounds and exploit some of the same prey (McFarlane and others, 2005), although Pacific Sardine are exclusively filter-feeders and have a range that extends further south. Schweigert and others (2010) did not find strong evidence of Pacific Sardine competition as a factor in Herring abundance. Herring compete with juvenile and sub adult Coho Salmon, *O. kisutch*, for food in the shallow sublittoral habitat (Fresh, 1981) or for krill in the offshore pelagic habitat (Fresh and others, 1981). A similarity in diets of YOY Walleye Pollock, *Gadus chalcogrammus,* and Herring indicates a potential for competition between those species, and competition between or predation by juvenile hatchery Pink Salmon, *O. gorbuscha,* on Herring juveniles may have limited the recovery of a Herring stock in Prince William Sound (Deriso and others, 2008). Herring larvae compete with some of the soft-bodied zooplankton (medusae) for microplankton (Purcell and Grover, 1990).

3.3.2 Predators of Herring

All life stages of Herring are a food source for many species of birds, fish, invertebrates, and marine mammals in the CCE (Californa Department of Fish and Game, 2015; Rice and others, 2011; Schweigert and others, 2010; Womble and Sigler, 2006), and thus provide an important trophic linkage between predator health and the bottom-up processes that influence oceanic productivity (Section 3.1). Changes in abundance and age structure of forage species can lead to changes in growth, reproduction, and behavior of predators, including important recreational and commercial species as well as threatened and endangered fish, marine mammals, and sea birds (Pikitch and others, 2012). In the CCE Herring were found to be the fourth most commonly consumed prey group, behind rockfishes, Northern Anchovy, and krill (Szoboszlai and others, 2015). Predation is particularly high during spawning when adult fish and eggs are concentrated and available in shallow areas, and predation during spawning is a significant cause of natural mortality for Herring (Bayer, 1980; Haegele and Schweigert, 1985; Hardwick, 1973) (Section 3.8).

3.3.2.1 Predation on Herring Eggs

Herring ranked second in importance as a prey source for seabirds in a meta-analysis of predator-prey relationships in the CCE (Szoboszlai and others, 2015). At least 33 species of birds are known to feed upon Herring eggs (Table 3-2), and Herring eggs may provide an important source of dietary nutrients for migrating birds in San Francisco Bay. Glaucous-winged gulls, *Larus glaucescens,* appear to be dominant bird predators on eggs deposited within the intertidal zone in some areas (Norton and others, 1990). Two species of scoters were found to alter movement patterns in response to herring spawning events in British Columbia in order to feed on herring roe (Lok and others, 2008). Non-avian predators on Herring eggs include sturgeon, *Acipenser* spp., Surfperch (family Embiodocidae), silversides (family Atherinopsidae), and crabs (family Cancridae) (Hardwick, 1973).

Table 3-2. List of observed predators of Herring spawn (Bayer, 1980; Weathers and Kelly, 2007). Bold indicates species that also eat adult Herring.

Predators of Herring Spawn	
American Coot (*Fulica americana*)	Lesser Scaup (*A. affinis*)
American Widgeon (*Anas americana*)	Long-tailed Duck, formerly Oldsquaw (*Clangula hyemalis*)
Barrow's Goldeneye (*Bucephala islandica*)	Mallard (*Anas platyrhynchos*)
Black Brant (*Branta bernicla nigricans)*	**Mew Gull (*L. canus*)**
Black Scoter (*Melanitta americana*)	Northern Pintail (*A. acuta*)
Bonaparte's Gull (*Chroicocephalus philadelphia)*	Horned Grebe (*Podiceps auratus*)
Brandt's Cormorant (*Phalacrocorax penicillatus*)	**Pelagic Cormorant (*P. pelagicus)***
Bufflehead (*B. albeola*)	**Red-breasted Merganser (*Mergus serrator)***
Canvasback (*Aythya valisineria*)	Redhead (*A. americana*)
Common Goldeneye (*B. clangula*)	Ring-billed Gull (*L. delawarensis*)
Common Loon (*Gavia immer*)	Ruddy Duck (*Oxyura jamaicensis*)
Eurasian Wigeon (*Mareca penelope*)	Surf Scoter (*M. perspicillata*)
Glaucous-winged Gull	**Western Grebe (*Aechmophorus occidentalis)***
Greater Scaup (*Aythya marila*)	**Western Gull (*L. occidentalis)***
Harlequin Duck *(Histrionicus histrionicus*)	White-fronted Goose (*Anser albifrons*)
Hooded Merganser (*Lophodytes cucullatus*)	White-winged Scoter (*M. deglandi*)

3.3.2.2 Predation on Larval Herring

Herring larvae are preyed upon primarily by invertebrates (Arai and Hay, 1982; Blaxter and Holliday, 1963; Hourston and others, 1981; Moller, 1984; Purcell and others, 1987), including jellyfish (*Sarsia tubulosa* and *Aequorea victoria*), and comb jellies. *A. victoria* is a significant predator for a short period, consuming yolk sac larvae (12 mm) (0.5 in) with limited swimming ability. Small Surfperch, young salmon, amphipod crustaceans and arrowworms (Chaetognatha) have also been identified as predators on larval Herring (Stevenson, 1962).

3.3.2.3 Predation on Herring Adults by Fish, Birds, and Marine Mammals

A wide variety of fish, bird, and marine mammal species prey on Herring juveniles and adults in the CCE (Table 3-3) (Szoboszlai and others, 2015). Herring are more important to predators in British Columbia and Alaska, where Herring are generally more abundant, and many of the observed predator-prey interactions were from studies in coastal British Columbia (Szoboszlai and others, 2015). Table 3-3 describes the observed percentages of Herring in predator diets from studies near San Francisco Bay.

Many of these predators listed in Table 3-3 are opportunistic feeders (Emmett and others, 1986; Rosenthal and others, 1988), suggesting that none of these species are dependent on Herring alone. However, the diet composition data in Table 3-3 are primarily from studies conducted in the summer and may not reflect winter diet compositions when Herring migrate and aggregate to spawn. Forage fish predators often rely on specific locations where forage abundance may be high for a short period of time, such as near breeding areas (Hilborn and others, 2017). Diet data in winter are extremely limited due to logistical constraints on sampling, but winter data for central California that do exist suggest the potential for strong seasonal dependencies. The best winter predator diet data on Herring exists for Chinook Salmon, *O. tshawytscha*, in the GOF, just outside San Francisco Bay (Table 3-4). Herring are dominant in salmon diet when salmon were collected from coastal Herring holding areas during winter (Merkel, 1957). Salmon diets contained 49% Herring (by mass) from February-March; when averaged over the ten months of the study, Herring made up 13% of salmon diet (Merkel, 1957). Herring in the winter diet of salmon peaked at roughly 20% in a similar study in the early 1980s (Thayer and others, 2014).

Table 3-3. Known predators of adult Herring from the CCE (Szoboszlai and others, 2015). When available, the average percentage of Herring observed in predator diets is also reported. Bold indicates species from central or northern California. Note, studies are primarily from April-September, and do not reflect diet compositions in winter during Herring spawning season, when fish are densely concentrated near spawning areas.

Fish		**Marine Mammal**		**Bird**	
Spiny Dogfish (*Squalus acanthias)*	29%	**Humpback Whale (*Megaptera novaeangliae)***	13%	**Caspian Tern (*Hydroprogne caspia*)**	7%
Pacific Hake adults (*Merluccius productus*)	11%	**Northern Fur Seal (*Callorhinus ursinus)***	7%	**Common Murre (*Uria aalge*)**	7%
Black Rockfish (*Sebastes melanops)*	10%	**Harbor Seal (*Phoca vitulina)***	5%	**Rhinoceros Auklet (*Cerorhinca monocerata*)**	6%
Chinook Salmon	9%	**California Sea Lion (*Zalophus californianus)***	4%	**Double-crested Cormorant (*Phalacrocorax auratus*)**	2%
Coho Salmon	9%	**Fin Whale (*Balaenoptera physalus)***	2%	**Marbled Murrelet (*Brachyramphus marmoratus*)**	2%
Jack Mackerel (*Trachurus symmetricus)*	2%	**Harbor Porpoise (*Phocoena phocoena)***	2%	Least Tern (*Sternula antillarum*)	<1%
Pacific Hake juv.	1%	**Sperm Whale (*Physeter macrocephalus)***	2%	**Cassin's Auklet (*Ptychoramphus aleuticus*)**	<1%
Sablefish (*Anoplopoma fimbria)*	1%	**Common Dolphin (*Delphinus delphis)***	<1%	**Sooty Shearwaters (*Ardenna grisea)***	<1%
Arrowtooth flounder (*Atheresthes stomias)*		**Dall's Porpoise (*Phocoenoides dalli)***		Ancient Murrelet (*Synthliboramphus antiquus*)	
Bat Ray (*Myliobatis californica)*		**Gray Whale (*Eschrichtius robustus)***		**Arctic Loon (*Gavia arctica*)**	
Blue Shark *(Prionace glauca)*		Orca Whale (*Orcinus orca)*		**Bonaparte's Gull**	
Chum Salmon *(O. keta)*		**Pacific White-Sided Dolphin (*Lagenorhynchus obliquidens)***		**Brandt's Cormorant**	
Copper Rockfish (*S. caurinus)*		**Sei Whale (*Balaenoptera borealis)***		**California Gull (*L. californicus*)**	
Cutthroat Trout (*O. clarkii)*		**Steller Sea Lion (*Eumetopias jubatus)***		Common Merganser (*M. merganser*)	
Gray Smoothhound (*Mustelus californicus)*				**Glaucous-winged Gull**	
Jumbo Squid (*Dosidicus gigas)*				**Mew Gull**	

Lingcod				**Pelagic Cormorant**	
Pacific Cod (*Gadus microcephalus)*				**Pigeon Guillemot (*Cepphus columba*)**	
Shortspine Thornyhead (*Sebastolobus alascanus)*				Red-breasted Merganser	
Soupfin Shark (*Galeorhinus galeus)*				Western Grebe	
Yelloweye Rockfish *(S. ruberrimus)*				**Western Gull**	
Yellowtail Rockfish *(S. flavidus)*					

Table 3-4. Herring in predator diets in California, spatially and temporally focused on localized data for Herring spawning in San Francisco Bay. The CCE includes Monterey Bay and the GOF. For GOF diet, percentage of Herring in the diet is indicated by an average value with range in parentheses if data from more than one study was available (Table F-2, Appendix F).

Herring predator	**CCS summer diet[1]**	**Summer California diet**	**Winter California diet**	**GOF (Sep-Dec) diet**	**GOF (Oct-Mar) diet**	**GOF-Monterey Bay (Dec-Mar) diet**	**GOF (Feb-Mar) diet**	**GOF (Mar-Apr) diet**
Chinook Salmon	9%	4%	27%	3% (1-5%)	16% (5-27%)	29% (10-49%)	29% (10-49%)	24% (9-39%)
Humpback Whale	~13%		~19%	~5%		~33% (26-40%)		
Common Murre	7%	0%	6%		20% (12-28%			28%
Harbor Seal	6%	8%	1%					
Pacific Hake	11%	7%						
Rhinoceros Auklet	6%	1%	1%					

Herring are vulnerable to seabird predation in the shallow water embayments typical of most spawning grounds. Flocks of Brandt's and Double-Crested Cormorants, Brown Pelicans, gulls, and loons are often observed diving on adult Herring schools during spawning season in Tomales Bay and San Francisco Bay. Terns are likely consumers of Herring YOY in the summer.

San Francisco Bay is near the southern limit of the Herring range, and as a result, Herring are more prominent in predator diets in the northern CCE. The amount of marine mammal predation on California Herring stocks has not been documented, but Herring are likely one of many important prey sources. As an example, California Sea Lions specialize in feeding on schooling, open water fishes, and are often observed in large numbers during spawning events feeding directly from commercial fishing nets and spawning aggregations.

3.3.3 Other Forage Sources for Predators of Herring

The CCE is more resilient to fluctuations in forage fish abundance than other upwelling systems because many species make up the mid trophic levels that link primary producers to secondary and tertiary consumers. Other forage species in central California include other small pelagic fishes such as Pacific Sardine and Northern Anchovy; invertebrates such as krill and Market Squid; juvenile rockfish, *Sebastes* spp.; and to a lesser extent juvenile North Pacific Hake, *Merluccius productus;* and sanddabs, *Citharicthys* spp. (Brodeur and others, 2014; Szoboszlai and others, 2015). Some of these species are consumed year-round, while other species are more important in winter (when Herring are concentrated for spawning and thus particularly important as prey).

Large fluctuations in abundance of major forage species in the CCE can potentially have consequences for Herring's role as forage in that system (Appendix F). Declines in both Pacific Sardine and Northern Anchovy, if persistent, may elevate the importance of other forage species, like Herring, within the diet of CCE predators. In general, Pacific Sardines thrive during warm water regimes and decline in cool water periods, and Northern Anchovy show an alternate trend. After reaching a recent year peak of about one million metric tons in 2006, the Pacific Sardine biomass dropped to an estimated 86,586 metric tons (190 million lb) in 2017[2], resulting in a closure of the directed large-scale fishery during the 2015-19 period. Northern Anchovy biomass fluctuates (MacCall and others, 2016). The sedimentary deposition record from the Santa Barbara Basin clearly indicates lengthy episodes of disappearance or near-disappearance of Northern Anchovy and Pacific Sardine prior to western settlement of the West Coast and large-scale fishing (Baumgartner and others, 1992), and it is likely that predator populations withstood those fluctuations.

3.4 Incorporating Ecosystem Considerations into Herring Management

In 2012, the Commission adopted a forage species policy that recognizes the importance of forage species to the marine ecosystem off California's coast and intends to provide adequate protection for forage species through precautionary and informed management[3]. One of the goals in developing this FMP was to provide management recommendations for Herring that take into account their role as a forage species based on the best available science. While the majority of fish stocks around the world are managed using indicators that describe the health of the target stock, there have been increasing calls to

[2] https://www.pcouncil.org/2017/04/47571/council-votes-to-close-pacific-sardine-fishery-for-third-year-in-a-row/

[3] California Fish and Game Commission. Forage Species Policy. Adopted Nov 7, 2012. Retrieved Feb 1, 2019 from http://www.fgc.ca.gov/policy/p2fish.aspx#FORAGE

incorporate indicators that provide information on ecosystem structure, function, and health into fishery management frameworks. Section 7.7.2 describes how ecosystem status assessment is incorporated into the management strategy for Herring.

3.4.1 Utilizing Environmental and Biological Indicators Improve Forecasting Ability

Weak to non-existent stock-recruitment relationships (in which the size of the population provides little-to-no information on the number of recruits produced) have made estimation of current stock size and forecasting for dynamic species like Herring very difficult. However, because small pelagics are so responsive to environmental conditions, it may be possible to incorporate environmental indicators along with traditional metrics of stock health such as indices of recruitment and abundance to improve our ability to predict stock sizes (Tommasi and others, 2017). The correlations identified in Section 3.2.5 between environmental indicators and SSB suggest promising pathways for improving our ability to predict Herring stock abundance. This research formed the basis for the development of a new forecasting model (Section 7.6.2).

Chapter 4. The Fishery

Herring stocks in California support commercial fisheries for Herring roe products, bait, and fresh fish. Since 1973, landings of Herring have been dominated by the roe fishery, which targets Herring just prior to spawning when they come into bays and estuaries each winter (Spratt, 1992). At its peak this fishery was one of the largest and most commercially valuable in California, reaching landings of more than 12,000 tons (11,000 metric tons) and an ex-vessel value of almost $20 million, but has since declined due to lower demand and competition from other Herring fisheries. This chapter describes the commercial and recreational fisheries for Herring in California.

4.1 Historical Fishery

Herring have been fished for thousands of years as they move into shallow bays and estuaries in large numbers each winter to spawn. Herring are relatively easy to catch and have been an important seasonal source of winter protein for various coastal indigenous peoples. Archeological evidence suggests that humans along the west coast of North America have been catching Herring for at least 8,000 years (Thornton and others, 2010), and it is hypothesized that they were the most utilized fish species by communities of the coastal areas of the Pacific Northwest during the last several thousand years (McKechnie and others, 2014). Data suggest the indigenous fishery of Point Reyes in the homeland of the Coast Miwok people was directed toward the acquisition of mass-captured forage fish from the families Clupeidae, Atherinopsidae, and Engraulidae, in addition to Embiotocidae (Sanchez and others, 2018). Herring are still a species of cultural importance to some California Native American Tribes.

Herring have been harvested in California for a variety of commercial purposes since at least the mid-1800s (Spratt, 1981). The Department began recording annual landings in 1916 (Figure 4-1). Prior to 1916, annual catches were low, with most of the fish sold fresh. Small amounts also were salted, smoked, pickled, or canned for human consumption. As ocean sport fishing increased, more Herring were used for bait. Between 1916 and 1919, Herring were also harvested for canning and the production of fish oil and meal (Scofield, 1918). In 1918 the catch reached roughly 8 million pounds (4 thousand metric tons), mostly from Tomales and San Francisco Bays. The Reduction Act of 1919 prohibited the reduction of whole fish of any species into fishmeal except by special permit. Permits were not issued for Herring, effectively ending the first period of peak landings.

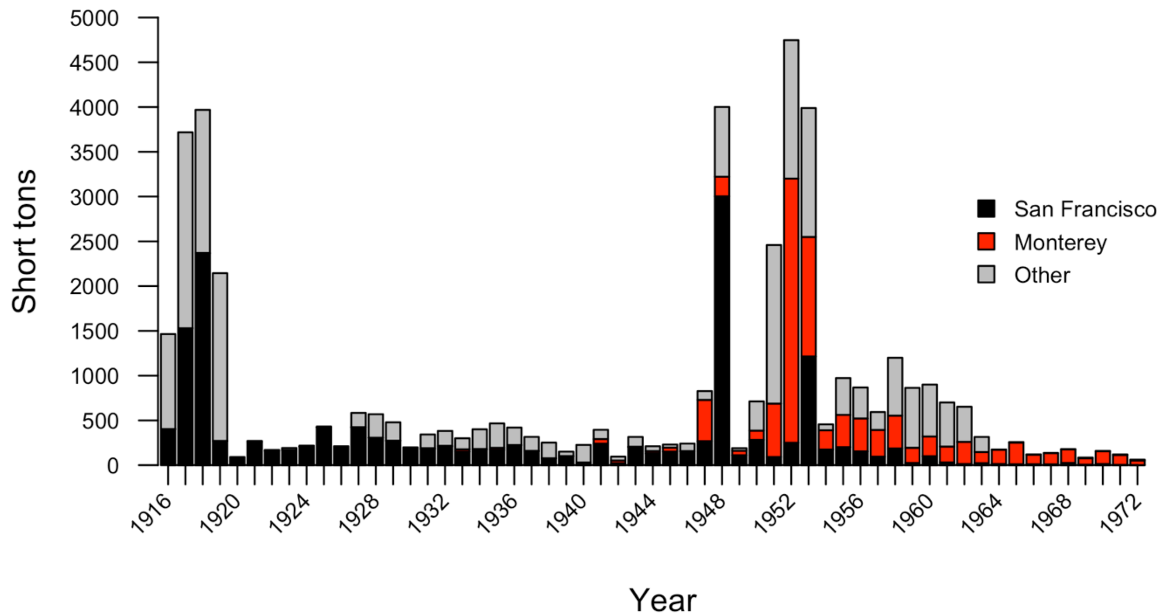

Figure 4-1. California historic Herring landings in San Francisco Bay (black), Monterey (red), and other locations (grey) from 1916-1972.

Between 1920 and 1946, there was little canning of Herring, though moderate quantities continued to be sold for fresh consumption, for salting and smoking, and for bait. The second peak in landings occurred in the late 1940s and early 1950s in an effort to replace Pacific Sardine. However, canned Herring was less desirable than Pacific Sardine and landings declined (Miller and Schmidtke, 1956). Some canning for human consumption continued and an unsuccessful effort was made to develop a pet food market for canned Herring. Landings, primarily for bait in the Monterey area, continued at low levels until the beginning of the sac-roe Herring fishery in the early 1970s.

4.2 Herring Fishery for Sac-Roe

In 1973, Japan began importing Herring roe from California. The traditional product from this fishery, kazunoko, is the skein (or sac) of eggs (roe) removed from the females, which is processed and exported for sale in Japan as a delicacy. Regulated harvest of Herring roe in California has occurred every year since 1973 except for a one-season fishery closure in 2010, and a complete lack of effort during the 2018-19 season. The sac-roe fishery is limited to California's four largest Herring spawning areas: San Francisco Bay, Tomales Bay, Humboldt Bay, and Crescent City Harbor. San Francisco Bay has the largest spawning population of Herring and produces more than 90% of the state's Herring catch (Figure 4-2).

The other stocks in California historically supported smaller roe fisheries, and the Department monitored landings and conducted surveys in some locations. Tomales Bay was intensively monitored annually through the 2005-06 season, the stock in Humboldt was monitored intermittently, and the Crescent

City Harbor stock has never had a spawning assessment survey. The Department established fixed quotas for these northern management areas, which have remained in place for a decade or longer. Fixed quotas are set to allow fishing opportunities, but Herring have not been fished in the northern management areas since 2002 in Crescent City Harbor, 2006 in Humboldt Bay, and 2007 in Tomales Bay. Permit renewals have also fallen over the past several years, reducing the fleet capacity in these areas.

Throughout this time whole Herring have also been harvested for the bait and fresh fish markets (Section4.4). The sections below describe each sector of the modern Herring fishery (Appendix G).

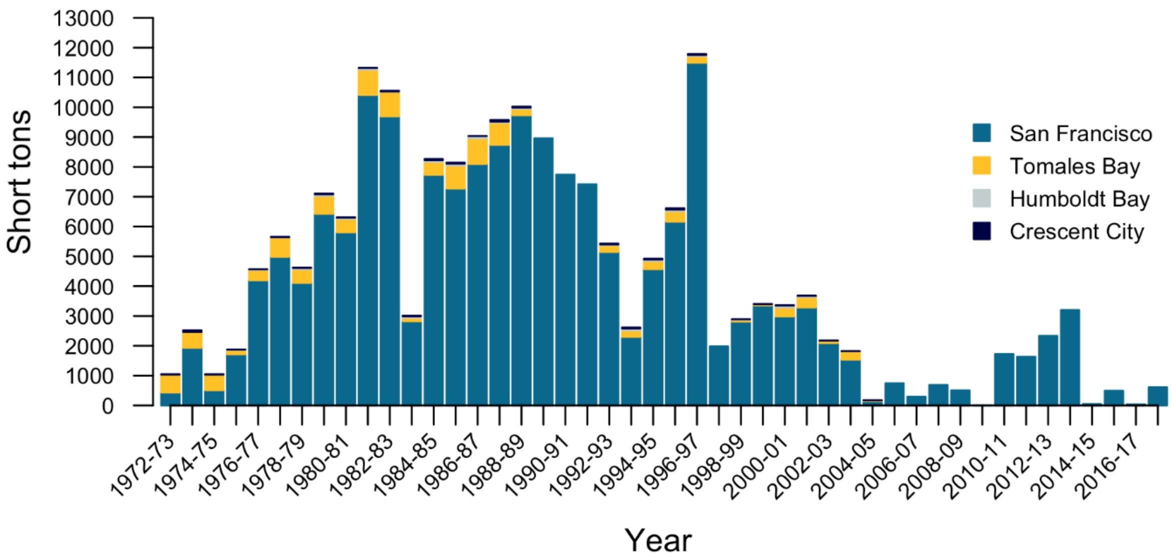

Figure 4-2. California Herring landings by area in short tons between 1973 and 2017 in San Francisco Bay (blue), Tomales Bay (yellow), Humboldt Bay (gray), and Crescent City Harbor (black). Note that this does not include landings from the ocean waters fishery (Monterey Bay).

4.2.1 San Francisco Bay

4.2.1.1 Controlled Expansion and Creation of Gill net Platoons (1970s)

When the sac-roe fishery began in the winter of 1972-73, emergency legislation was passed by the California State Legislature (Legislature) to set conservative quotas for three years in order to give the Department time to assess the population and develop a protocol for conducting surveys and setting quotas. During the 1975-76 season the Commission began issuing permits and setting annual quotas based on biomass surveys. As Department biologists learned more about the size of the San Francisco Bay Herring stock through annual surveys, both quotas and the number of permits were increased to provide additional access to the fishery.

Initially there were few regulations for gear type, and the fleet fished gill net and round haul (seine) gear, which consisted of lampara and purse seine. The legalization of set gill nets occurred in 1977 (previously, only drift gill nets were allowed), which made gill net gear more desirable and resulted in an increase in gill net permits. The Commission also stopped issuing new round haul permits for the California Herring fishery, with the intent of converting the sac-roe fishery entirely to gill net. Round haul gear had a tendency to catch smaller, younger, lower value fish, and it was suspected that seiners increased mortality in the fishery by catching and releasing Herring during roe percentage testing (Garza, 1996). Since permits were non-transferable, the round haul fleet declined gradually through attrition, and no further action was taken to remove round haul gear until the 1990s.

High prices for sac-roe caused rapid expansion of the fishery, and the fishing grounds in San Francisco Bay became congested. In the 1978-79 season the Commission divided the 220 gill net permit holders into two groups. Defined by permit number, these groups were known as the “Odd” and “Even” platoons. Each platoon was allocated a portion of the quota and allowed to fish during alternating weeks of the season. To further address concerns about congestion and high demand for Herring permits, the Commission issued permits for a three-week gill net fishery in December. Prior to this, commercial Herring fishing in San Francisco Bay had only been allowed January through March.

4.2.1.2 Stable Fishery (1980s)

By 1983, fishery participation was stable. There were 430 permits in San Francisco Bay, with the majority of them allocated to the three gill net platoons. Herring quotas continued to increase and reached 10,000 tons (9,074.4 metric tons) in the 1981-82 season. Following the strong El Niño event in 1982-83, stock size decreased, and the fishery saw a reduction in landings, but the stock recovered quickly and remained relatively steady until the early 1990s. Quotas during the 1980s were generally set with the intent to achieve an exploitation rate of approximately 15%, and landings remained high.

4.2.1.3 Stock Declines and Conversion to All Gill net Fleet (1990s)

The San Francisco Bay Herring stock declined during the 1992-93 season following a strong El Niño event. However, this decline coincided with record high prices so there was significant pressure to continue allowing a commercial fishery. The price per ton and landings reached record highs during the 1996-97 season, but in the following year abundance declined following another strong El Niño event. The stock showed signs of lower productivity, including smaller and younger fish.

In 1994, the Commission began to phase out round haul gear from the fishery. This was due to concerns about the reduction in older (age six and older) fish in the San Francisco Bay Herring stock. Regulations required seine operators to convert to gill net gear within five years, providing the ability to fish one CH permit in both platoons in exchange for a single round haul permit. All remaining round haul permits were converted to gill net permits by the 1998-99 season, and since that time, sac-roe has been taken commercially in San Francisco Bay by gill net only. The conversion from round haul to gill net gear resulted in an increase in the total number of permits to 457, which corresponded with 120 vessels in San Francisco Bay.

4.2.1.4 Precautionary Management (2000s into the early 2010s)

In response to the stock declines observed following the winter 1997-98 El Niño event, in 2003 a stock assessment and methodology review was conducted for the San Francisco fishery (Appendices C and I), and the quota-setting policy was changed with the aim of reducing exploitation rates from 15% to 10% or less. During this time, fishing effort in the San Francisco Bay Herring fishery has also decreased substantially due to declining prices, and in many years exploitation rates have been under 5%. In the 2010-11 season, the Commission, with support of industry representatives, eliminated the December fishery, and December permits were incorporated into the Odd and Even platoons. While this reduction in early season fishing pressure may have contributed to an increase in older age classes, Herring abundance exhibits a high degree of interannual variability. For example, a record high spawning biomass occurred in 2005-06, but was followed four years later (2009-10) by a fishery closure due to concerns over low estimated spawn stock biomass. This degree of variability highlights the importance of the Department's precautionary management approach.

4.2.2 Tomales and Bodega Bays

4.2.2.1 Expansion and Resulting Regulatory Changes

As in San Francisco Bay, commercial fishing for Herring sac-roe in Tomales Bay began in 1973 under a precautionary quota to give the Department time to assess the stock. A formal quota and limited entry system for Tomales Bay was established in 1974-75. The following year fishermen began fishing for Herring in outer Bodega Bay, north of the mouth of Tomales Bay. Herring have been observed to spawn in shallow areas of Bodega Bay, but the fishery targeted Herring in deeper water areas of the bay. Tomales and Bodega Bays were initially managed under separate permit systems until 1978-79 when they were combined into a single permit area with a cap of 69 permits. In the following years, a number of additional regulations were created to prevent conflicts between fishermen, recreational users, and residents. These included weekend fishing prohibitions, prohibition of round haul gear, and limits on the number and mesh size of gill nets (Appendix H). Beginning in 1979, Bodega Bay and Tomales permittees were also split into two platoons that fished alternate weeks to alleviate congestion and conflict on the fishing grounds. Between 1981 and 1983, Tomales-Bodega area Herring permittees were allowed to exchange their permits for available San Francisco Bay permits to further reduce congestion. This reduced the number of permits to 41, and later a cap of 35 permits was established for the Tomales-Bodega Bay fishing area. During this time, the platoon system in this area was also eliminated due to the reduction in permit numbers.

4.2.2.2 Stock Declines

The Tomales and Bodega Bays spawning stock had remained above 4,700 tons (4,300 metric tons) between 1973-74 and 1982-83, and the commercial fishery exploitation rate did not exceed 12% during that time. However, the spawning stock declined to 1,280 tons (1,160 metric tons) in 1983-84 following a strong El Niño event. The stock recovered in the following years, but the Tomales Bay permit area was closed to commercial fishing after a record low SSB estimate in 1988-89. The fishery remained closed for three years because the SSB did not exceed minimum thresholds required to support a fishery. Department staff hypothesized that Herring were displaced from Tomales Bay due to an ongoing drought. During the 1992-93 season, the six-year drought ended and a large, 4,072-ton SSB (3,695 metric tons) of Herring returned to Tomales Bay. Commercial fishing resumed under precautionary management measures that included a quota based on a 10% intended (target) harvest rate, an increase in minimum mesh size, and a reduction in the amount of gill net gear allowed per vessel (Appendix H).

Fishing was allowed to continue in Bodega Bay when Tomales Bay was closed. However, the outer Bodega Bay fishery was eventually closed during the 1993-94 season based on the concern that fishing activity in Bodega Bay intercepted potential Tomales Bay spawning stock and that an accurate estimate of the SSB in those areas could not be obtained as long as fishing was allowed in Bodega Bay.

4.2.2.3 Stable Biomass but Declining Market Access

Tomales Bay SSB estimates remained stable, although lower than they had been in the 1970s and 1980s, until the 1997-98 El Niño event. Following this event, Herring stocks statewide experienced a loss of older age classes and reduced growth rates. As a result, no fishing occurred during the 1997-98 season in Tomales Bay. In subsequent years, the stock began to recover, but fishery participation continued to decline due to market reasons. In 2006-07, only two vessels fished as a result of high operating costs and low market demand. This was the last year that commercial fishing occurred in Tomales Bay, and spawning biomass surveys were discontinued the following year due to limited Department resources.

4.2.3 Humboldt Bay and Crescent City

During the 1973-74 season, in response to demand from fishermen for a local commercial Herring fishery, the Legislature expanded its management authority to include Humboldt Bay. A 20-ton quota (18 metric tons) was established and a two-year population study was initiated to determine the status of Humboldt Bay Herring stock (Rabin and Barnhart, 1986). This study estimated the SSB in Humboldt Bay to be 372 tons (237 metric tons) in 1975-75, and 232 tons (210 metric tons) in 1975-76. After this study concluded, it was determined that the stock could support a 50-ton quota (45 metric tons) fishery, which was roughly 13% and 22%, respectively, of the two SSB estimates. Initially, six permits were issued for Humboldt Bay, but in 1977 the number of permits was reduced to four.

After the initial study, no population assessments were completed in Humboldt Bay until 1990. In 1982 the quota was increased to 60 tons (54 metric tons), however this change coincided with an El Niño event and landings were low that year. Landings increased the following year and generally stayed between 40 and 70 tons (36 and 64 metric tons) over the next 15 years, with the exception of the 1988 and 1993 seasons, the latter coinciding with another El Niño event. The quota was exceeded in some years due to the difficulty of monitoring and predicting catch levels.

Humboldt Bay's SSB was re-assessed during the 1990-91 and 1991-92 seasons and was estimated to be at 400 and 225 tons (363 and 204 metric tons), respectively. However, during the second-year weather conditions prevented timely observation of a large spawning event, so that year's survey was believed to be an underestimate (Spratt and others, 1992).

Between 2000-01 and 2006-07 the Humboldt Bay stock underwent annual spawning assessments. The estimated SSB showed high variability during those years, and in the final survey year, a record low biomass was observed. Fishermen reported that stocks had declined in Humboldt Bay since the late 1980s (Californa Department of Fish and Game, 2001), and fishing effort declined in the late 1990s and early 2000s, with only one permit being active in most years. The Humboldt Bay quota was only reached once after the 1997-98 El Niño. There was no fishing effort in the 2005-06 season by Humboldt Bay permittees. The low catches were attributed to a disproportionate amount of small Herring in the population, which could not be caught in the 2.25-in (57 mm) mesh nets (Mello, 2006).

Commercial Herring fishing in the Crescent City area has primarily targeted schools that spawn in Crescent City Harbor. Biomass has been estimated for individual spawning runs in Crescent City Harbor (California Department of Fish and Game, 1998), but no seasonal population estimates have been made for this stock. Anecdotal reports suggest that spawning activity can be intense, with large amounts of spawn deposited. Fishing in the Crescent City area began in 1972-73, and in the 1973-74 season a record high of 60 tons (54 metric tons) was landed. In 1977 a 30 ton (27 metric tons) quota was established for Crescent City Harbor, and four permits were issued. Since the 1983-84 season only three permits have been renewed annually.

No changes have been made to the regulations governing Herring fishing in the Humboldt and Crescent City permit areas since 1983. These areas did not have the same levels of participation that resulted in the competition and conflict experienced in the southern permit areas. Until the late 1980s, landings varied considerably from year to year. It is unknown if this reflects annual variability in stock abundance or fishing effort. However, from the late 1980s to the late 1990s, catch rates were stable, and the quota was exceeded in a number of years due to monitoring difficulties. Fishing effort in Crescent City declined in the early 2000s, and the last landings were made in 2002. At the time this FMP was being drafted, fishing had not resumed in either Humboldt Bay or Crescent City Harbor due to low market prices and lack of processing facilities.

4.3 Herring Eggs on Kelp Fishery

In 1965, a new market for California Herring opened when Japan began importing Herring eggs spawned on seaweed, known as kazunoko kombu, which was highly prized in Japanese markets. The Commission began accepting bids (in the form of a royalty per ton) for the right to harvest five tons (4.5 metric tons) of Herring eggs on seaweed (total product weight) in Tomales and San Francisco Bays (Spratt, 1981). The harvesting was done by SCUBA divers collecting primarily *Gracilaria* spp. and *Laminaria*. This fishery operated from 1966 to 1986, but the quota was never reached. Harvest of Herring eggs using suspended kelp rather than collection of native seaweed was first allowed in San Francisco Bay during the 1985-86 season under an experimental gear permit (Moore and Reilly, 1989), and this is still the current method of harvest used in the fishery.

To fish Herring Eggs on Kelp (HEOK), Giant Kelp, *Macrocystis pyrifera*, is suspended from rafts or cork lines in shallow areas for Herring to spawn. HEOK fishing does not result in mortality to adult Herring, as only the eggs are removed with the kelp once Herring spawning has concluded. Rafts and cork lines are positioned in locations where Herring spawning is expected to occur. Suspended kelp is left in the water until egg coverage reaches a marketable amount or spawning has ended. The product of this fishery is the egg-coated kelp blades, which are processed, graded by quality and exported to Japan. Giant Kelp does not occur in large quantities in the bays where Herring spawn, so kelp is typically harvested off central California and then transported to San Francisco Bay. The kelp begins to deteriorate within 8-10 days, so the location and timing of kelp suspension must be carefully considered to maximize the chance of coverage with eggs.

The method of HEOK fishing employed in California's is termed "open pound" because Herring (and other animals) can freely move in and out of the suspended kelp. This differs from the "closed pound" method, which is more commonly used in HEOK fisheries outside of California. In the closed pound method, fishermen hang kelp in floating net pens (pounds) and mature Herring are captured by purse seine and confined for several days until spawning occurs. The capture, transport, and confinement associated with the closed pound method has been shown to result in damage to the fish, including bruising, scale loss, and other injuries, and results in some mortality (Shields and others, 1985). Closed pound fishing has also been shown to increase rates of disease in confined Herring (Hershberger and others, 2001).

4.3.1 Evolution of the HEOK Fishery

In preparation for opening the HEOK fishery, Department biologists sampled landings from the experimental HEOK rafts during the 1987-88 season (Moore and Reilly, 1989). The study objectives were to determine the appropriate conversion rate between adult Herring spawning biomass and the weight of the eggs-on-kelp product, as well as to collect biological data and determine ongoing monitoring needs for a sustainable fishery. They found that 4.853 tons (4.403 metric tons) of Herring could produce 1 ton (0.907 metric tons) of eggs on kelp, which led to the development of a conversion factor of 0.206 to determine an equivalent amount of eggs-on-kelp produced by a given Herring spawning biomass.

When the HEOK fishery was established there was a desire to reduce the number of vessels in the sac-roe fishery. Sac-roe permit holders were allowed to transfer into the HEOK fishery, forfeiting their ability to participate in the sac-roe fishery for that season. The HEOK permit was classified as a gear transfer rather than a separate permit. There was a cap of 10 permit transfers annually into the HEOK fishery, and each HEOK permit was entitled to an individual quota equivalent to 1% of the total San Francisco Bay Herring quota, converted into "equivalent" eggs on kelp using the 0.206 conversion factor.

Historically, HEOK was a high value product, and landings remained relatively stable between the 1989-90 and 2003-04 seasons. Subsequently, HEOK effort and landings began to decrease. At the time of FMP development, HEOK landings had last occurred during the 2012-13 season. Primary factors for the decrease in effort are high operating costs, reduced market value, and reduction in demand. The fishing industry has also indicated that an increase in the number of marine mammal (sea lion and seal) interactions presents challenges to this fishery because marine mammals target schools that spawn around HEOK rafts, potentially damaging the kelp product.

4.4 Whole Fish

Prior to the start of the sac-roe fishery, a "bait" fishery for whole Herring existed in San Francisco Bay. In 1973-74, when Herring sac-roe permits were first issued, six of the permits were for bait and were not subject to the quota established by the Legislature (Spratt, 1981), but it was suspected that these bait fish entered the roe market (Spratt, 1992). The baitfish loophole was closed in 1975, and during the 1975-76 season, ten "special permits" were issued in San Francisco Bay and five in Tomales Bay for bait (whole fish). These permits were issued on a first come first serve basis, and fish were primarily taken using beach seine gear.

In 1979-80, the whole ('fresh') fish allocation in San Francisco Bay was modified so that a permittee had to possess a valid market order for Herring, not to exceed 500 lb (0.25 tons) per day. The whole fish season was also changed so that Herring could be taken between 02 November and 31 March, but closed during the sac-roe season to prevent Herring from being sold illegally into the roe market. Beginning in 1981 and continuing through 2013, separate 20-ton (85 metric tons) San Francisco Bay and 10-ton (9.1 metric tons) Tomales Bay whole fish quotas were allocated each season. Participation and landings of whole fish during this period were low.

Beginning in the 2013-14 season, regulations were modified to facilitate a local market for fresh Herring for human consumption. The separate quotas and restrictions on landing whole fish during the sac-roe fishery in Tomales and San Francisco Bays were eliminated to provide a pathway for participants in the gill net fleet to explore alternative local markets. Following this change, any portion of the gill net quota could be landed either for whole fish or sac-roe. The Department and Commission have recently been asked to consider allowing alternative gear (cast nets) to be used to catch Herring for the whole fish market. Innovation in this fishery, as new methods of take continue to evolve, may be explored through the use of experimental fishing permits (FGC §1022). See Section 4.7.4 for a discussion of market access to whole Herring, and Chapter 7 for management recommendations regarding gear innovation.

4.5 Ocean Waters Commercial Fishing

Commercial fishing for Herring in ocean waters (outside of Crescent City Harbor and Humboldt, Tomales and San Francisco Bays) occurred prior to the establishment of a sac-roe fishery (Section 2.2) and continued until 2009. The majority of landings came from Monterey during the summer months, though small amounts of landings were reported south of Monterey, and in the Eureka and Crescent City areas. In 1976, the Commission established a season from April 1 to September 30. Beginning in 1979, the season was extended to December 1. This was later changed to allow fishing from April 1 to November 30 from Pigeon Point, San Mateo County south to Monterey, and from April 1 to October 31 between Pigeon Point and the California-Oregon Border.

Between 2003 and 2008, the ocean commercial fishery landed approximately 36% of the overall California commercial Herring catch. During this period, six purse seiners participated in the ocean fishery and landings averaged 144 tons (131 metric tons) per year. After the 2008-09 San Francisco Bay stock collapse, the Commission implemented an emergency closure of the ocean waters fishery as a conservation safeguard. Beginning January 1, 2010, all directed commercial fishing for Herring in ocean waters was prohibited.

Herring are still caught incidentally in ocean waters by purse seiners targeting other coastal pelagic fish species, primarily in Monterey Bay. An incidental take of no more than 10% Herring by weight of any landing composed primarily of other coastal pelagic fish species or Market Squid may be landed. Herring typically make up a small percentage of any given vessel's overall catch and revenue. This incidental catch supplies markets for whole fish (bait), aquarium food, and animal feed.

4.6 Sport Fishery

Spratt (1981) noted the presence of a sport fishery for Herring in San Francisco Bay and the Noyo River estuary during the 1970s and early 1980s, and recreational catch of Herring has continued since that time. Fish are caught with hook and line, hoop nets, and cast nets, primarily from beaches, piers, jetties, and small skiffs during times when Herring spawning aggregations are easily accessible. Few data are available on recreational catch or effort. Fishing effort, however, is observed to be the highest in San Francisco Bay because of the number of spawning aggregations accessible by sport fishermen. Crescent City Harbor also provides limited access to recreational fishermen when Herring spawns occur. Historically, managers believed that recreational catch made up a small percentage of the total Herring landings due to the opportunistic nature of this fishery, no catch restrictions on recreational take of Herring were implemented. However, observations by Department staff suggest that landings have been growing in recent years, with reports of recreational anglers taking large amounts of Herring, estimated to be up to several thousands of pounds each, which has led to concern about the illegal commercialization of the recreational catch. See Section 4.7.6 for further characterization of the sport fishery, including socioeconomic considerations, and Chapter 7 (Section 7.8.7) for limits established under this FMP regarding the recreational take of Herring.

4.7 Socioeconomic Considerations

FMPs provide an opportunity to revise, update, and modernize fishery regulations. Many of the regulations that have been established in the Herring fishery over time were in response to the socio-economic considerations for a much larger fleet. These included the development of a platoon system to eliminate vessel congestion on the fishing grounds, restrictions on the number of permits each participant could hold to maximize access, and permit caps to maintain the economic viability of the fleet. However, since the early 2000s, the Herring fishery has undergone significant changes, with declines in prices and quotas effectively reducing overall fishery participation. One of the primary goals of this FMP is to develop new regulations that help meet the needs of the modern fleet and associated fishery support businesses. This section describes the roles of these businesses in product offloading, processing, and pricing, as well as how changes in fleet composition since the early 2000s have prompted the need for a new permitting system. The current socio-economic composition of the fleet is discussed, and consideration is given to how that composition might be impacted by the regulatory changes established under this FMP.

4.7.1 Product Offloading, Processing, and Pricing

The primary product from the modern commercial gill net fishery is sac-roe, which consists of the mature (ripe) egg skeins of gravid female Herring. Fishing operations target mixed schools of male and female fish, and thus both male and female Herring are caught in the gill nets. At the time of FMP development, 24 vessels were registered to permit holders, with an average reported vessel capacity of 20 tons (18 metric tons). When Herring vessels reach their maximum capacity (or when the spawning event is over), the boats leave the fishing grounds and return to port for offloading to licensed Herring buyers.

In the past, during the peak of fishing in San Francisco Bay, offloading sites and their associated infrastructure were situated at several locations around the bay, including the San Francisco Waterfront, Port of Oakland, and Sausalito. Multiple sites were necessary to prevent long waits for fishing vessels to offload. Currently, however, offloading, processing, and buying takes place only in San Francisco, with the majority of activity and associated infrastructure confined to the area of Fisherman's Wharf. During offloading, fish are pumped from the boat into holding containers (fish totes) and weighed using certified scales. Commercial landing receipts are completed and Herring buyers report the weight of Herring purchased to Department staff. This allows the Department to track the season's quota and predict when an individual platoon's quota might be reached. Department staff are regularly onsite to oversee offloading and collect samples from the commercial catch. This in-season tracking helps minimize the potential for quotas overages, and as a result the San Francisco Bay quotas have rarely been exceeded.

Licensed Herring buyers pay fishermen based on the percentage of ripe skeins in the catch. This is calculated from several random 10-kilogram (kg) samples per landing. Each fish sampled is sexed and ripe skeins are extracted, placed on a scale and weighed. The total weight of the ripe skeins is then divided by 10 kg, resulting in the roe percentage. San Francisco Bay roe percentages are typically 10% or higher, while Herring buyers in Eureka required roe percentages of at least 12% (K. Bates, personal communication). The roe percentage for San Francisco averaged 12 to 14% through the mid-90s, but has increased since the late 1990s. The ex-vessel price is based on minimum 10% yield and is adjusted for percentage points above the minimum (Figure 4-3). Despite increases in roe percentage, price per ton has declined since the late 1990s.

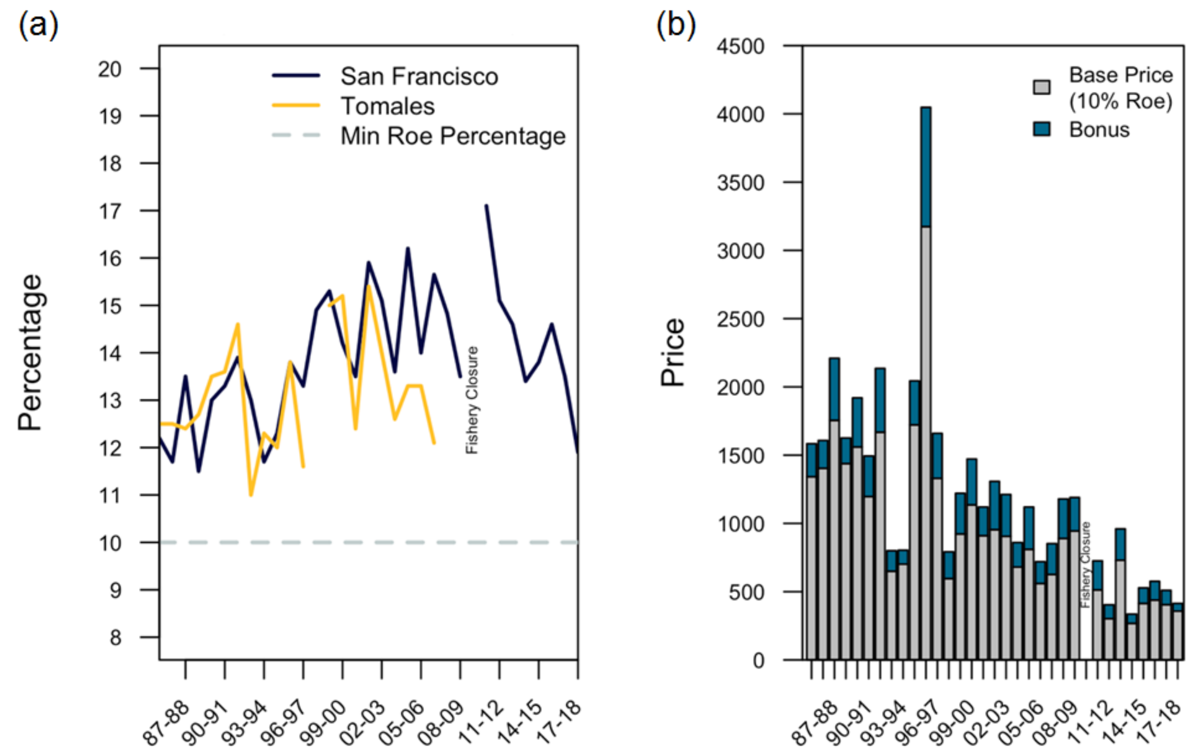

Figure 4-3. Roe percentage of gill net fishery (a) in San Francisco Bay (purple) and Tomales Bay (yellow) and pricing for the sac-roe fishery (b) including the base price (10% roe, grey) and bonus (blue).

Herring are iced and then trucked from the port of landing to a processing plant for skein removal, brining, and grading. Roe skeins are graded by size, color and shape, and then packed for export to the primary market in Japan. Brined skeins are leached in freshwater overnight and served with condiments or as sushi. They are associated with good luck, and typically eaten in New Year's celebrations or given as gifts. High demand for kazunoko in Japan resulted in high ex-vessel prices for Herring roe between the 1970s and the 1990s, and the Herring fishery was one of the most valuable in California, reaching almost 20 million dollars in ex-vessel value at its peak (Figure 4-4). However, a combination of low prices and reduced quotas has resulted in a much lower total value for the fishery since the early 2000s.

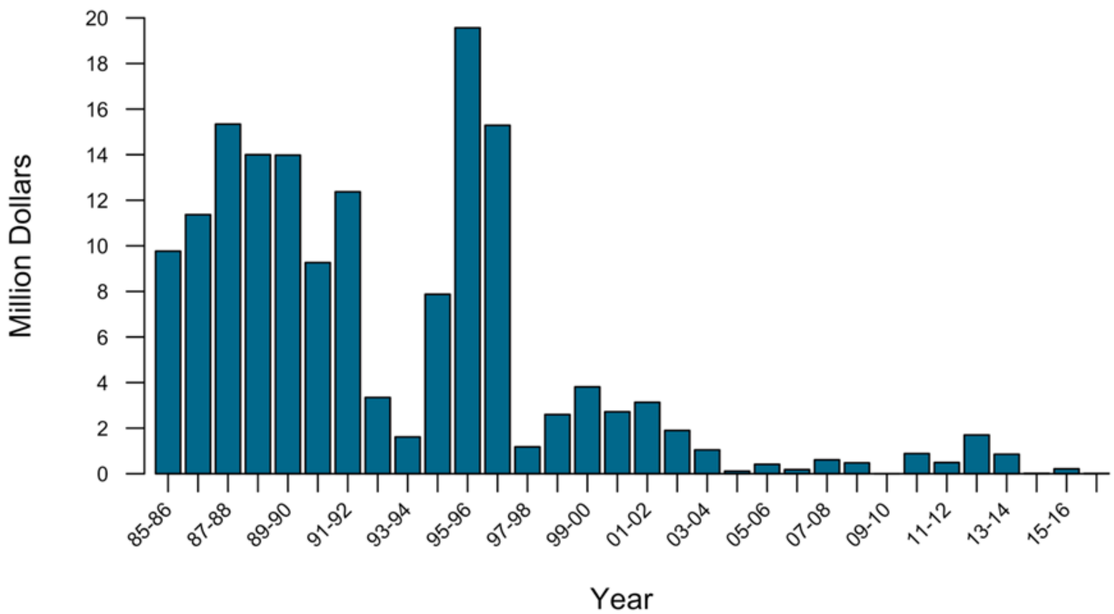

Figure 4-4. Ex-vessel value (in millions of dollars) for the California sac-roe fishery, 1985-2017.

4.7.2 Changes in Participation and Implications for Permitting System

Between the mid-70s and the late 1990s participation in the fishery was high. At the peak, the fishery had over 400 permits, and many more qualified applicants. In 1989, Herring permits became transferrable, meaning that they could be sold to any licensed fisherman. This change had wide ranging implications, and made Herring permits a valuable commodity. Individual Herring permits were valued at approximately $60,000 each in the early 1990s (Spratt, 1992). Herring permits could also be leased to other fishermen, further reducing permit turnover, because permit holders could profit from their permit by allowing someone else to utilize it through a lease arrangement.

With the declines in the price of Herring since the late 1990s there has been a steady reduction in the number of permits fished each year (Figure 4-5). In recent years, the number of permits fished each season has been below 40. In 2014-15 only six permits were fished, due to disagreements between the fleet and buyers in setting the ex-vessel price of Herring. Additionally, permit holders have elected not to renew their permits to avoid paying annual renewal fees, resulting in a decrease in permit renewals. Permit transfers have decreased as well.

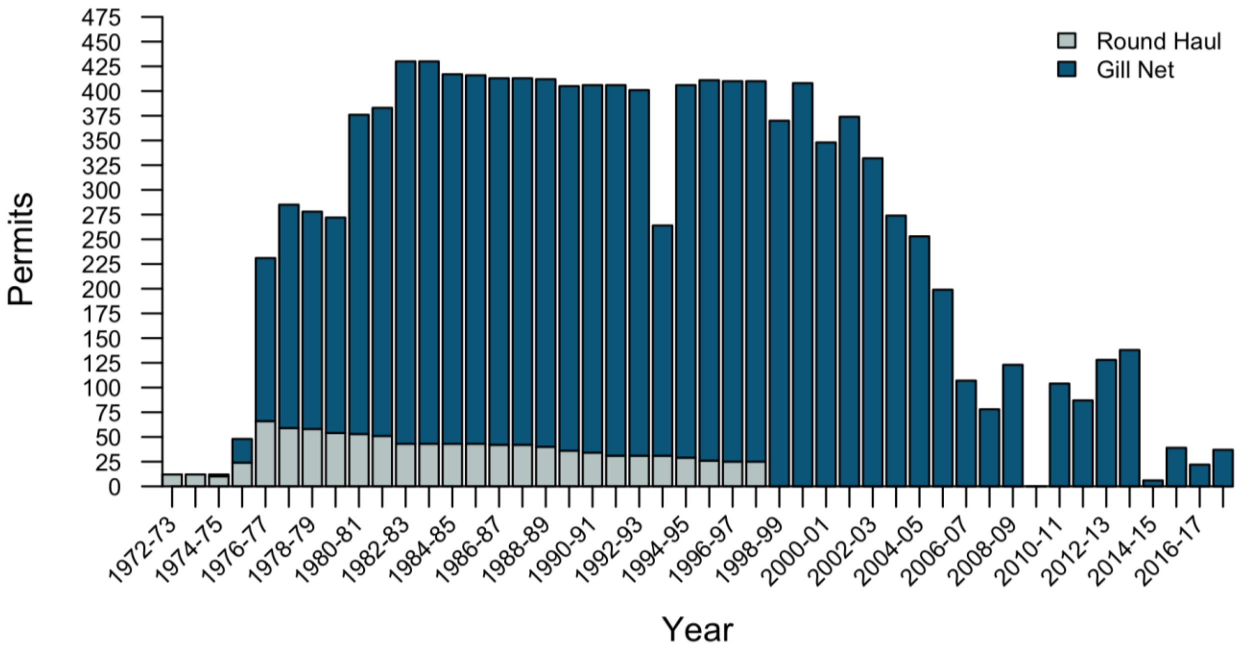

Figure 4-5. Number of permits fished in the sac-roe fishery by gear type each year since the beginning of the fishery in San Francisco Bay.

This FMP establishes a consolidated permit system. Prior to the implementation of this FMP, permit holders were not allowed to own more than one permit within the same platoon, but could own a permit in each of the platoons (December, Odd and Even). Under that system, two permits could have been assigned to a vessel in order to fish two nets. However, each permit had to be owned by a different individual. This led to a system in which permit holders substituted their permits to other fishermen so that vessels could fish a full complement of gear (two nets). Due to the reduction in permit renewals and overall decline in fishery participation, the platoon system is unnecessary, as there is no longer a concern about congestion and conflict on the fishing grounds. Under the consolidated permit system, for permits other than Temporary permits, a permit allows the holder to fish two nets during every week of the season. The Temporary permit allows the holder to fish one net in the San Francisco Bay management area, and up to two Temporary permits may be fished from one fishing vessel. Fishermen are able to own one permit in the Tomales Bay, Humboldt Bay and Crescent City Harbor management areas and fish up to two gill nets of 65 fathoms in length each at the same time from a single vessel with a Tomales Bay Herring permit, or in combination up to 150 fathoms of gillnet with a Humboldt Bay or Crescent City Herring permit. In the San Francisco Bay management area fishermen are able to own up to one Temporary Permit and one San Francisco Bay permit, however a maximum of two nets may be fished from a single fishing vessel. Additionally, a long-term capacity goal of 30 vessels (equivalent to approximately 120 permits under the prior Platoon system) is established for the San Francisco Bay fleet, and no new permits will be issued until the number of renewed permits falls below the long-term capacity goals of 30 San Francisco Bay permits.

In 2014, the SFBHRA, a group of commercial Herring fishermen, filed a lawsuit against Pacific Gas and Electric (PG&E) for contamination of the San Francisco Bay waterfront. The contamination was the result of PG&E's operation of a manufactured gas plant at Fisherman's Wharf in the late 1800s and early 1900s that turned coal and oil into gas for residential use. The process created large concentrations of chemicals known as poly-aromatic hydrocarbons (PAHs), which have been shown to cause mortality in larval and juvenile Herring. These chemicals are extremely persistent and remain highly toxic for hundreds of years after being released into the environment. PAHs released into the bay have been buried in the sediment, but can be reintroduced to the water column if they are disturbed via dredging or other activities, where Herring may re-encounter these chemicals and be affected by them.

The lawsuit was settled in 2018 (concurrent with the development of this FMP), and the terms of the settlement included a permit buyback agreement in which PG&E agreed to buy at least 40, and up to 80, Herring permits from commercial fishermen. These permits will be permanently retired and cannot be renewed as a condition of the settlement. While this is an external process, it aligns with the Department's permit consolidation goals.

4.7.3 Modern Fleet and Fishing Community Composition

To understand how changes to the permitting system under this FMP affect permit holders and their communities, it is helpful to have information about the composition of the commercial Herring fleet. Ideally, this information would include demographics on permit holders, crews they employ, and the communities where they reside, as well as how they have changed over time. It is also useful to know which other fisheries permittees and crewmembers participate, because changes in regulations in one fishery can affect others. Finally, demographic information about shore-based infrastructure and ancillary employment required to support fishing activity can be useful for understanding socioeconomic impacts to fishing communities. This section presents the state of knowledge concerning the community composition of the commercial Herring fleet at the time this FMP was prepared.

During the 2017-18 season, 138 Herring permits were held for all fishing areas. Of these, four permits were for the Humboldt Bay, five for Tomales Bay, and 129 for San Francisco Bay. Some permittees in the San Francisco Bay fishing area held multiple permits, with nine individuals holding three permits, 14 individuals holding two and 74 individuals holding a single permit. The average age of the permittees at the beginning of the 2017-18 season was 61.5 (Figure 4-6). The majority of permittees as of 2017-18 had participated in the Herring fishery, as crew or as permit holders, for more than 30 years.

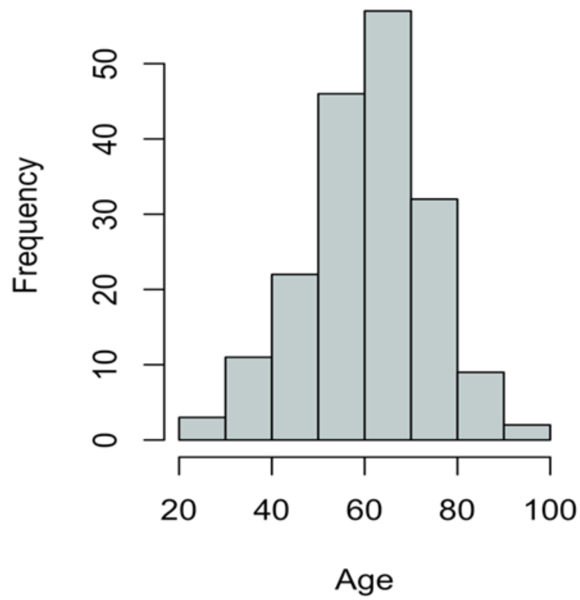

Figure 4-6. Age of permittees in the California sac-roe Herring fishery at the time of FMP development.

Herring permittees primarily live along the West Coast and of those who live in California, the highest percentage of permittees reside in Monterey County (Table 4-1). Most other permittees live in counties adjacent to San Francisco Bay. The remaining permittees live primarily in counties in eastern or northern California, though several permittees reside out of state or in southern California.

Table 4-1. Residence of Herring permit holders.

State	Residents	California Residents - County	Residents
California	78%	Monterey	34%
Washington	19%	Marin	13.5%
Oregon	2%	Sonoma	8.5%
Other	<1%	Mendocino	5.6%
		Contra Costa	5.6%
		Solano	4.2%
		San Mateo	4.2%
		San Francisco	2.8%
		Alameda	2.8%
		Other	18.8%

Four Herring permittees hold general gill net permits, four permittees also hold permits in the deeper nearshore fishery, and three permittees hold drift gill net permits. Three or fewer permittees also hold sea urchin diver permits, non-transferrable lobster permits, and rock crab trap permits. Given the age composition of the fleet, it is likely that Herring permit holders participated in additional fisheries in the past, but have only retained permits that are valuable or transferrable. However, there is limited information regarding permit holders' active participation in other fisheries besides Herring, and there is no information currently available on what federal permits Herring participants hold.

Landings by port area may provide insight into active participation in other fisheries by Herring permits holders. Table 4-2 shows the five largest fisheries by value for the San Francisco, Tomales Bay, Eureka, and Crescent City areas. A number of Herring permit holders that operate out of these ports also participate in the Dungeness Crab and Chinook Salmon fisheries, suggesting that changes in these fisheries might impact effort in the Herring fishery.

Table 4-2. 2017 Commercial landings and ex-vessel value for the San Francisco, Tomales, Eureka, and Crescent City ports.

Port	**Species**	**Landings (lbs)**	**Value**
San Francisco Bay	Crab, Dungeness (*Metacarcinus magister)*	2,316,341	$8,560,751
	Halibut, California (*Paralichthys californicus*)	178,512	$1,157,536
	Swordfish (*Xiphias gladius*)	294,383	$1,016,771
	Salmon, Chinook	107,353	$995,818
	Squid, Market (Doryteuthis *opalescens)*	1,217,776	$570,710
Tomales Bay	Crab, Dungeness	1,904	$9,520
	Surfperch, Barred (*Amphistichus argenteus*)	1,206	$2,474
	Surfperch, Shiner (*Cymatogaster aggregate*)	229	$2,290
	Hagfishes (*Eptatretus* spp.)	2,400	$1,800
	Halibut, California	56	$445
Eureka (Humboldt Bay)	Crab, Dungeness	1,432,549	$4,439,861
	Sablefish (*Anoplopoma fimbria*)	683,484	$1,662,447
	Sole, Dover (*Microstomus pacificus*)	2,849,683	$1,257,613
	Sole, Petrale (*Eopsetta jordani*)	740,367	$811,408
	Tuna, Albacore (*Thunnus alalunga*)	143,645	$285,795
Crescent City	Crab, Dungeness	1,466,899	$4,621,571
	Shrimp, Ocean (pink) (*Pandalus jordani*)	2,717,635	$1,262,032
	Sablefish (*Anoplopoma fimbria*)	160,657	$484,217
	Shrimp, Coonstriped (dock) (*Pandalus danae*)	56,131	$279,604
	Rockfish, Black (*Sebastes melanops*)	117,314	$227,112

There is limited information regarding the demographics of crewmembers employed in the Herring fishery, because crewmembers do not need a special permit (only a general California Commercial Fishing License is required). In a survey conducted in 2017 respondents indicated that each permit holder who fishes employs an average of 1.6 crewmembers. There is no information available on how long those crewmembers have been employed or in what other fisheries they may participate.

4.7.4 Market Access

Since the beginning of the roe fishery in California, the primary market for Herring has been overseas. In 1973 sac-roe fisheries developed along the West Coast of North America to supply the demands of the Japanese market. This occurred after domestic Japanese stocks crashed and Japan and the Soviet Union agreed to ban the harvest of sac-roe Herring in the Sea of Okhotsk to prevent continued overfishing of a depleted stock. The Japanese government also liberalized import quotas, which opened the sac-roe market to United States and Canadian exporters.

In recent years, demand for kazunoko in Japan has declined, and roe gift boxes are no longer sold at premium pricing. In addition, reduced demand has led to an oversupply, where unsold roe is carried over to the following year. This has led to very low prices in recent years. The California roe fisheries must compete with those in British Columbia and Southeast Alaska, which have much larger stocks and, consequently, much larger quotas. However, California Herring produce roe that are typically smaller in size than those from British Columbia and Alaska markets, and have a unique golden coloration. This has made the roe product from San Francisco valuable to buyers despite the small size of the fishery, as it allows them to offer a more diverse portfolio of Herring roe products.

Because the primary market for California's Herring is in Japan, it is necessary for fishermen to sell their product to fish receivers who can facilitate processing and export. Herring roe buyers typically process the Herring, but may simply ice and ship whole Herring to a wholesaler. The buyer/processor then sells the Herring roe to a distributer for export to Japanese markets (Figure 4-7). There are currently no local Herring buyers in California, so buyers travel from Washington or British Columbia during the Herring season. Out-of-state buyers typically partner with local fish receivers and off-loading facilities to handle fish coming into each port area. Low quotas and pricing provide little incentive for buyers to travel to San Francisco Bay for the season, and in some years almost no fishing has occurred due to a lack of interest from Herring buyers. At the time this FMP was drafted one to three buyers participated in the annual Herring fishery in San Francisco Bay. As noted earlier, there is no active fishery in the northern management areas.

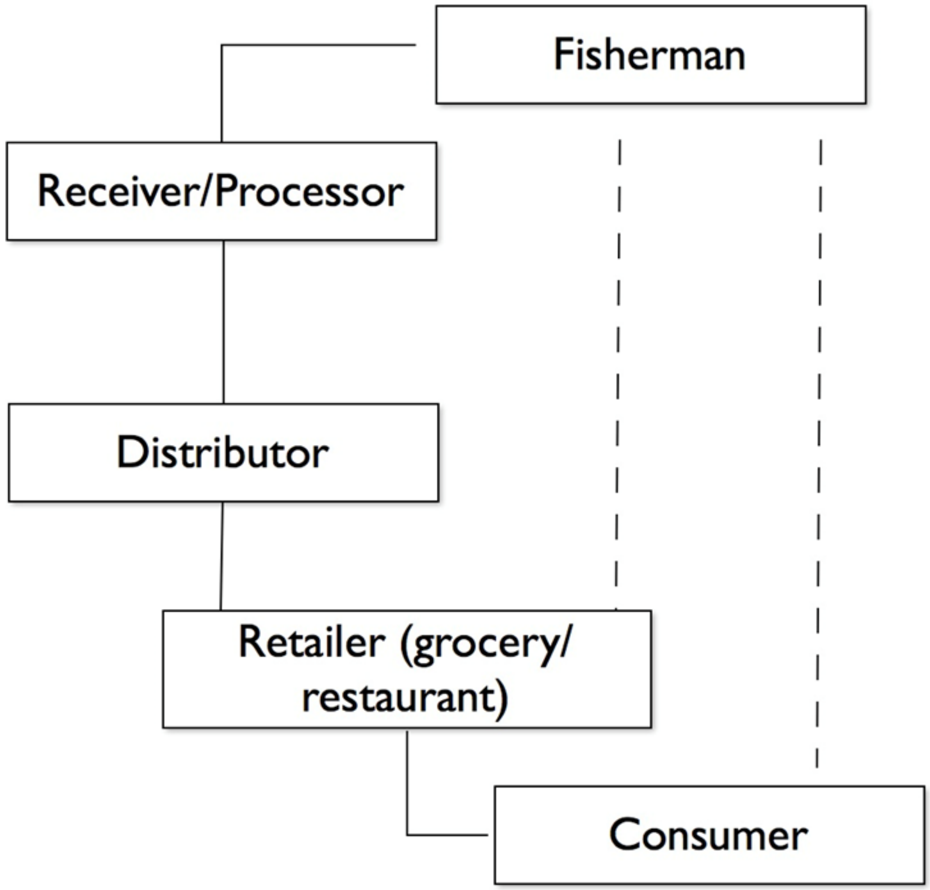

Figure 4-7. Supply chain for commercially-caught Herring caught in California. The black lines show the distribution channels for the Herring roe fishery. The dashed lines show potential channels for a local whole fish market. Note that under this FMP, commercially landed Herring may only be sold to an appropriately permitted buyer (Section 9.1).

Fishermen are typically not contracted to a single buyer. Instead, fishermen consider a number of factors in deciding who to sell their fish, including the agreed price, the reputation of the buyer and the volume each buyer will purchase. Fishermen will also consider who else is fishing for that buyer, and some may choose to avoid a particular buyer to reduce conflict. As additional incentives, buyers may also offer to cover vessel shipping costs (as some Herring fishermen reside in other states) or berthing costs during the fishing season.

While market conditions have depressed Herring fishing along the U.S. West Coast, it is possible that these conditions could change. A change in the amount of roe Herring caught in British Columbia or Alaska, whether due to environmental or management needs, could result in increased demand for California Herring roe, and a subsequent increase in price. Potential markets elsewhere in Asia, particularly in China, could also alter market conditions.

There is also a minor but increasing interest in supplying a local market with fresh, whole Herring for human consumption. A fresh whole fish product could be sold directly to local fish markets or consumers with little processing (Figure 4-7). Proponents believe this could result in higher ex-vessel prices than the roe fishery currently receives. Some stakeholders have expressed concerns that the current Herring regulations present barriers to the development of a local market. However, the available Herring quota can be caught and sold for either roe or fresh fish purposes.

There is currently a requirement that all Herring buyers be in possession of a Herring buyer's permit. This requirement allows the Department to closely monitor Herring landings and avoid quota overages. The fees associated with this permit however could inhibit smaller operators from participating due to cost. Stakeholders have proposed reducing the Herring buyers permit fee to promote local market access. Stakeholders have also petitioned the Commission to allow cast nets to be used in the commercial Herring fishery. Cast nets are able to land smaller quantities of Herring and may produce better quality product than the much larger gill net fishery. It is also possible to alter gill net handling processes to increase the quality of the fish. However, given the fact that Herring are harvested during spawning activity, and are thus of lower overall fat content, there may be an inherent limit to the quality and market value of whole Herring as a human food product (Suer, 1987; Wyatt and others, 1986).

4.7.5 Socio-Economic Considerations for the Northern Management Areas

Much of the focus of regulatory changes to address socio-economic needs during development of the FMP has been on the San Francisco Bay area. This is due to the fact that over 90% of participants fish in this management area. Even though there has been no fishing outside of San Francisco Bay since the 2006-07 season, permits are still held for these areas. The primary market obstacles have been low prices, insufficient offloading facilities, and storage and transportation costs. Department staff and shifts in management priorities have also occurred in these areas. As a result, these stocks have gone unmonitored since 2006-07, except for limited data that have been collected for the Humboldt Bay stock. One of the goals of this FMP is to establish a monitoring and management procedure in the event that fishing resumes in the northern management areas (Chapter 7), which could occur if there were a change in product value or market access. Socioeconomic considerations should be part of any proposed changes to management in the northern fishing areas in the future.

4.7.6 Characterizing the Sport Fishery

Another goal of this FMP is to develop regulations to manage the sport Herring fishery, which at the time of development of this FMP had no restrictions on catch or effort. Concerns about a growing level of take by the recreational sector and potential for commercialization made this a priority area to address in this FMP. Sale of any sport-caught fish in California is illegal (FGC §7121). Herring are primarily targeted by sport fishermen when a spawning aggregation moves close to shore to spawn, and must also be in an area that can be accessed by the public. When this occurs, fishing effort is concentrated and intense for a short period. However, very little effort data is available on the recreational sector due to difficulties in intercepting participants. Current recreational fishery surveys employ a random sampling design and do not frequently intercept participants in this fishery (Section 6.1.2.9). A more targeted sampling protocol may be necessary to collect data on the Herring sport fishery and its participants.

Incomplete information has made it challenging to evaluate the likely impacts of potential regulations on the recreational Herring fishery. A better understanding of the socio-economics of the recreational fishery is needed. Comprehensive information on fishery participants, fishing locations, fishing gear, catch utilization, and primary motivation for fishing is lacking, but this section describes what has been observed about the recreational fishery.

Fishing activity associated with each spawning event generally lasts for 48 hours or less and participants must be able to access a spawning event quickly. Information on the location of spawns is commonly shared using social media and through person to person communication networks. Anglers will typically fish along the shoreline in the intertidal zone, or on piers, docks, and jetties. Recreational anglers are not required to have a sport-fishing license when fishing from public piers in ocean or bay waters. The majority of anglers fish from shore but some use small skiffs to access shallow water areas. Participants primarily use small cast nets (<12 ft) (>3.7 m) in diameter) or hook and line gear known as sabiki rigs, which consist of six hooks attached along the line and are cast from shore. The amount of fish caught per participant ranges widely and based on Department observations, catch can range from a few pounds to thousands of pounds.

Anecdotal information indicates that substantial amounts of Herring caught are used for bait in other fisheries. Herring bait is used for salmon, California Halibut, and Lingcod by recreational anglers. Herring may also be smoked, pickled or canned for personal consumption, or shared with friends and family. Chapter 7 of this FMP addresses management recommendations for the recreational fishery and identifies ways to improve data collection among participants and understanding of the socioeconomics of this sector.

Chapter 5. History of Management

5.1 Evolution of Management System

This chapter describes the evolution of Herring fishery management in California, including the rationale for using a quota-based system, as well as how management measures contribute to the sustainability and orderly conduct of this fishery. Since the beginning of the Herring sac-roe fishery, the primary basis for ensuring the sustainable use of the resource has been annual quotas that are set to achieve harvest rates that are appropriate to the size of the stock. When the sac-roe fishery first opened, the stock size in each management area was unknown. Herring are highly dynamic, and their stock size can fluctuate widely from year to year. As a result, annual monitoring programs were developed to estimate the total SSB during each spawning season (November – March) in San Francisco and Tomales Bays, and these estimates were used to set the following year's quota.

These monitoring programs and annual quota-setting procedures allowed the Department to adaptively manage the Herring fishery based on stock health indicators. Concerns about stock health in the 1990s led to a reduction in harvest rates, and since 2000 quotas have been set to target harvest rates of approximately 10% or lower. One of the goals of this FMP is to develop a plan that formalizes and builds upon this precautionary management approach employed since 2000.

The sac-roe sector of the California commercial Herring fishery was tightly regulated from its inception, and many of the management procedures that would shape the fishery for decades were developed in the early years of the fishery. Due to the initial high value of sac-roe, high participation levels, as well as congestion and conflict in the San Francisco fishing area, the Herring fishery has benefitted from an intensive level of management. Herring regulations changed yearly as the fishery expanded, and many regulations were designed to address socio-economic rather than biological issues. As a result, the Herring fishery served as a testing ground for many new management concepts in California, including a limited entry system, permits issued by lottery, individual vessel quotas, quota allocation by gear, the platoon system used to divide gill net vessels into groups, the transferability of fishery permits, and the conversion of permits between gear types (Californa Department of Fish and Game, 2001). Many of these management tools were controversial, but were necessary to address socioeconomic conflicts in a congested fishery.

The MLMA directs FMPs to outline the types of management measures they employ to promote a sustainable and productive fishery. This Chapter describes these measures, as well as the rationale behind them.

5.2 Catch Limits

5.2.1 Limits on Catch

Since the beginning of the sac-roe fishery, annual quotas (catch limits) have been the primary management tool for ensuring stock sustainability. Fish that form spawning aggregations are potentially vulnerable to overfishing, and a single unit of effort can produce very high catch rates. In addition, CPUE may remain high even when stock abundance declines. For this reason, quotas are a reliable way to achieve desired harvest rates and maintain fishery sustainability.

5.2.2 Target Harvest Rates

Quotas are often set to achieve a desired harvest, or exploitation, rate. The Pacific Fishery Management Council (PFMC) recommended that the maximum harvest rate of Herring not exceed 20% of the available biomass (Pacific Fisheries Management Council, 1982). Quotas in California were set to achieve a harvest rate of 15% for the first two decades in this fishery (Figure 5-1). This was viewed as a precautionary approach because, given that a previous season's estimated stock size was used to set the subsequent season's quota, a 15% intended harvest rate provided a buffer in the event fewer spawning Herring than expected returned in the following year. However, after a variety of indicators suggested declines in stock health, including decreased spawning abundances, reduced number of older individuals in the stock, and increased variability in year-to-year abundance, a 15% target harvest rate may not have provided adequate protection for California's Herring stocks.

While fishing likely contributed to declines observed earlier in the fishery, changing environmental conditions and alterations to spawning and rearing habitat may have reduced the productivity of the Herring stock in recent years. Additionally, Herring are at the southern end of their range in the central CCE, and target harvest rates applied to northern stocks may not be appropriate for use in California. A review of the Department's management protocol in the early 2000s recommended that target harvest rates between 10-15% should be applied (Appendix C). Since then quotas have been set to achieve harvest rates of 5-10%, depending on stock status and environmental conditions (Figure 5-1). In Tomales Bay, the quota-setting policy changed to a 10% target harvest rate in the mid-90s after the fishery was closed due to low abundances (Appendix H).

Herring fisheries outside of California still set quotas at 20% of the estimated spawning biomass. However, these fisheries typically use in-season survey methods to determine whether a certain level of spawning has occurred (spawn escapement) prior to the quota being taken, which results in a quota that more accurately implements the intended harvest rate. In California, it is not possible to set in-season harvest levels due to survey methods used and staffing constraints. Rather, quotas are set based on the previous year's SSB estimate, which comprises the estimated weight of all spawning Herring plus commercial catch for that year. Due to natural fluctuations in the size of Herring stocks, the actual exploitation rate (i.e. tons of Herring landed as a proportion of SSB that season) may be higher or lower than the intended (target) harvest rate (i.e. a given season's quota as a proportion of the prior season's SSB). When this management approach was first developed in the 1970s and 1980s, Herring stocks in San Francisco Bay exhibited more stability from year-to-year than they have since 1990 (Sydeman and others, 2018). As the variability in the stock increased through the 1990s and 2000s, the probability of exploitation rates exceeding target harvest rates has also increased. Conservative target harvest rates (i.e. in the 5-10% range) have helped buffer against this type of management uncertainty.

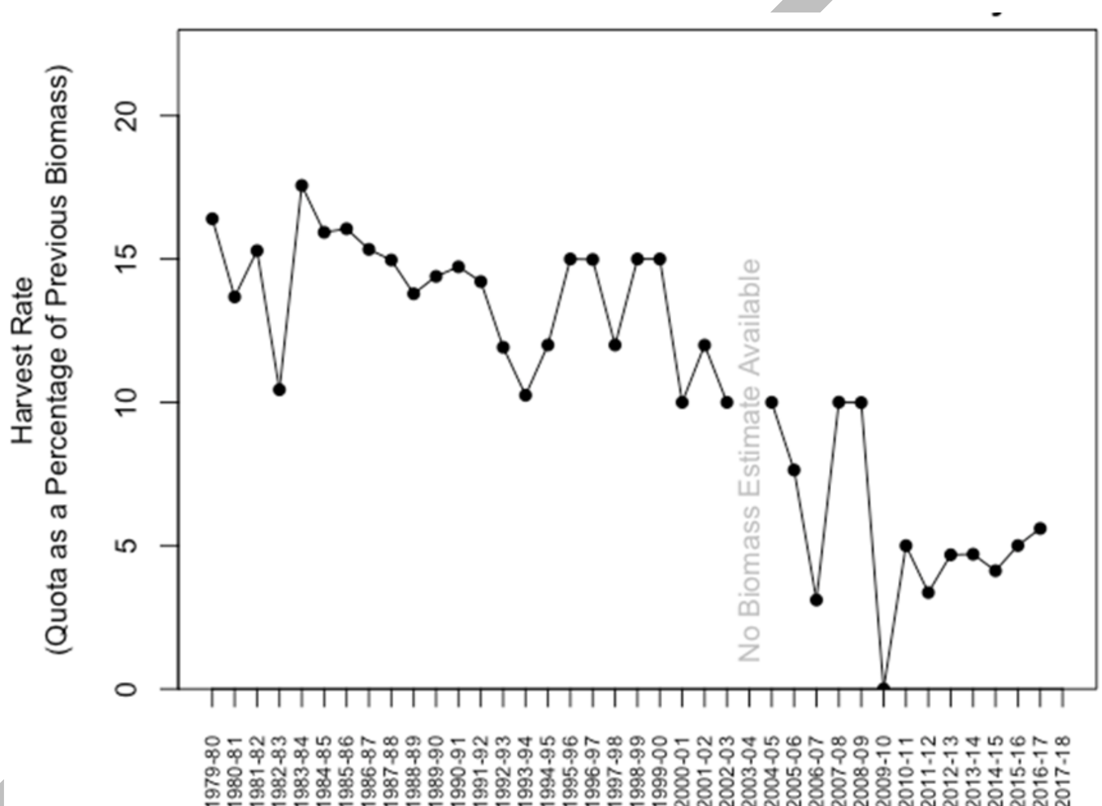

Figure 5-1. Intended harvest rates for the San Francisco Bay Herring fishery.

5.2.3 Requirements for a Quota-Based Harvest Rate Approach

Achieving a sustainable harvest rate requires the ability to estimate the size of the stock. Survey methodologies are employed annually to provide an estimate of the size of SSB in each year. This is possible because Herring spawn in a relatively well-defined area in specific habitats in California. However, stock declines in San Francisco Bay may have been masked because two separate survey methods (spawn deposition and hydro-acoustic) used during the late 1980s and 1990s produced differing spawn abundance estimates (Section 6.1.2.3). A 2003 external review recommended the Department manage based on the more conservative metric of observed spawn deposition (Appendix I), and in light of this recommendation, a retrospective analysis suggests that harvest rates may have been higher than intended, and in some years surpassing 20% of the spawning stock.

Quota-based management also requires an ability to track catch in near real time, as well as the ability to stop fishing quickly when the quota is reached. This is difficult in many California fisheries because landings are reported on paper landing receipts, and there is often a lag of several weeks before this information is mailed and manually entered into the Department's landings database. To overcome this issue, Herring roe buyers are required to obtain a special permit, which has allowed Department staff to monitor offloading and has facilitated communication between Department staff and Herring processors to manage quotas. However, in some years quotas were exceeded in Humboldt Bay and Crescent City Harbor, suggesting that catch monitoring was more difficult in those areas.

5.2.3.1 Allocation of Quota between Sectors

Allocation of the quota between sectors of the fishery evolved as the fishery expanded in the early years. By the 1980s an allocation policy was in place, and fishery quotas were split (67/33%) between the gill net and round haul gears (Spratt, 1992). Quotas were further allocated to each fleet (Odd/Even platoons, and December gill net fleets, and purse seine and lampara fleets) based on the number of participants. In San Francisco Bay a vessel quota was established for round haul gear beginning in 1981-82, which helped to reduce competition as well as dockside congestion (Spratt, 1992). Round haul gear was ultimately phased out in 1998 and the quota was reassigned to the gill net fleet. The whole ('fresh') fish fishery was also allocated a 20-ton quota (18 metric tons) each year until 2013, when it was combined with the sac-roe quota to provide better access for the local whole fish market for Herring.

When the San Francisco Bay HEOK fishery began, quotas were initially allocated for each participant by calculating each permittee's share of the total sac-roe sector quota based on whether they had converted a round haul or gill net permit to the HEOK sector. A conversion factor based on fecundity and sex ratios (Moore and Reilly, 1989) (Section 4.3.1) was used to determine the total product weight of eggs on kelp that could be landed. Prior to implementation of this FMP, each HEOK permittee was allocated an egg-on-kelp 'equivalent' of 1% of the total roe fishery quota (up to 10% with the maximum of ten participants fishing) (Section 7.8.1.1, Appendix N).

In Tomales Bay individual quotas were implemented in 1975-76, with a larger allocation going to round haul permits due to their greater operating costs (Spratt, 1992). Individual quotas were eliminated the following year in favor of group gear quotas. According to Spratt (1992), permittees favored a single sector quota, preferring the possibility of larger individual catches. Gear-based allocation was eliminated in the mid-80s when round haul gear was prohibited in Tomales Bay. Quotas in Humboldt Bay and Crescent City Harbor have always been a general quota and not assigned by gear or allocated to an individual permittee or vessel.

5.2.3.2 Determining When the Stock is Overfished and Initiating Rebuilding

The Herring fishery has been intensively managed for many years, and over time the policy for setting quotas evolved. Quota setting policy prior to FMP implementation did not include the use of a true HCR, which is a predetermined method for determining when management changes are warranted. An HCR specifies the stock conditions that would indicate that the stock is overfished or below its limit threshold, and what actions should be taken to rebuild the stock. They also dictate the magnitude of management response required to meet stock objectives.

While prior management policy for Herring had many desirable aspects, when and how to reduce quotas below a 10% harvest rate each year was based on ad hoc recommendations from Department staff. In addition, there were no defined limits for determining when the stock was overfished or otherwise in a depressed state, or if overfishing was occurring. Fishery closure guidelines were not clearly defined, and there was no established rebuilding plan should the population be in a depressed state. The formal HCR-based management policy established by this FMP improves managers' ability to promote the sustainability of California's largest Herring fishery in San Francisco Bay.

5.2.4 Limits on Incidental Catch in Other Fisheries

Herring were commonly taken in fisheries targeting other coastal pelagic species up until 2010. The primary gear type utilized was purse seine, and the majority of these landings occurred in the summer months in the Monterey area, though a small number of landings were reported further south. The ocean waters fishery was closed in 2010 due to concerns about low abundances in the San Francisco Bay stock. Regulations now specify that Herring may only be taken as an incidental species, provided the landed catch is no more than 10% Herring by weight.

5.3 Effort Restrictions

While a quota has been the primary mechanism for limiting fishing mortality, the sac-roe fishery in San Francisco Bay has been managed through a limited entry system since its early years. Limiting effort through a permitting system has had a number of benefits. First, each of the fishing areas has limited space and a number of other concurrent uses, and restricted access has reduced crowding and user conflicts. The restricted access system has also provided an incentive for regulatory compliance because violators could have a permit suspended or revoked. Finally, the restricted access program has provided an incentive for industry stewardship and involvement in the management process, because permit holders were assured continued access to the resource in future years.

5.3.1 Permits in San Francisco Bay

During its first year, the sac-roe fishery in San Francisco Bay was open to all interested participants, but in the following years the number of permits was capped, and a lottery was held when the number of applicants exceeded the number of permits available. When quotas began to increase, it was decided to increase the number of permits as well because demand for a Herring permit was high and there was a desire not to create a windfall for existing permit holders (Spratt, 1992). Qualification criteria and a points system based on fishery participation were established, and the number of permits slowly expanded over a period of ten years until the fishery was deemed to be at maximum capacity in the early 1980s, when permit caps were established. After that the number of participants remained steady for the next two decades (Figure 4-5, Appendix J).

The permit system evolved over time to meet the needs of the fleet and to address regulatory issues as the fishery evolved. The following sections describe some of the major changes to the permitting system that have shaped the current fishery. Permit consolidation under this FMP, including the elimination of the platoon system, is discussed in Sections 4.7.2 and 7.8.2.

5.3.1.1 Development of a Platoon System

High prices for sac-roe caused rapid expansion of the fishery, and by the late 1970s, the fishing grounds in San Francisco Bay became congested. In the 1978-79 season the Commission divided the 220 gill net permit holders by permit number into two groups, known as the “Odd” and “Even” platoons. Each platoon was allocated a part of the quota and allowed to fish during alternating weeks of the season. To further address concerns about congestion in the face of high demand for Herring permits, the Commission issued permits for a three-week gill net fishery in December. Prior to this, commercial Herring fishing in San Francisco Bay had only been allowed January through March.

Prior to FMP implementation, regulations allowed an individual to own a permit for each of the three gill net platoons (December, Odd, and Even) in San Francisco Bay. Permittees could not hold more than one permit in each platoon and not more than three permits in total. This restriction prevented individuals from consolidating a large number of permits and maintained access to the sac-roe sector for as many participants as possible. Due to lower stock abundance in December, that fishery was closed in 2011, and all December permits were assigned to either the Even or Odd platoon.

5.3.1.2 Transferability

In 1989, the Legislature made Herring permits transferrable, meaning that they could be transferred to any licensed fisherman. Prior to this, Herring permits could only be transferred to partners, heirs, or siblings. This drastically changed the system by which permits were acquired, and no further lotteries for new permits were held. This also made it much more difficult for the Department to meet permit caps through attrition alone.

5.3.1.3 Vessel Reduction

In 1993-94 the San Francisco gill net permit regulatory structure was changed such that two permits could be fished on the same vessel simultaneously, often by substituting one's permit to another permit holder. This effectively reduced the number of vessels in the fleet without reducing the number of nets fished. Prior to this change, only one gill net could be fished on each vessel.

5.3.1.4 Elimination of Round Haul Permits

In 1994, the Commission adopted regulations stating that all round haul permittees had five years to convert their permit to a gill net permit. Those who converted voluntarily were issued a CH permit, equivalent to two gill net permits, to incentivize conversion. In 1998 all remaining round haul permits were converted to gill net permits.

5.3.2 Permits in Tomales Bay, Humboldt Bay, and Crescent City Harbor

A limited entry system was established for Tomales Bay in 1975-75. In 1978-79, Tomales Bay and Bodega Bay were combined into a single permit area with a cap of 69 permits. Tomales permittees were split into two platoons to alleviate congestion and conflict on the fishing grounds. Between 1981 and 1983, Tomales permittees were allowed to exchange their permits for available San Francisco Bay permits, reducing the number of permits in Tomales to 41. Subsequently, a cap of 35 permits was established for Tomales Bay.

Few permits have been issued in the northern management areas. In Humboldt Bay, six permits were initially issued, but in 1977 the number was reduced to four. In 1977 four permits were issued for Crescent City Harbor. Since the 1983-84 season only three permits have been renewed annually. At the time this FMP was drafted, no changes had been made to the regulations governing Herring fishing in the Humboldt and Crescent City Harbor permit areas since 1983. These areas did not have the same levels of participation that resulted in the competition and conflict experienced in the southern permit areas.

5.4 Gear Restrictions

Prior to FMP implementation, each gill net permit in San Francisco Bay allowed the holder to fish a single net (65 fathoms (ftms) in length) in the platoon to which it was assigned. Each vessel could fish up to two nets, and two permit holders could fish their gear from the same vessel simultaneously. This section discusses changes in gear restrictions leading to the modern fishery.

5.4.1 Transition from Round Haul to Gill net

When the Herring sac-roe fishery first began, there were no restrictions on gear type specific to this fishery. However, when set (anchored) gill nets were legalized by the Department in 1976-77 they became the preferred gear type. By the late 1970s the impacts of each gear type on the stock had become more apparent. Catch sampling revealed that round haul gear primarily caught 2 and 3 yr old Herring, while the gill net catch was dominated by 5 and 6 yr olds. Gill nets consistently caught larger Herring and a higher percentage of females, leading to higher roe percentages (Spratt, 1981). The Commission determined that no new round haul permits would be issued for the San Francisco Bay fishing area. During the 1980s the number of round haul permits declined due to attrition (Figure 4-5, Appendix J). However, in 1989 permits became transferable, which eliminated the mechanism for decreasing the number of round haul permits and stabilized the round haul fleet at 42 permits.

In the early 1990s there was concern about declining age structure of the San Francisco Bay stock, particularly the decrease in age five and older Herring that had once dominated commercial catches. In addition, there were concerns about mortality associated with test sets by seiners (round haul permittees), testing roe content and releasing the Herring if the roe percentage was not desirable. Following the 1994 Department recommendation, the Commission adopted regulations to convert the fishery to an all gill net fleet (Appendix K).

5.4.2 Reduction in Gear Fished per Permit

In the 1993-94 season the amount of gear that could be fished by an individual gill net permit was reduced from 130 ftms of net (2 shackles) to 65 ftms (1 shackle). This effectively reduced each permit to a single net and reduced the amount of gear being used by half.

5.4.3 Changes in Gill net Mesh Size

Regulations specify the total length in fathoms (ftms) and height (depth of net in number of meshes) of each net in order to limit the efficiency of the fleet and reduce the potential for spatial conflicts between fishermen. There are also restrictions on the minimum and maximum allowable mesh size, which determines the selectivity of the gear (i.e., the size and age of fish it will catch). Nets with larger mesh size catch larger fish and more females, suggesting that larger mesh sizes are beneficial to the fishery both economically (by increasing roe percentages) and biologically (by focusing take on larger and older fish) (Reilly and Moore, 1987). The minimum mesh size in the San Francisco Bay permit area has varied over time, while maximum mesh size has remained unchanged (Table 5-1, Appendix L). After the 1997-98 El Niño, a decline in the size and condition of Herring was observed, and the fishing industry proposed a reduction in mesh size to 2-in (50 mm) to improve catch rates. The fishing industry expressed concern that the use of 2.125-in (54 mm) mesh in San Francisco was harmful to the resource because fish were squeezing through the gill nets, and in turned harmed or killed in the process. Department staff expressed concern that 2-in (50 mm) minimum mesh size would increase the catch of 2 and 3 yr old Herring, which conflicted with management objectives of targeting older age classes. Despite these concerns, the Commission reduced the mesh size in 2005 to 2-in (50 mm). Since that time, the proportion of age four and older fish caught in the fishery has increased (Figure 5-2), likely due to several years of low harvest rates increasing the number of older fish available in the stock. By 2014-15, the proportion of age three fish had returned to a level similar to that observed in the early- and mid-90s, and in 2016-17 a measurable proportion of 7 yr old Herring were taken for the first time in 20 years. Poor recruitment is likely cause for the drastic reduction in the proportion of 3 yr old fish observed in 2017-18.

Table 5-1. Summary of mesh size requirements for the San Francisco Bay gill net fleet.

Period	**Gill net Mesh Size (in)**	
	Minimum	**Maximum**
1976 to January 14, 1983 (No restrictions prior to 1976)	2	2.5
November 28, 1982 – December 16, 1983	2.25	2.5
January 2, 1984 – March 11, 2005	2.125	2.5
December 19, 2005 – Present	2	2.5

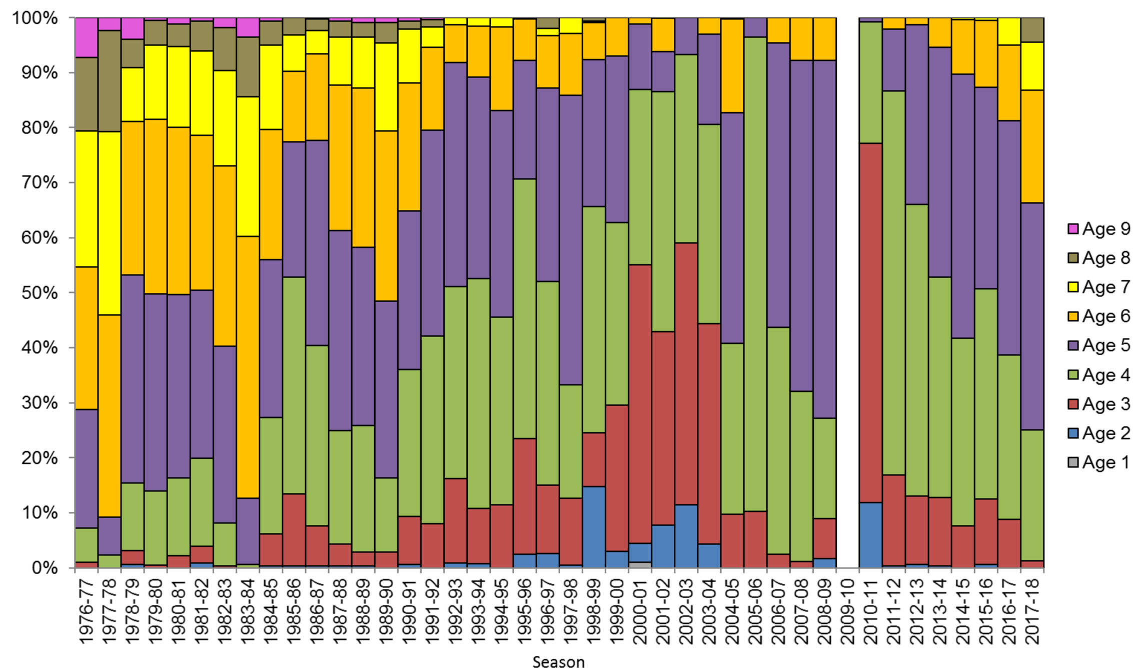

Figure 5-2. Age structure of the commercial Herring catch between the 1976-77 and 2017-18 seasons (the fishery was closed in 2009-10).

5.5 Spatial Restrictions

Commercial fishing for Herring is confined to four management areas in California: San Francisco Bay, Tomales Bay, Humboldt Bay, and Crescent City Harbor. Commercial Herring fishing is prohibited in all other areas, including ocean waters governed by the state, though Herring may be landed as incidental catch provided they are no more than 10% of total landings.

There are numerous fishing area closures across San Francisco Bay (Figure 5-3). Spratt (1992) provides a comprehensive description of how spatial restrictions evolved in San Francisco Bay in the early years of the fishery. Most were instituted due to conflicts between Herring fishing gear and other on-the-water activities that occur in a highly populated urban area. There are closures that protect Herring spawning areas near Sausalito, as well as restrictions on fishing in the deep-water holding areas in the South Bay to protect Herring prior to spawning. Richardson Bay is considered a conservation area and has never been open to commercial gill net Herring fishing activity. Since subtidal spawn deposition surveys began, a majority of observed spawns have occurred in Richardson Bay. This closure therefore protects Herring during spawning in one of the most important spawning areas in San Francisco Bay. HEOK fishing is allowed in specified areas provided rafts and cork lines are affixed to permanent structures to prevent impacts associated to anchoring in eelgrass beds. This regulation also helps Department staff to locate and monitor HEOK fishing activity.

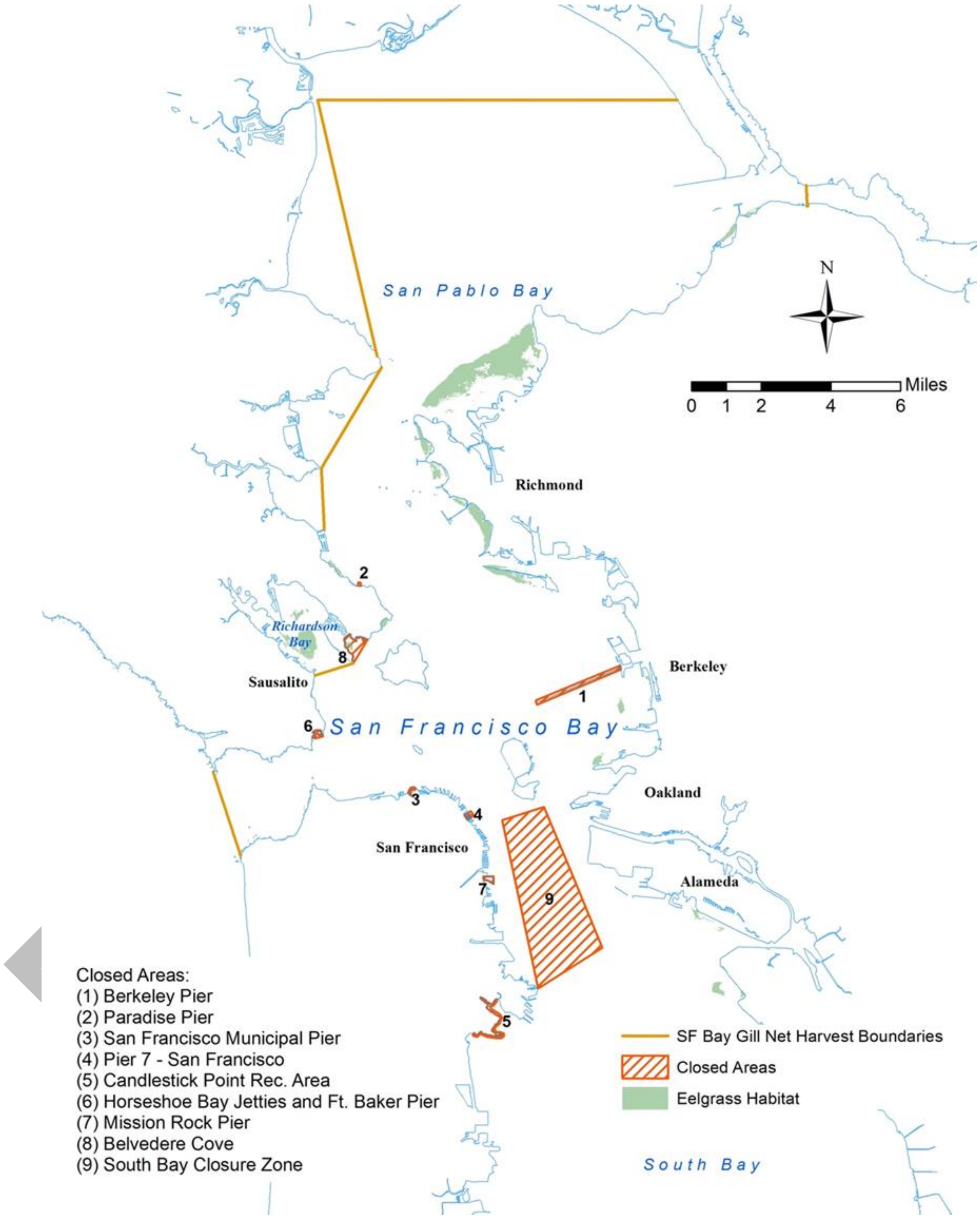

Figure 5-3. Spatial restrictions on Herring fishing in San Francisco Bay. Eelgrass habitat from Merkel and Associates (2014).

5.6 Temporal and Seasonal Restrictions

5.6.1 Herring Fishing Seasons

The Department regulates commercial Herring fishing in California via seasonal closures. The Herring sac-roe fishery is limited to the winter months when Herring come into bays, estuaries, and coastal areas to spawn (December-March in California) and additional weekend closures are used to protect the Herring stock and minimize user conflict in San Francisco Bay (Table 5-2). The Herring roe fishery begins January 1 and extends to March 15, though in practice the quota is usually taken by mid to late February.

Between 1980-81 and 2008-09 there was a three-week fishery in December for those who held December permits. This fishery had a separate quota from the regular season. If the full December quota was not taken during the month of December, these permits could be fished again after the regular season Herring Odd/Even quotas were reached. This fishery was eliminated after very low biomass was observed in 2008-09 to protect the older age classes of fish that tend to spawn earlier in the season and were often targeted by the December fishery.

Herring spawning typically occurs later in Humboldt Bay and Crescent City Harbor, which is reflected in the opening and closing dates for these areas (Table 5-2). HEOK can be fished in San Francisco Bay any time between December 1 and March 31.

Table 5-2. California Herring fishery season dates.

Sector	Start	End	Notes
San Francisco Bay	1-Jan	15-Mar	Starts at 1700 on January 1, may delay to first Sunday if January 1 falls on Friday or Saturday. Closes at 1200 each Friday until Sunday at 1700 weekly.
Tomales Bay	26-Dec	22-Feb	
Humboldt Bay	2-Jan	9-Mar	
Crescent City Harbor	14-Jan	23-Mar	
HEOK	1-Dec	31-Mar	
Whole ('Fresh') Fish	1-Jan	15-Mar	Incorporated into sac-roe fishery beginning in the 2013-14 season. Previous dates were November 2 - March 31.
December Fishery (San Francisco Bay)	1-Dec	3 weeks later	Inoperative as of 2010
Open Ocean - North	1-Apr	30-Nov	Inoperative as of 2010
Open Ocean - South	1-Apr	31-Oct	Inoperative as of 2010

Prior to the 2013-14 season the commercial take of Herring for the whole ('fresh') fish market was open between November 1 and March 31, but restricted during the roe fishery to prevent Herring taken under fresh fish regulations from entering the roe market (Spratt, 1992). In 2013, regulations were changed to eliminate distinctions between whole fish and sac roe fishery sectors, effectively allowing Herring to be landed for either purpose, at any time during the roe fishery, without a market order. The ocean waters fishery was also regulated by a season before it was closed in 2010 to protect Herring stocks (Table 5-2).

5.6.2 Temporal Restrictions

5.6.2.1 Weekend Closure

In San Francisco Bay, weekend restrictions are in place for the commercial Herring fishery to prevent conflicts between user groups, primarily recreational boaters that frequent the bay beginning on Friday. A weekend closure occurs at 1200 each Friday to Sunday at 1700 each week through the season. Tomales Bay, Humboldt Bay and the Crescent City Harbor commercial Herring fisheries are permitted to fish seven days per week.

5.6.2.2 Nighttime Restrictions on Unloading

In San Francisco Bay, Herring fishermen are only allowed to unload between 0600 and 2200. This restriction was put in place to reduce the noise associated with Herring offloading pumps near residential areas such as those in Sausalito, it also benefits Department staff for enforcement and quota monitoring. Currently, Herring offloading only takes place at Pier 45 on the San Francisco waterfront. No similar nighttime restrictions exist for the other fishing areas.

5.7 Limits on Size or Sex

There are no direct limits on the size of Herring that are retained in either the sac-roe or whole fish sectors. However, the restrictions on mesh size ensure that the gill nets select larger, older fish.

There are no limits on which sex of fish can be retained in the Herring fishery. The sac-roe fishery sector targets mature, ripe females because the product of this fishery are the egg skeins. Spawning Herring are part of large, mixed-sex spawning aggregations so there is no method to effectively target only female fish. As a result, both females and males are landed in this fishery. However, fishing later in a given spawning aggregation results in catch of a higher proportion of females, because the males initiate spawning by releasing milt prior to females depositing their eggs.

5.8 Management of the Recreational Sector

The recreational fishing of Herring was long thought to contribute a small percentage to the total Herring removals each year, and prior to the development of this FMP there were no restrictions on catch or fishing effort. Recreational participants are not required to have a fishing license if fishing from a public pier or jetty. However, recent concerns about increasing catch levels and the possible commercial sale of recreationally caught Herring have prompted the Department to propose regulations to better manage the recreational sector (Chapter 7).

5.9 Management Measures to Prevent Bycatch

A number of restrictions have been put in place to reduce the impact of bycatch during Herring fishing activities. These include limits on the species that can be retained and gear restrictions designed to minimize interactions with other species. In addition, there are restrictions on Herring discards.

5.9.1 Amount and Type of Bycatch

No data exist on the relative rates of incidental take of other fish species in Herring gill nets, but a number of species are accidentally taken during commercial Herring fishing operations (California Department of Fish and Game, 1998). The species most likely to be taken are relatively small in size and more vulnerable to the mesh size used in Herring gill nets. Species observed in gill nets include: Jacksmelt, *Atherinopsis californiensis*; Pacific Sardine; Surfperch; Soupfin Shark, *Galeorhinus zyopterus*; American Shad*;* White Croaker, *Genyonemus lineatus*; and unidentified crab (California Department of Fish and Game, 1998).

Department staff observed the incidental catch in the research gill nets used to survey the fishery during three different years in San Francisco Bay and found the bycatch rate to be less than 0.5% (Table 5-3). The species taken included: Brown Smoothhound, *M. henlei;* Spiny Dogfish*;* English Sole, *Parophrys vetulus;* Pacific Sanddab, *Citharichthys sordidus;* Staghorn Sculpin, *Leptocottus armatus;* silverside smelt, family Atherinopsidae; Shiner Perch, *Cymatogaster aggregata;* and Jack Mackerel. While the research gill nets use a variety of mesh sizes and are not identical to commercial gill nets, they provide some indication of the relative rate of the incidental take of other fish species during the Herring season.

Table 5-3. Proportion of total take of incidentally caught fish in Herring research gill nets (California Department of Fish and Game, 1998).

Season	Hours Fished	Herring caught (Numbers)	Incidental Catch (Numbers)	Incidental Catch Rate
1982-82	154	4393	7	0.0016
1983-84	78.6	1636	8	0.0049
1988-89	18.3	440	1	0.0023

Bycatch rates are low due to a number of different management restrictions. Herring vessel operators are required to be no more than three nautical mi from their nets while fishing the waters of San Francisco Bay. Due to operational needs of the fishery Herring nets are typically not left unattended for long periods of time. As a result, should a seabird or marine mammal become entangled they are likely to be freed quickly, reducing the chance of mortality.

5.9.2 Interactions with Sensitive Species

All fish caught in Herring gill nets must be retained except for the following species: sturgeon; California Halibut; salmon; Steelhead, *O. mykiss;* and Striped Bass, *Morone saxatilis*. If caught these species must be returned to the water immediately (CCR Title 14 §163 (e)(6)). Given the size of Herring gill net mesh, larger fish such as sturgeon are unlikely to be gilled. Combined with the shallow depths at which fishing occurs, mortality of large released fish is thought to be low (Spratt, 1992).

Small fish, however, are more vulnerable to the fishing gear. The primary ecological concern is the effect of the Herring gill net fishery on young salmonids in San Francisco Bay, with both listed species of salmon and Steelhead present. These include the Sacramento River winter-run Chinook Salmon, which is listed as endangered under both the California Endangered Species Act (CESA) and the Federal Endangered Species Act (ESA). Central Valley spring-run Chinook Salmon, Central Coast California Steelhead, and the Central Valley Steelhead are listed as threatened under both CESA and ESA.

Although Sacramento River winter-run and Central Valley spring-run Chinook Salmon smolts occur in Central San Francisco Bay during the Herring fishing season, the peak timing of smolt emigration typically occurs in March and April, after the Herring fishing season has ended, though the timing of these peaks can vary and smolt emigration can overlap temporally with the commercial Herring fishery. Despite any temporal overlap, most smolts remain in the main channels and move through the bay relatively quickly and are therefore not likely to occur in the nearshore areas where gill nets are often set. The Department's Bay Study Program has sampled Chinook Salmon smolts during the Herring fishing season since 1981, and the majority of fish sampled are much smaller than 165-170 mm (6-7 in), the point at which fish become vulnerable to the Herring gill nets (California Department of Fish and Game, 2005). As a result, the Herring fishery in San Francisco Bay is unlikely to pose a threat to Chinook Salmon.

Steelhead from both the Central Coast California and Central Valley Evolutionarily Significant Units (ESU) occur in San Francisco Bay during the Herring fishing season. Most Central Valley and Central Coast Steelhead emigrate after two years in freshwater, with peak emigration between January and May (McEwan, 2001; Rabin and Barnhart, 1986). The Department's Bay Study Program surveys collected Steelhead ranging from 112-277 mm (4-11 in) FL (mean=213 mm (8 in) FL, n=36) during the Herring fishing season. Because of their size, emigrating Steelhead could be captured or injured by the Herring gill nets. While there are no data indicating that Steelhead are caught by the Herring fishery, these fish are the most vulnerable salmonid species due to their life history while in the bay, particularly near the mouth of Steelhead-producing streams in the South Bay and Central Bay near Corte Madera Creek.

5.9.3 Historical Restrictions on Round Haul Gear to Prevent Bycatch

Bycatch rates for round haul gear are generally much higher than gill net. Historically, most of San Francisco Bay has been closed to encircling nets (including purse seine, lampara, and beach nets) in order to prevent the take of salmon, Striped Bass, sturgeon, and American Shad. Round haul gear is currently prohibited, but when round haul vessels were allowed in the Herring fishery, they were required to place rigid metal grate with parallel bars no more than 3 inches apart over the hatch when loading fish into the hold to prevent the bycatch of sport fish. Any large fish would be deflected onto the deck where they could be returned to the water. There are no data on the post release survival of these fish, though Spratt (1992) reports that they were returned to the water “unharmed”.

5.9.4 Discards and Herring as Bycatch

5.9.4.1 Discards

Currently, all fish caught in Herring gill net other than the prohibited species listed above must be retained, including all Herring landed in excess of quotas. This helps Department staff monitor all removals from the spawning stock.

A vessel quota was established for round haul gear beginning in the 1981-82 season to reduce competition with the gill net fleet as well as dockside congestion (Spratt, 1992). However, this vessel quota led to the practice of seiners setting on Herring, testing roe content and releasing the school of Herring if the roe content was not desirable (Spratt, 1992). The degree of injury caused by this practice is not known, but Department staff were concerned that multiple boats testing the roe content would increase mortality of Herring. In the 1991-92 season the Department instituted a test boat program to sample roe content. If the roe content was adequate the fishery would open for the day and all sets made had to be retained and landed (Spratt, 1992). The need for a test boat program was eliminated with the conversion of the round haul fleet to gill net permits.

5.9.4.2 Herring as Bycatch

In ocean waters, an incidental allowance of no more than 10% Herring by weight of any load composed primarily of other coastal pelagic fish species or Market Squid may be landed. If more Herring than this is caught it must be released.

5.9.5 Ghost Fishing

Gill nets may be lost in the course of Herring fishing activities. If these nets are not recovered, there is a potential for "ghost fishing", defined as the continued capture of fish and invertebrates. This is particularly true when floats and anchors are removed and only net mesh attached to the lead or float line remains. During the 1989-90 season, the crew of the Department's Patrol Vessel Chinook recovered 22 ghost nets. At this time the fishery was fishing up to 256 nets during each week of the season. Changes to the management of the fishery have contributed to the reduction in the potential for ghost fishing. The amount of gill net gear in San Francisco Bay was reduced by 50% beginning with the 1993-94 season, when regulations were enacted limiting each permittee to one net, 65 ftms (one shackle) in length. The number of actively fished nets has been at most 68 nets each week in the last ten years, and in many years the number of nets deployed was far less (Appendix J). In addition, the current fishery is heavily monitored, and nets are required to be marked with buoys and permit numbers. For these reasons the risk from ghost fishing has been greatly reduced.

5.10 Management Measures to Prevent Habitat Damage

5.10.1 Mitigating Habitat Threats from Fishing Activities

Gill nets are set in shallow waters (typically less than 20 ft deep) (6 m) and anchored at both ends to prevent them from moving. Set gill net gear is thought to have minimal impacts on habitat associated with each fishing area. However, anchors and nets both have the potential to disturb the bottom, affecting bottom dwelling, benthic species as well as subtidal vegetation. However, the soft-bottom benthic communities where Herring sac-roe and HEOK fisheries occur are dynamic, and are likely to recover quickly from disturbances provided they are not continuous (Herrgesell and others, 1983).

The potential for individual organisms or vegetation (particularly eelgrass) to be damaged is recognized, but no data exist to quantify those impacts. Gill net fishing for Herring is not allowed in a number of areas in San Francisco Bay, including in Richardson Bay and Belvedere Cove, which support subtidal eelgrass habitat and where the majority of Herring spawns have taken place (Figure 5-3, Section 5.5). These closures and boundaries prevent gill net fishing for Herring in approximately 361 acres (146 hectares) of total 2,790 acres (1,129 hectares) of eelgrass in San Francisco Bay, based on the most recent eelgrass habitat estimates (Merkel and Associates, 2014). This is roughly 13% of total eelgrass habitat present in the entire San Francisco Bay. However, eelgrass beds in other areas are vulnerable to disturbance by gill net gear. Areas where fishing is intense could suffer the greatest short-term adverse effects, although the limited depths associated with eelgrass beds provide some limitation on fishing pressure in those areas. The reduction in the active fleet size over the last 15 years has likely reduced the impact of fishing nets on benthic habitats.

The rafts and cork lines used in the HEOK fishery to suspend kelp can be deployed in Richardson Bay, Belvedere Cove and other areas of the bay. They must however be tied to permanent structures. While this requirement was originally implemented to facilitate HEOK regulation enforcement, it also provides protection to eelgrass beds from raft anchors (the rafts themselves do not come in contact with the bottom). The HEOK fishery may also affect the surrounding habitat by releasing kelp blades into the water during and after fishing. Giant kelp does not occur in significant quantities in San Francisco Bay, and kelp blades released by HEOK fishing have been shown to break down within 20-30 days, with faster deterioration occurring when temperatures are higher or in areas of lower salinity (Azat, 2003).

5.10.2 Mitigating Habitat Threats from Non-Fishing Activities

Given the unique life history of Herring, the primary threats to Herring habitat are from non-fishing activities that occur in the bays where Herring spawn each winter (Section 2.13.3). The Department has authority to manage habitat threats from fishing and non-fishing sources as a trustee agency. As a trustee for the State's fish and wildlife resources, the Department has jurisdiction over the conservation, protection and management of fish, wildlife, and habitats necessary for biologically sustainable populations of those species (FGC §1802). In this capacity, the Department administers the CESA, the Native Plant Protection Act, and other provisions of the FGC that afford protection to the State's fish and wildlife resources.

Primarily, there are two different processes through which the Department provides input on projects that may impact spawning Herring and habitat. The first is the interagency consultation process (Section 5.10.2.1), and the second is the CEQA process (Section 5.10.2.2).

5.10.2.1 Environmental Work Windows and the Interagency Consultation Process

Through the interagency consultation process, the Department provides input on projects that include in-water work that may result in environmental impacts, including to spawning Herring and habitat.

One of the primary threats to Herring spawning habitat is dredging in areas used by Herring during the spawning season. Dredging and dredge material disposal causes sediment to be suspended in the water column, which can affect Herring in a variety of ways. Increased turbidity, smothered eggs, and interference with larval development are some of the documented impacts (Griffin and others, 2012). These threats are mitigated via environmental work windows, which are temporal constraints placed upon dredging or dredged material disposal activities. The work windows were created to minimize environmental impacts by limiting dredging activities to time periods when biological resources are not present or when they are least sensitive to disturbance.

Work windows control dredging activities in all of the Herring fishery management areas, though the process may be best illustrated via the San Francisco Bay Long Term Management Strategy for the Placement of Dredged Material in the San Francisco Bay Region (LTMS). The LTMS was adopted in 2001, and represents a cohesive strategy amongst regional, state, and federal agencies with jurisdiction over dredging and development in San Francisco Bay waters to minimize environmental impacts. Under the LTMS, the primary mitigation method for impacts to Herring or Herring habitat in San Francisco Bay is via environmental work windows. Any project proposing to conduct dredging activities outside of the LTMS environmental work windows is required to undertake either informal or formal consultation with the appropriate resource agencies (National Oceanic and Atmospheric Administration Fisheries (NOAA), United States Fish and Wildlife Service, or the Department).

Consultation allows these agencies to consider the potential adverse effects from dredging and disposal to species that are protected by the designated work windows. Consultation is required for any project operating between December 1 and March 15 within the Herring spawning season. If there is a delay in project completion, a waiver can be requested to allow the project to continue during the work window. Under this process, when permitting agencies are considering whether to approve a project that may disturb Herring spawning habitat, they request comments from Department staff to assist them in evaluating the impacts of allowing the project to proceed. Department staff evaluate the proposed project and determine whether the project is likely to impact a Herring spawning aggregation. If the Department determines that the project may impact Herring or its spawning habitat, the Department will recommend that the project be modified, delayed to avoid any potential impacts, or issue a work window waiver with specific conditions.

If a waiver is granted, the Department imposes conditions associated with it in order to minimize impacts should Herring spawn near the project. These conditions include, but are not limited to, the following:

- Projects are required to have an independent biological observer present to look for Herring spawning activity. These observers are trained by Department staff, and are required to report weekly on their observations.
- If Herring are observed within 500 m (1,640 ft) of a dredging project work must stop.
- Shore-line surveys are required daily or after every eight hours of inactivity at the dredging location.

The number of waivers granted varies each year, but has ranged between five and 12 since 2013. Most waivers are issued for dredging activities and some for in-water work requiring pile driving or sediment core removal. The length of waivers typically ranges from one day to through the entire spawning season. Locations have included Redwood City Harbor, Oakland Harbor, Port of San Francisco and Richmond Harbor.

5.10.2.2 California Environmental Quality Act Consultation Process

By California law, all new projects are required to go through the CEQA process to inform decision makers and the public about the potential significant environmental impacts of proposed activities, and identify ways that potential significant environmental impact(s) can be avoided or significantly reduced. If a project is deemed to have potentially significant environmental impacts, the lead agency must complete an EIR with a description of the project, its anticipated impacts, and any steps to mitigate those impacts. The EIR is distributed to state, regional, and local agencies for comment. Through this process, the Department, as a trustee agency, is able to evaluate a proposed project's impacts on Herring or its habitat. The lead agency considering the project must respond to the comment in the EIR. If the Department finds the project is likely to have adverse effects that are not properly mitigated, the lead agency may be required to alter the proposed projects alternatives to reduce impacts.

5.11 History of Regulatory Authority and Process for Regulatory Changes

When the fishery began in 1972-73, concern about the effects of a large unrestricted fishery on Herring stocks motivated a state senator from the San Francisco Bay area to introduce emergency legislation giving the Legislature temporary control over the Herring fishery (Spratt, 1992). The Legislature recognized that fish that aggregate during their spawning season are uniquely vulnerable to overfishing. A cautious management approach was chosen, and conservative catch quotas were set for the first three Herring seasons. This allowed the Department to conduct a two-year study to assess the size of the Herring population and develop a framework for setting sustainable quotas. The Legislature controlled Herring quotas for the first three seasons, before granting management authority of the Herring fishery in all four fishing areas to the Commission in 1975. For a discussion of changes to quota-setting authority established by this FMP, see Sections 7.9 and 9.1.

5.11.1 The California Fish and Game Commission Regulatory Process

Prior to the adoption of this FMP, the San Francisco Bay commercial quota was adjusted annually through a Commission regulatory process. The Commission comprises five governor-appointed members who are confirmed by the Legislature. All changes to the management of the Herring fishery was done through a rulemaking process (governed by the California Administrative Procedure Act, or APA), requiring formal noticing and public comment processes before being approved by the Commission. This annual cycle takes months to complete and many hours of staff time to develop proposals and meet rulemaking process requirements.

The annual quota setting and regulation development cycle began just after the completion of the Herring season. Department staff analyze the data collected from spawn deposition surveys, research catch surveys, and commercial catch sampling to prepare a season summary. This summary describes the number of spawns, locations surveyed, the age structure, length structure, and condition of the stock. An estimate of the total spawning biomass and information on the total catch and roe percentages is included. Department staff present this information to the Director's Herring Advisory Committee (DHAC) in March or April each year. The DHAC has historically been composed of representatives from each of the different sectors of the fishery, as well as Herring buyer representatives. The purpose of DHAC meetings is to review the status of the fishery and for the Department to propose management changes (quotas and regulations) in advance of the annual rulemaking process. Department staff draft alternatives for management changes based on the feedback provided by the DHAC. The Department recommendations (proposals) are brought before the Commission for consideration and adoption as a rulemaking using the APA. This process is open to the public and interested stakeholders.

During the rulemaking process, a document on the environmental impact of the proposed changes is also drafted under CEQA. The Department initiates a broader consultation by distributing a NOP announcing the intent to prepare the CEQA document. The NOP is distributed to members of the public, responsible agencies, and organizations that have an interest in Herring management. The Commission considers all comments submitted during the notification and review process, then selects one of the management alternatives described in the DED. The Commission votes on whether or not to approve changes in the fishery and adopts new regulations through the rulemaking described above. A FED is approved and all comments received are appended to the final document. The Office of Administrative Law reviews the regulations and sets an effective date.

5.12 San Francisco Bay Stock Assessment Model Development

In 2011, with funding provided by the SFBHRA, the Department contracted with scientists at Cefas to develop a stock assessment model for the Herring population in San Francisco Bay (Appendix B). Cefas developed and fit an age-structured population model to available data on the San Francisco Bay Herring stock. This stock assessment formed the basis for an operating model that was intended to be used to evaluate the expected impacts of various management decisions going forward as part of a Management Strategy Evaluation (MSE) framework. It was anticipated that this analysis would be used in developing a HCR as part of an adaptive management approach during development of the FMP for the Herring fishery.

Following the stock assessment peer review, the reviewers concluded that they could not recommend its use as a method for estimating biomass and setting quotas for the commercial Herring fishery in San Francisco Bay without further model development (Appendix B). This was partly because the model that best fit the available data (the preferred model) did not reflect current understanding of Herring stock dynamics. The modeling exercise and review highlighted the level of uncertainty about the dynamics of the San Francisco Bay stock and the inability to base management decisions on any single model. The reviewers emphasized the following areas of concern with the Cefas model and associated data:

- inability to establish a defensible stock recruitment relationship,
- lack of empirical support for various mortality factors used,
- unresolved issues related to gear selectivity at age, and
- over-weighting of age composition data inputs relative to YOY-based recruitment and spawn deposition-based SSB indices.

The reviewers also recommended that the model not be used as the base model for the MSE analysis, but as one of a number of uncertainty scenarios. The Department accepted the recommendations of the review panel and agreed that the deficiencies in the Cefas model, identified above, could lead to the overexploitation of the Herring stock if adopted as a management tool. The Department followed the review panel's recommendation and used Cefas' preferred model (Model 6) as one of a range of operating models representing alternative hypotheses of how the stock functions as part of an MSE.

The results of Cefas' model development and review, as well as the discussions between Department staff, the review panel and Cefas scientists, have provided valuable insight into San Francisco Bay population dynamics. They have also helped identify which areas still represent major uncertainties, which have informed the MSE work for testing the HCR (Chapter 7, Appendix M).

Chapter 6. Monitoring and Essential Fishery Information

The MLMA requires the Department to develop FMPs that are based on the best available science (FGC §7072(b)) and include the relevant Essential Fishery Information (EFI). EFI helps to manage a fish stock sustainably, and the amount and type of EFI for a given stock will depend on a number of factors. These factors include, but are not limited to, the biology and life history strategy of the stock, the socio-economic value of the fishery, the management objectives for that stock, and the availability of information that can be derived from past and current monitoring efforts. This chapter describes the history of monitoring in each of California's commercial Herring fishery areas, the EFI produced by these monitoring efforts, and how the monitoring protocols in those areas have evolved over time. It outlines EFI for commercial Herring management in California by type, how each is used in management, and its priority level (Table 6-1). Finally, this chapter identifies gaps in EFI for Herring and outlines potential monitoring protocols to address those information gaps through future research.

Table 6-1. EFI for the management of Herring, use of that EFI, and priority level.

Type of EFI Produced	**Priority for Management**	**How EFI is used in management**
Spawn Deposition Surveys		
Annual fall/winter-season vegetation densities for spawning areas	High	Used in conjunction with estimated fecundity and other Spawn Deposition Survey EFI to calculate annual abundance (biomass) of spawning stock
Dates, locations, and area estimates for each observed spawning event (shoreline and subtidal)	High	Used in conjunction with estimated fecundity and other Spawn Deposition Survey EFI to calculate annual abundance (biomass) of spawning stock
Egg density per kilogram of spawned substrate for each spawning event	High	Used in conjunction with estimated fecundity and other Spawn Deposition Survey EFI to calculate annual abundance (biomass) of spawning stock
Commercial Catch Monitoring		
In-season catch	High	Used to determine when the quota has been reached
Total removals	High	Added to biomass estimate from spawn deposition surveys to determine total spawning biomass for the season
Commercial Catch Sampling		
Age and size (weight and length) distribution of the commercial catch	Medium	Used to understand selectivity of the gear, potential recruitment issues

Weight-at-age of the commercial catch	Medium	Used to estimate the removals at age and to understand the selectivity of the gear in terms of age, helps determine fishery impacts on age structure of the stock
Research Trawl Surveys		
Research catch at age	High	Used to monitor the age structure of the spawning population
Sex ratio of each spawning wave/event	Low	Used to calculate final SSB estimate
Bay Study Trawl Survey Program		
CPUE of YOY Herring in bay	High	Provides information on the number of recruits each year, which is an index of the productivity of the stock
Spatial distribution of YOY Herring	Low	Provides information on juvenile habitat for Herring
Biological Information		
Average fecundity of spawning adult Herring	High	Used to convert observed eggs per m^2 to Herring biomass each year
Environmental and Ecological Information		
July-Sept sea surface temperature from buoy N26	High	Used in predictive model to estimate herring SSB
Alternative forage indicators as tracked by the CCIEA program	High	Used to determine whether ecosystem-based quota adjustment is warranted
Unusual mortality events of herring predators	High	Used to determine whether ecosystem-based quota adjustment is warranted

6.1 Description of Essential Fishery Information and Research Protocol

The Department initiated seasonal monitoring programs in San Francisco and Tomales Bays when the sac-roe fishery began in 1973. The primary aim of this monitoring program was to estimate population abundance in terms of the weight of the annual SSB in each bay, but additional metrics on the age and size structure of the stock were also collected (Spratt, 1981). A number of studies were conducted during the early years of the fishery to understand the biology of those stocks (Rabin and Barnhart, 1986; Spratt, 1981). Intermittent monitoring was also conducted in Humboldt Bay to estimate the size of that stock, and no monitoring had been conducted in Crescent City Harbor until 2015-16, when a limited monitoring effort commenced.

6.1.1 Fishery-Dependent Monitoring

6.1.1.1 In-Season Landings

Tracking commercial catch in near-real time is essential to successfully managing a quota fishery. In most fisheries, landings are tracked via landing receipts, but there is often a lag between the time of landing and the time at which these receipts are received by the Department and entered into the landings database. In order to monitor landings in real-time, Herring buyers report daily landing totals directly to Department fishery managers. The E-tix landings reporting system (online July 1, 2019) will allow for near real-time quota tracking. This assists Department staff in maintaining catch records within season and effectively determining when the commercial fleet has reached its quota and the fishery should be closed.

6.1.1.2 Total Commercial Landings

Commercial landings data (reported in short tons) has been collected via landing receipts each season since the fishery began in the winter of 1972-73. Historically, quotas were set for the different commercial fishery sectors, necessitating the need to track landings by individual gear type.

6.1.1.3 Commercial Catch Sampling

The Department began sampling the commercial catch in San Francisco Bay and Tomales Bay in 1973-74 (Spratt, 1981). Due to the difference in selectivity between commercial gear types, each sector of the fishery is sampled separately. Commercial catch is sampled from each spawning wave that is fished in order to capture temporal variability in catch composition. Each sample consists of approximately 20 fish taken from a commercial vessel during fishing operations or during offloading. Up to ten samples are taken per wave of spawning fish, though fewer commercial samples may be available in smaller spawning waves or when fewer vessels are participating in the fishery. When collecting samples, the vessel name and date of the landing is recorded. For each fish, length (in mm), weight (to the nearest 0.1g), sex, and maturity are recorded, and the otoliths are removed. Spent or immature fish are rare in the commercial samples, but they are included when encountered.

Otoliths collected from commercial samples are aged by Department staff at the end of each season. The age-structure information obtained from the commercial catch samples is used to calculate commercial catch-at-age in terms of numbers and weight for each gear type in each landings event.

6.1.2 Fishery Independent Monitoring

6.1.2.1 Spawn Deposition Surveys in San Francisco Bay

Since the 1973-74 season, Department staff have surveyed egg deposition from all observed spawning waves (Spratt, 1981; Watters and Oda, 2002). For each spawn event, the number of eggs laid is converted to the biomass of adult Herring that must have been present to lay that number of eggs. These estimates of biomass are summed and then added to the total landings data to provide an estimate of the total SSB (in short tons) for each spawning season. During the early years of the fishery, the sampling protocol evolved to meet management needs as they became apparent. Since the 1982-83 season a standardized protocol has been used with only minor modifications made in response to the expansion of Herring spawning season and changes in the spatial distribution of spawn events over time (Watters and Oda, 2002).

Intertidal Spawn Sampling Protocol

Beginning with the 1973-74 season, searches for intertidal Herring spawn activity have been conducted from a small boat approximately four days per week during low tide periods, from December to mid-March (Spratt, 1981; Watters and Oda, 2002). When intertidal spawns are located, the area of the spawn is estimated and eggs are collected to calculate the average egg deposition density for the area. Spratt (1981) contains a detailed description of the intertidal sampling protocol.

Beginning in 1981-82 Herring were also observed to spawn on pier pilings. Pier pilings are sampled using a protocol similar to that for intertidal spawns (Spratt, 1984). During the 1982-83 season the methods used to convert the number of eggs spawned to tons of Herring was altered to include information on the sex ratio for individual spawning runs, improving the accuracy of the estimate (Spratt, 1984).

Subtidal Spawn Sampling Protocol

Prior to the 1978-79 season, only intertidal spawns were sampled, therefore SSB estimates from these years are likely an underestimation of the stock size. Beginning in 1979-80, subtidal spawns have been sampled as well, providing a more accurate estimate of the yearly SSB. Subtidal vegetation samples are collected via SCUBA, prior to the season from spatially-random sampling locations within beds composed primarily *Gracilaria* spp., and eelgrass, at known spawning areas around the bay. At each sample site, scuba divers collect one sample from each of four 0.25 m^2 quadrats. Samples are processed in the lab, weighed, and averaged to estimate vegetation biomass (kg/m^2).

When a spawning event occurs, a rake is deployed at regular intervals throughout the bed to determine the extent of the spawning area using the Global Positioning System. As with the intertidal spawn samples, the subtidal sample is processed in the lab to calculate the number of eggs per kilogram of vegetation. These data, along with estimated vegetation biomass and estimated extent of the spawning area, are used to calculate the total number of eggs, which is then converted to short tons of adult Herring based on the average fecundity per gram of Herring (Section 3.12) (Watters and Oda, 2002).

6.1.2.2 Spawn Deposition Surveys in the Northern Fishery Areas

Tomales Bay

During the 1973-74 season Department staff began spawn deposition surveys in Tomales Bay using the subtidal sampling protocol on eelgrass beds, the principal spawning substrate in Tomales Bay (Spratt, 1981). Spawn deposition surveys continued through the 2005-06 season, after which time they were discontinued due to staffing constraints. During the 2006-07 season, limited monitoring was undertaken in preferred spawning areas when time and weather permitted, and the dates and locations of spawns were recorded. This was also the last year that commercial fishing occurred in Tomales Bay.

Humboldt Bay

Herring spawning biomass was surveyed during 1974-75, 1975-76, 1990-91, 1991-92, and from the 2000-01 through the 2006-07 seasons using the subtidal sampling protocol (Rabin and Barnhart, 1986; Spratt and others, 1992). Herring spawn occurs on the extensive eelgrass beds in both the northern and southern portions of Humboldt Bay, with the North Bay typically receiving the most spawning activity. Surveys were discontinued after the 2006-07 season due to staffing constraints and lack of fishing effort. Although SSB has not been calculated for the Humboldt Bay stock since 2007, monitoring to evaluate population characteristics and determine spawn timing and spatial extent, resumed in 2014-15.

Crescent City Harbor

No spawn deposition surveys have been conducted in this area. However, limited monitoring of spawn timing and spatial extent began in 2015-16.

6.1.2.3 Hydro-acoustic Surveys for Estimating SSB in San Francisco Bay

Between 1982-83 and 2001-02, the Department conducted hydro-acoustic surveys in San Francisco Bay to explore an alternative method for estimating SSB (Watters and Oda, 1997). These surveys primarily occurred in the deeper waters of the bay over Herring schools prior to spawning. Surveys occurred up to four days a week during the spawning season on slack tides (typically high slack) to reduce error due to tide-related school movement. Schools were initially found and qualitatively surveyed with a fish finder. Herring-like marks were confirmed by sampling the school with a midwater trawl. Once the school was verified as Herring, quantitative hydro-acoustic surveys were conducted with a Raytheon model DE-719B paper recording fathometer. Biomass was estimated for each school from paper traces using the 'visual integration' method (Reilly and Moore, 1983).

Beginning in 1989-90 season, the protocol for estimating SSB (calculation from spawn deposition surveys) was revised to incorporate the hydro-acoustic surveys. For each Herring school observed during the season, the estimates of biomass from each of the two survey methods were compared. If one survey was missing, the other was used. If the two estimates were similar they were averaged. If Department staff had more confidence in one survey than the other, that survey result was used, and if there was equal confidence in both surveys, the higher estimate was usually chosen (Spratt and others, 1992). The chosen estimates for each school were then summed to determine a final biomass estimate for the season (Figure 6-1).

Beginning in the late 1990s the hydro-acoustic and spawn deposition survey estimates began to diverge, with the spawn deposition surveys showing declines in stock size. During the 2002-03 season the SSB could not be estimated due to a substantial divergence between the spawn deposition and hydro-acoustic surveys (Figure 6-1). As a result, the Department initiated a review of the survey methods used (Appendix I). This study examined how well the spawning biomass estimates from each method correlated with the following year's spawn deposition estimate. The review found that while the spawning deposition surveys could explain 50% of the variation seen from year to year, the hydro-acoustic surveys could only explain 4%. Based on the results of this study the Department discontinued the hydro-acoustic surveys and continued only using the spawning deposition surveys to estimate biomass and set quotas.

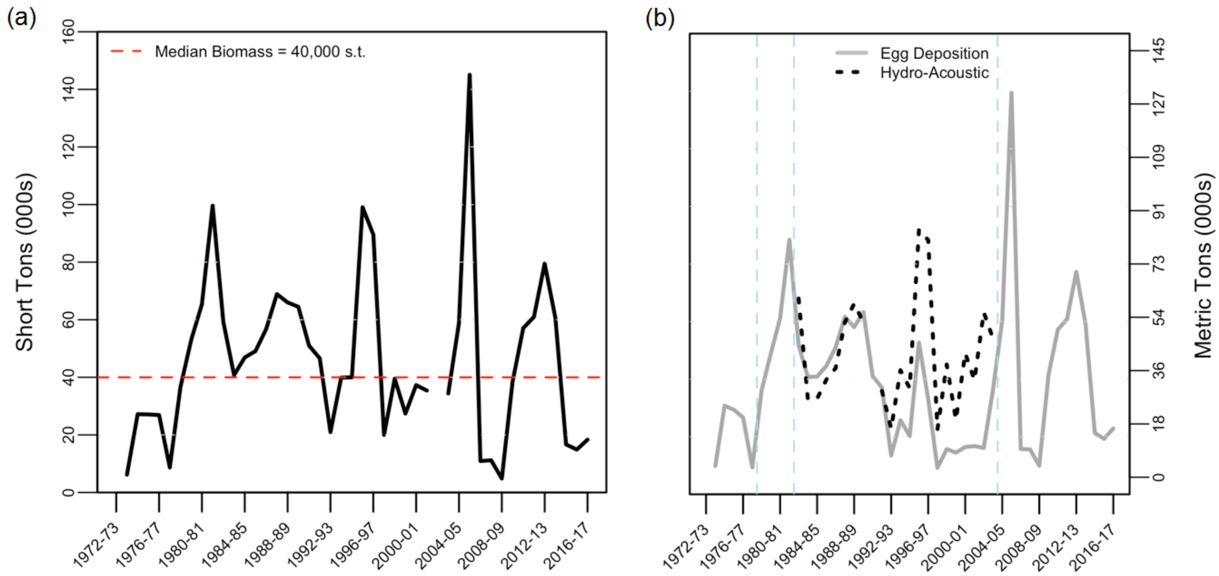

Figure 6-1. Department estimated yearly SSB of San Francisco Bay Herring between 1972-73 to 2016-17 in short and metric tons. The left panel (a) shows the reported biomass (with a median biomass of 40 Kt/36 Kmt), and the right panel (b) shows the individual biomass estimates from the spawn deposition and hydro-acoustic surveys. Dates corresponding to changes in the survey methodology are indicated by light blue vertical lines.

6.1.2.4 San Francisco Bay Study Midwater Trawl Young of the Year Survey

Data on the number of age zero, one, and two or older Herring throughout the year in San Francisco Bay are available as part of the Department's Bay Study Program (Baxter and others, 1999). This program began in 1980 with the goal of determining the trends in environmental variables and the distribution and abundance of living resources in San Francisco Bay. A Department research vessel operates a midwater trawl and an otter trawl monthly, year-round at each of 52 open-water sampling locations. These locations range from southern San Francisco Bay through San Pablo and Suisun Bays and into the Delta (Figure 6-2).

Juvenile Herring are caught in the midwater trawl, and this survey produces monthly CPUE (number caught/tow volume*10,000) of age zero, one and two or older fishes. Age zero fish are most prevalent in the trawl catch during the months of April to July, and less prevalent from August onward, when they are likely to have started moving out of the bay to ocean waters. The CPUE of YOY Herring was found to be significantly correlated to the observed SSB three years later (Roel and others, 2016; Sydeman and others, 2018) and data from this survey provide one of the key indicators used to predict SSB (Section 7.6.2). As a result, these data serve as a core component to the management strategy for Herring proposed in this FMP.

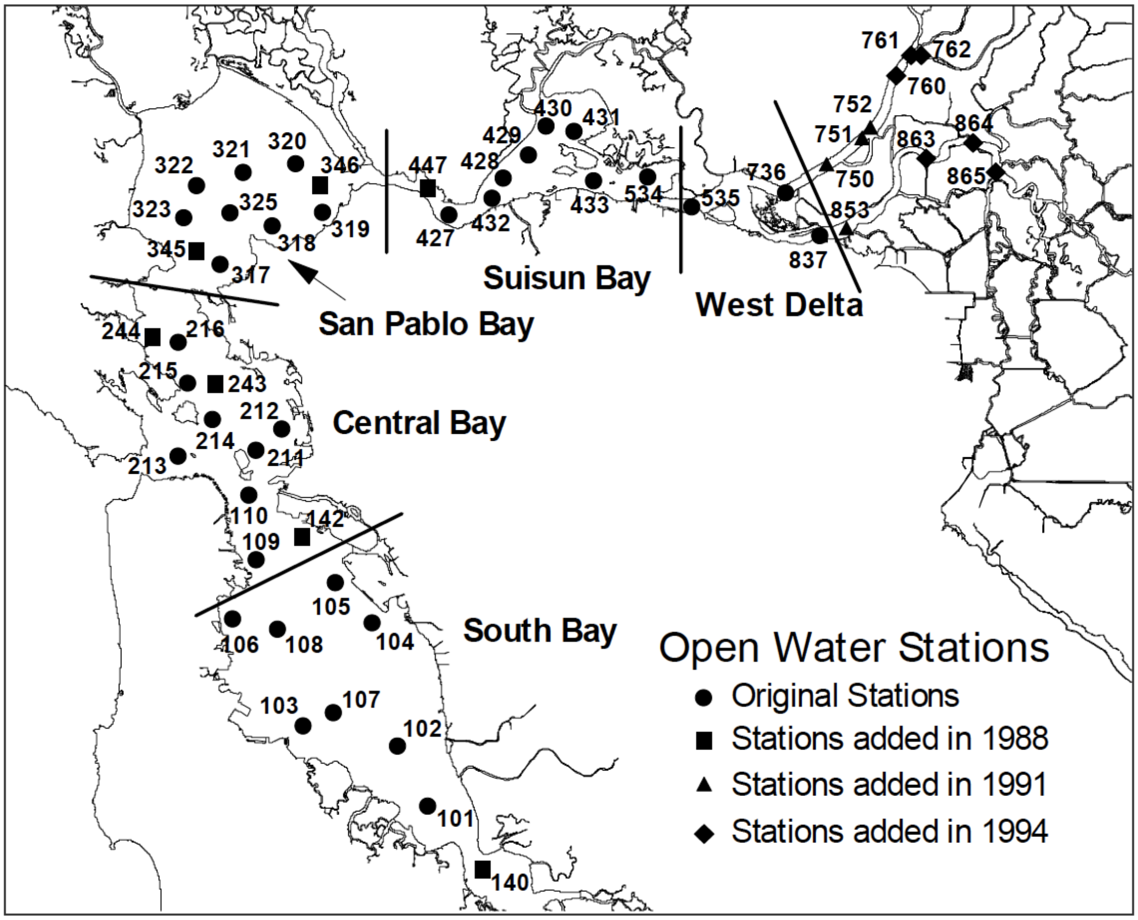

Figure 6-2. Station map for San Francisco Bay Department midwater trawls, from which YOY Herring abundance data are obtained.

6.1.2.5 Herring Research Midwater Trawl Survey in San Francisco Bay

The Department has used a midwater trawl to sample the population in San Francisco Bay since the 1982-83 season. Surveys usually begin in late-November or early December, when Herring schools start moving into the bay in spawning waves, and usually end in March. Trawl samples are taken roughly once a week throughout this time period using the Department's research vessel, with the goal of sampling every spawning wave that enters the bay prior to a spawn occurring. This sampling resolution provides information on the spatial and temporal variability of spawning waves during each season. Department staff transit the bay using a fathometer to detect Herring schools, and opportunistically sample each school using the midwater trawl. A typical population sample obtained via this method comprises anywhere from a minimum of 30 to a maximum of 200 individual Herring.

6.1.2.6 Multi-panel Gill net Survey in San Francisco and Tomales Bays

A midwater trawl is the primary method for obtaining population samples from spawning waves in San Francisco Bay. However, multi-panel gill nets are also used as a supplemental technique when the midwater trawl vessel is unavailable or in areas that are too shallow for the midwater trawl gear to operate. The research gill nets are constructed of varying mesh sizes, including 1.5, 1.75, 2.0, 2.25, and 2.5-in (38, 44, 50, 57, and 64 mm) to sample the entire range of Herring sizes present in the population. The research net is able to capture younger age classes than the commercial fishery due to the minimum commercial mesh regulation of 2.0-in (50 mm). The Department also employed research gill nets in Tomales Bay prior to ending the surveys in 2006-07.

6.1.2.7 Population Data Collection

Population samples obtained via the midwater trawl and multi-panel gill net surveys compose the research catch for a given season. The research catch is the Department's source of demographic data for that season's SSB. Length and gonad maturity data are recorded for all sampled fish. Immature and spent fish are discarded, and mature fish are weighed and otoliths are removed. Note that Herring typically do not spawn until age two or three so there are few age one fish in the research catch-at-age data.

Surface reading of otoliths are completed at the end of the season by Department staff. The resulting age data are used to calculate raw numbers at age and weight at age for each spawning wave. The raw numbers-at-age are then weighted by the estimated size of the spawning wave and then summed over all waves to estimate the total numbers-at-age in the spawning stock. This wave-by-wave analysis is necessary because each spawning wave may have different sex ratios or age compositions. Weighted numbers-at-age data are available from 1982-83 on with the exception of the 1990-91 and 2002-03 seasons. During these seasons, the spawning stock numbers-at-age data were not available due to incomplete datasets. From the 1982-83 season to 2003-04 a subsample of Herring from the fishery-independent samples was aged and a key was constructed annually based on those ages, which was applied to the entire catch to characterize the age composition of the SSB (Reilly and Moore, 1983). However, in 2003 an independent review committee recommended direct aging (MacCall and others, 2003). Since that time the Department has aged a sub-set of each spawning wave to assign age composition.

6.1.2.8 Collaborative Research

The SFBHRA was formed in 2009 with funds made available from the responsible party following the Cosco Busan oil spill (November 2007). The SFBHRA is a non-profit fishing industry group dedicated to working with the Department to assist in monitoring the San Francisco Bay Herring stock. A collaborative monitoring protocol was developed to assist Department staff in tracking Herring schools and locations of Herring spawning activity. Spawn surveys are conducted at regular intervals through close coordination with Department staff. SFBHRA members follow a streamlined spawn deposition sampling protocol and collect adult Herring using the same multi-panel research gill net described above. Samples are provided to Department staff for processing and inclusion into existing datasets.

In Humboldt Bay, another collaborative research program has been active since the 2014-15 season. This collaboration was also developed and supported by local fisherman to assist Department staff in updating information related to stock status in Humboldt Bay for Herring. Beginning in late 2014, this effort has helped to monitor the approximate size, number, and location of spawn events, as well as to conduct biological sampling. This collaboration has helped to improve the Department's understanding of the Herring resource in Humboldt Bay, which has historically only had intermittent research and monitoring.

6.1.2.9 California Recreational Fisheries Survey

As part of the California Recreational Fisheries Survey (CRFS), Department personnel intercept recreational anglers at boat ramps, on commercial passenger fishing vessels, at man-made structures, and along beaches and banks in order to collect catch and effort data[4]. Because Herring aggregate during spawning events, recreational catch can be very high for a short period of time, and thus CPUE may not be indicative of abundance. Catch data from CRFS monitoring is useful to begin to understand the extent of recreational take and gear types used in the fishery. Unfortunately, due to the unpredictable nature of spawning activity and the low likelihood of encountering recreational anglers targeting Herring, only a few interceptions have been made.

6.2 EFI Needs and Future Management Options

Additional EFI data are necessary for effectively monitoring the Herring resource. Table 6-2 identifies EFI gaps for California Herring. The abundance of the spawning stock in terms of biomass is the primary type of EFI required for sustainable management of the Herring fishery in California, but this information is currently missing for the management areas outside of San Francisco Bay. Spawn deposition survey methodologies that have been applied in the past obtain the best estimates of absolute SSB on an annual basis. However, these surveys are resource intensive and may not be appropriate for relatively small-scale fisheries with a limited number of participants. The MLMA 2018 Master Plan for Fisheries directs managers to scale monitoring and management activities relative to the value of the fishery and the risk to the stock (Californa

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[4] The CRFS Sampler Manual (available at https://nrm.dfg.ca.gov/FileHandler.ashx?DocumentID=62348&inline) describes the history of the survey, general information, methods, and the roles and responsibilities of supervisors, leads, and samplers.

Department of Fish and Wildlife, 2018). However, Herring stock abundance can vary widely from year to year and applying the existing spawn deposition surveys less frequently may increase risks to the stock and the sustainability of the fishery. Instead, the consistent application of a less intensive survey method that results in a proxy for spawning stock abundance is more appropriate for monitoring smaller Herring fisheries. This section describes a potential research protocol to fill this gap. It also highlights other monitoring opportunities for Herring.

Table 6-2. EFI gaps for Herring and their priority for management.

EFI Type	Priority for Management	How EFI would support future management
Fishery Independent		
Index of abundance in unfished management areas	Medium	Implementing Rapid Spawn Assessment Method would inform quota setting should fishing resume in these areas.
YOY abundance	Medium	Ensuring completion of annual surveys allows for use of predictive statistical model, which relies on indices of abundance of YOY, for SSB estimation.
Fecundity	Medium	Frequent fecundity estimates increase accuracy of spawning biomass estimates derived from egg deposition surveys.
Maturity at age	Low	Up-to-date maturity-at-age estimates could inform future attempts at stock assessment.
Population structure	Medium	State-wide population structure, including timing and geography of spawn events and genetic structure, may help inform whether spatial or temporal considerations in management are necessary
Fishery Dependent		
In-season commercial catch outside San Francisco Bay	High	Inform managers on level of take achieved and when to close if fishing resumes in management areas outside SF Bay.
Age distribution of any catch outside San Francisco Bay	Medium	Age distribution of catch can provide managers with secondary indicator of stock status.
Size distribution of any catch outside San Francisco Bay	Medium	Size distribution of catch can provide managers with a secondary indicator of stock status.
Recreational catch estimates	Low	Provide managers with tools to better regulate recreational fishing in all management areas.

6.2.1 Index of Abundance in Unfished Management Areas

A current gap in EFI is the lack of active monitoring programs for assessing Herring spawning populations in management areas where commercial fishing activity does not occur, and the Department isn't investing staff resources in producing full SSB estimates (see Sections 7.2 through 7.6 and 8.1). Spawn surveys in Tomales and Humboldt Bays were discontinued after 2006-07 due to staffing and resource constraints. Due to low Herring roe prices and lack of processing facilities, no commercial fishing has occurred in these areas since 2006-07 and 2004-05 respectively. Despite the lack of commercial fishing pressure, Herring are known to be very sensitive to fluctuations in environmental conditions, and the status of these stocks is unknown. Should fishing resume, it will be necessary to resume some level of monitoring to understand the impacts of fishing on the stock, and to avoid over-fishing during natural declines in productivity.

6.2.1.1 Rapid Spawn Assessment Method

To explore future management options, Department staff have been piloting a new sampling protocol in Humboldt Bay with the following objectives: 1) identify the number and timing of spawns, 2) identify the locations and extents of spawns, and 3) qualitatively assess spawn density if possible, depending on staff and collaborative resources. Information on numbers of spawns and spawning extents, along with locations and timing of those spawns, can be compared with historical information to inform fishery management decisions (Appendix P). This Rapid Spawn Assessment Method provides Department staff with a less intensive strategy to monitor the relative condition of stock status in management areas that are either unfished or fished at a low intensity.

6.2.1.2 Building Collaboration

Collaboration with key partners is a potentially useful tool to provide information in areas where the Department lacks the resources to monitor Herring populations. The Department has collaborated in the past and will continue to work with outside entities such as academic organizations, NGOs, citizen scientists, and both commercial and recreational fishery participants to help fill information gaps related to the management of state fisheries. The Department will also reach out to outside persons and agencies when appropriate while conducting or seeking new fisheries research required for the management of Herring. Several of the information gaps identified above (Table 6-2) are potential areas for collaboration. While the Rapid Spawn Assessment Method is primarily designed to be carried out by Department staff, its efficacy will be greatly aided by collaboration with fishermen and other interested parties. For example, Department staff can request that active fishermen voluntarily notify staff when they observe Herring spawning activity (time and location of spawn). This increased observational data will increase detection of spawns and allow the Department to better assess these events. As these partnerships are developed, fishermen may assist the Department by collecting samples to document spawn intensity through a collaborative research program. The program design could follow the successful collaboration between the SFBHRA and the Department.

6.2.2 Fishery-Dependent Monitoring

6.2.2.2 In-Season Catch Outside of San Francisco Bay

Should commercial fishing resume in areas outside of San Francisco Bay, fishery-dependent monitoring could help Department staff monitor the status of the stock. In-season catch levels will be monitored so that the fishery can be tracked and closed when it reaches its quota. Close communication between the Department and fishing industry will be critical to ensure catch targets are not exceeded. In areas where limited or no monitoring occurs, the licensed Herring buyers will notify the Department prior to landing Herring. Communication between Department staff and fishery participants will help track real-time fishing effort, and monitoring offloads will ensure quotas are closely adhered to in these areas. Department staff will be able to sample commercial catch and collect length and weight data. This information will help fishery managers monitor the catch for changes in size distribution, which may signal a need for management action.

6.2.2.3 Periodic Collection of Age Distribution Data Outside of San Francisco Bay

When resources are available, otoliths should be removed from commercial catch samples and aged to produce catch-at-age data and weight-at-age data. These can then be used to develop length-at-age and length-weight relationships for stocks in these periodically sampled areas. Surface reading of otoliths to determine fish ages is resource intensive but collecting and aging every few years will provide a check on stock condition and age distribution. For example, if fishery managers detect a loss of older age classes it may signal a need for management action depending on fishing activity levels in a given area.

6.2.2.4 Size Distribution Data in Areas Outside of San Francisco Bay

Size distribution in the commercial catch can be sampled opportunistically when fishing occurs in the northern management areas. Ideally, size distribution data could be collected annually and be used as a secondary indicator of stock status. Size-at-age is known to fluctuate in Herring due to environmental conditions, but it is possible to classify fish into size classes that provide an indicator of their approximate age (Cope and Punt, 2009). Monitoring the relative proportions of commercial catch in each category can provide fishery managers with important data on stock condition and changes in catch composition over time may suggest a need for additional research or a more precautionary management approach.

6.2.2.5 Accurate Recreational Catch Estimates

Currently, recreational removals are assumed to be a small proportion of the total catch each year. However, anecdotal reports from commercial and recreational fishermen as well as Department staff suggest that the catch from the recreational sector has been steadily increasing in recent years. There is also concern that large volumes of recreationally caught Herring may end up being sold as bait or for food, which is illegal under FGC §7121 (Unlawful sale or commercialization). Based on Department observations and CRFS catch estimates, annual take could range from 50 to 100 tons (45 to 91 metric tons). Given the nature of recreational fishing it would be difficult to obtain accurate catch estimates unless licensing or reporting requirements were changed.

Recreational anglers tend to target Herring spawning aggregations that are accessible from piers or the shoreline, and can spur intense fishing effort, with anglers participating in close proximity to one another. Currently, there is very little information on the number of recreational anglers because there are no licensing requirements or bag limits for the recreational take of Herring from public piers. While effort is not a useful indicator of Herring abundance, data on number of recreational participants in each bay could be used as a proxy for total recreational removals per season by assuming a constant catch amount per participant. The implementation of a daily bag limit (Section 7.8.7) provides a baseline assumption of daily catch and provides managers a simple tool to better regulate catch. An opportunistic sampling protocol, in which Department staff observe recreational fishery participants during a spawning event and estimated CPUE, could result in improved catch estimates, which would inform fishery managers and better address any future sustainability concerns.

Chapter 7. Management Strategy for California Herring

This chapter describes the Department's comprehensive and cohesive management strategy for Herring fishery, including: 1) monitor Herring populations in the four management areas (San Francisco Bay, Tomales Bay, Humboldt Bay, and Crescent City Harbor), 2) analyze data collected via the monitoring protocol to estimate SSB, 3) develop quotas based on current SSB using a HCR, 4) track indicators to monitor ecosystem conditions, and 5) establish additional management measures to regulate fishing. This management strategy is based on an adaptive management framework that seeks to improve management through monitoring and evaluation, in order to better understand the interaction of different elements within marine systems[5].

The primary mechanism for ensuring stock sustainability in California's Herring management areas is to set precautionary limits on catch (quotas) using a harvest rate cap and a cutoff below which no harvest is allowed. For San Francisco Bay, quotas are set with the goal of achieving harvest rates that do not exceed 10% of the SSB, which is more precautionary than what is used in the management of other Herring fisheries such as in Alaska and British Columbia. However, given the changes in Herring stocks observed over the 45-year history of the sac-roe fishery, such precaution is warranted. Low harvest rates provide a buffer against scientific uncertainty, particularly during periods of high interannual variability in SSB, when the SSB is lower than predicted, or when poor environmental conditions may negatively affect stock size. Similarly, cutoffs prevent continued depletion and allow for rebuilding during low productivity periods. Low harvest rates also potentially allow more Herring to spawn successfully, protecting the spawning potential of the stock. Herring are an important forage species in the CCE and low harvest rates, as well as fishing closures when stock sizes are reduced below the cutoff, help increase the likelihood that the needs of these predators are met. The 10% target harvest rate cap and cutoff were agreed upon by a group of representatives from the commercial fishing industry and conservation NGOs during the development of this FMP. This continues the precautionary management approach the Department has employed since 2004 (Section 5.2.1.1).

Additional management measures are in place in San Francisco Bay to help ensure that commercial harvest targets primarily age four and older fish, that spawning aggregations receive temporal and spatial refuges from fishing, and to minimize interactions between fishermen and the other users of the bay. Lower harvest rates also help to protect the age structure of the stock, which

[5] (California Fish and Game Code §90.1) "Adaptive management," in regard to a marine fishery, means a scientific policy that seeks to improve management of biological resources, particularly in areas of scientific uncertainty, by viewing program actions as tools for learning. Actions shall be designed so that even if they fail, they will provide useful information for future actions. Monitoring and evaluation shall be emphasized so that the interaction of different elements within the system can be better understood.

may in turn allow the stock to be more resilient to non-fishing impacts such as changes in environmental conditions or degradation of habitat. Recent analyses have shown that warm water events may result in lower survival of YOY Herring, and thus a smaller year class recruiting to the stock three years later (Appendix E). Maintaining a stock with a greater proportion of older fish may help to buffer the stock against those years when juvenile survival is poor. The age structure of the stock may also influence the timing and location of spawn events. Maintaining a diverse age structure may help ensure that spawning occurs throughout the historical spawning period and throughout the available spawning areas (Berkeley and others, 2004; Watters and others, 2004). The northern management areas also have precautionary quota recommendations based on a combination of historical SSB estimates and commercial catch data. Additionally, temporal and spatial closures as well as gear restrictions augment the precautionary approach in those areas.

7.1 Management Objectives

Fisheries are complex socio-ecological systems, and managers must ensure, to the extent possible, that target stocks can sustain themselves, while balancing the needs of the fishermen with the ecological role of the fished species. The management objectives for California's Herring stocks were developed in recognition of these various, and at times competing, needs, and are described below.

7.1.1 Promote a healthy long-term average biomass

This objective recognizes the fact that Herring populations are most able to reproduce successfully, support a productive fishery, and provide forage to predators when they are at healthy levels. If the stock is not in a healthy state the Department is required to rebuild to achieve a healthy long term biomass.

7.1.2 Minimize the number of years stocks are in a depressed state

This objective recognizes that due to the population dynamics of Herring, natural fluctuations can result in low stock size even in the absence of fishing. However, with a responsive management system in place it is possible to detect these declines and reduce fishing pressure to avoid high harvest rates that may result in overfishing when stocks are low.

7.1.3 Maintain a healthy age structure

This objective recognizes that the stock is most sustainable when it comprises Herring from a variety of year classes, including recruits (age two and three), the age four and five fish that make up the majority of the commercial catch, and older fish (ages 6+).

7.1.4 Maintain an economically viable fishery

This objective recognizes that California's natural resources should be managed in order to maximize their long-term benefit to the State and its residents. This objective is multi-faceted and includes maximizing yield while maintaining stable quotas from year to year, minimizing the number of years with a zero quota to maintain access to markets, and matching the capacity of the fleet to the amount of take that the resource can sustain.

7.1.5 Help Ensure Herring remain an important component of the ecosystem

This objective recognizes that Herring are an important forage fish in the CCE, adheres to the Commission's forage species policy, and helps the Department in meeting the goals of the MLMA, principally, managing for non-consumptive values and helping to maintain intact ecosystems.

7.2 Tiered Management Approach

To ensure that target harvest rates are achieved despite the dynamic nature of Herring stocks, the Department estimates the size of the spawning stock and describes its age structure and condition annually in San Francisco Bay through spawn deposition and midwater trawl surveys. This fishing area has historically had the largest population and largest fishery, and at the time of FMP development, is the only management area with an active commercial fishery. Implementing these intensive surveys in all four management areas is not feasible due to resource and staffing constraints. When no commercial fishing effort occurs in a management area, there is no risk to those stocks from commercial fishing. However, should commercial fishing resume in a management area, it may be necessary to implement monitoring protocols that are sensitive enough to detect years when SSB is low and fishing could harm the stock. Therefore, a tiered management approach will help prioritize monitoring efforts and apply appropriate levels of management to fit the fishery activity level.

This section describes a tiered approach that scales management effort to the level of fishing effort and amount of information available for each management area. In this approach, areas with less fishing effort require less monitoring effort, and areas that have less information available have precautionary quota setting procedures with low maximum harvest rates available to them (Figure 7-1). This allows management to direct its resources proportionally, depending on the amount of fishing effort in that area in terms of catch or participation. This approach is also consistent with the Commission's forage species policy.

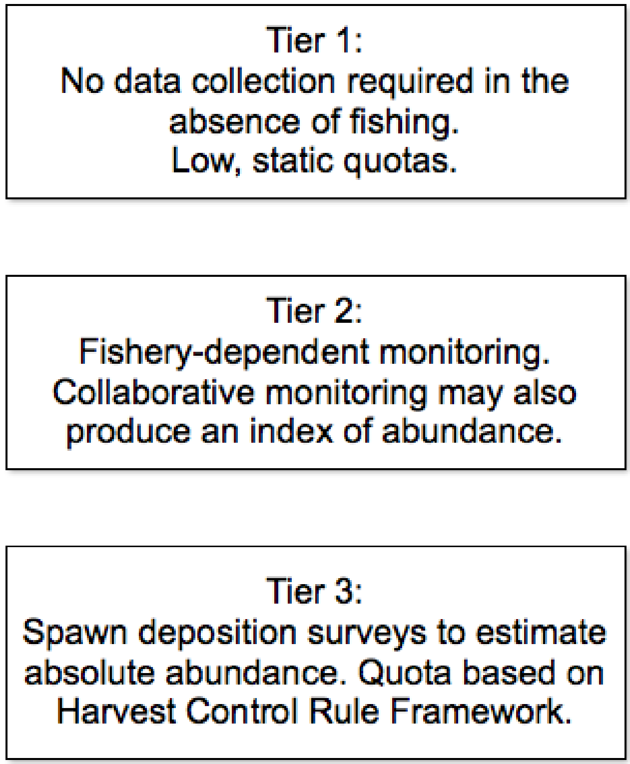

Figure 7-1. Schematic of tiered approach to Herring management, in which each management area falls into one of three tiers based on the level of fishing occurring. The level of monitoring effort is dictated by the size of the fishery, and the quota setting approach is determined by the information available.

7.3 Defining Management Tiers

In order to implement a tiered approach to management, it is necessary to define the management tiers and describe how management areas transition between tiers. This section describes the conditions that would necessitate assignment of a management area to a new tier level.

Tier 1 management areas are those areas where low, precautionary quotas are available, but no fishing has occurred in the prior season. These quotas are based on historical catch and/or SSB data for these areas. At the time of FMP development, Tomales Bay, Humboldt Bay, and Crescent City Harbor are Tier 1 management areas. No commercial fishing has taken place in these areas since 2005-06 or earlier.

If any Herring permits are fished in a Tier 1 management area, that area will be managed as a Tier 2 management area during the subsequent season (Section 7.5). The same quota is retained when an area transitions from Tier 1 to Tier 2. The differences between Tier 1 and 2 management are the collection of fishery-dependent data and the potential for collection of additional fishery-independent data via the Rapid Spawn Assessment Method (Section 6.2.1.1, Appendix P) or spawn-deposition survey (Section 6.1.2.1), and that Tier 2 may have a quota increase if additional fishery-independent monitoring is conducted (Section 7.5.2) and the Department deems that stock conditions warrant the increase (Section 7.5.3).

A Tier 2 management area becomes a Tier 3 management area when the Department determines that the size of the fishery in that management area, in terms of potential catch or the number of participants, warrants more intensive monitoring, including annual estimation of SSB and use of an HCR. This may occur due to increases in the ex-vessel price of Herring, resulting in increased utilization of existing permits and/or requests for new permits. Tier 3 management areas require a more comprehensive management protocol to promote sustainable harvest, as well as additional Department staff and resources. At the time of FMP development, San Francisco Bay is the only Tier 3 management area. However, should market or stock conditions change, it is possible that other management areas could become Tier 3 management areas. It is important to note that many aspects of the Tier 3 management area HCR framework described in this chapter were developed using data from San Francisco Bay, which lies within the central California region of the CCE. A change to a higher tier level in the other three management areas may also require a HCR that is specifically parameterized for those individual stocks and environmental conditions.

A Tier 3 management area may also be assigned to a lower tier should effort decrease substantially or should commercial fishery activity cease altogether. During these periods of reduced fishing effort, low landings, or permit attrition, the Department may determine that, given the many competing priorities of staff, the fishery no longer warrants an intensive management system.

7.4 Tier 1 Management Areas

Fishery monitoring is designed to measure the impact of fishing on a stock, and to alert managers when fishing is likely to negatively impact the sustainability of the stock so that appropriate management actions can be taken to reduce those impacts. In management areas where no fishing has occurred in recent years, there is no monitoring required and no data are produced. As a result, no assessment methodology or quota adjustment is required. Such areas are considered Tier 1 management areas.

In Tier 1 management areas, the quota will remain set at a precautionary level that provides opportunity for fishing should economic or market conditions change. The Tier 1 quota for San Francisco Bay is 750 tons (680 metric tons), which is approximately 1.5% of the average historical SSB. Because recent SSB data were unavailable in the northern management areas during the drafting of this FMP, the Tier 1 quotas are set at levels that consider historical stock size, average historical catch, and the overall management framework. In Tomales Bay, where extensive historical biomass data are available, the quota for Tier 1 management is set at 133 tons (121 metric tons), which is approximately 3% of the average historical SSB estimate of 4,446 tons (4,033 metric tons). The Tier 1 quota for Humboldt Bay is set at 11 tons (10 metric tons), which is 3% of historical SSB estimate of 351 tons (318 metric tons). However, no SSB estimates were made for Crescent City Harbor prior to the drafting of this FMP. Consequently, developing Tier 1 quota ranges for this stock is more difficult. The Tier 1 quota for Crescent City Harbor is set at 12 tons (11 metric tons), which is 50% of the average historic landings and a 60% decrease from the quota prior to the adoption of this FMP. These are precautionary quotas that include buffers for the impacts that ecological changes may have had on the productivity of these stocks since they were last fished. The rationale for retaining these precautionary quotas in the absence of active fishing is to provide access to the resources should market conditions in these areas change. This also aligns with a goal outlined in the MLMA regarding fishing communities, which recognizes the long-term interest of fishing dependent communities, and aims to maintain fishing opportunities wherever possible.

7.5 Tier 2 Management Areas

The Tier 2 management strategy is designed to scale the amount of monitoring required by the Department to the level of fishing effort that occurs in an area, which will help determine the level of risk to the Herring stock associated with fishing. When a management area is assigned to Tier 2, the quota level from Tier 1 remains in effect, and the catch must be monitored via fishery-dependent monitoring protocols (Section 7.5.1). If spawn deposition surveys are conducted to produce an estimate of SSB (Section 7.5.2) and the Department deems that stock conditions warrant it, the quota may be adjusted for the following season (Section 7.5.3).

7.5.1 Fishery-Dependent Monitoring in Tier 2 Management Areas

In Tier 2 management areas, the Department monitors commercial catch. This includes monitoring landings to ensure that the fishery is closed when the quota has been reached, as well as collecting data to understand the size distribution of the catch when staff resources are available. The Department will also determine age class structure of the commercial catch through appropriate sampling when staff and resources allow, with a goal of sampling every five years. At the time of FMP development, management areas outside of San Francisco Bay (the three northern management areas) have not been subjected to commercial fishing since 2005-06 or earlier. During this time, stocks have likely returned to unfished age distributions. For this reason, sampling the age distribution before or concurrent with the resumption of fishing activities would provide a benchmark with which to assess the impacts of fishing on the age structure of the stock in the future.

Generally, age keys are not recommended for fish stocks that have high variation in growth between years and cohorts because of overlap in size distributions between age classes. However, the Department may use a length-frequency key to monitor for major changes in the size distribution of the stock, which, if detected, may signal the need for additional data collection and/or increased precaution in management. As an example, a high proportion of small fish in the commercial catch might suggest that the fishing gear is selecting too many young fish, before they have had an opportunity to spawn. The goal of the current tiered management approach is to target older age classes, age four and five. Conversely, a decline in the number of age six and older fish in the catch over time might suggest that mortality rates (due to fishing or natural mortality) are increasing.

7.5.2 Fishery-Independent Monitoring of Tier 2 Management Areas

In Tier 2 management areas, the Department monitors spawning behavior of the Herring stock. This helps ensure that harvest is not taking place on an un-monitored stock, and alerts Department biologists to situations that may require implementation of a zero-ton quota. The full spawn deposition survey protocol used historically (Section 6.1.2.1) is resource and staff intensive, and conducting this survey in reduced-capacity management areas fishing the precautionary Tier 1 quota is not necessary. Accordingly, under Tier 2, the Department can employ a Rapid Spawn Assessment Method (Section 6.2.1.1, Appendix P). This methodology can be used to monitor the number of spawns, spatial extent of spawns, and relative egg density per spawn in a given season. Together, these indicators provide a basis for detecting changes that may signal the need for additional data collection or management actions. The Rapid Spawn Assessment Method could be built into a collaborative research program to assist the Department in ensuring that all spawning events are sampled each season. For example, agency staff, fishermen, citizen scientists, or organizations could report the location of spawning events to Department staff. Assistance may also include collecting the spawn samples and recording the spatial extent of spawning (Section 6.2.1.2). Permit holders could also be incentivized to assist with monitoring to increase the likelihood of potential increased quota adjustments.

Should Herring permit holders request, through a DHAC meeting, a quota increase from the precautionary quota carried over from Tier 1, Department biologists may implement a full spawn deposition survey during a single season in order to produce an estimate of SSB for that season. That SSB estimate would be used to inform any potential quota increase (Section 7.5.3)

7.5.3 Adjusting Quotas in Tier 2 Management Areas

A Tier 2 management area allows the commercial fleet to fish a precautionary quota set at 1.5 to 3% of the average historical SSB, or 50% of historical catches for that area. If spawn deposition surveys are conducted to produce an estimate of SSB, the Department's Director may increase the quota for a given management area up to either 4% of the average historical SSB for Tomales and Humboldt Bay management areas, or up to 60% of the historical average catch for Crescent City Harbor. For San Francisco Bay, the Tier 2 adjustment will be based on the HCR. When selecting a quota for each management area, the Department will consider any available recent and historical data on spawning stock abundance, fishery-dependent information on the size/age structure, and the catch history. Conversely, under a Tier 2 monitoring protocol, the quota shall be reduced to zero in years where either the employed Rapid Spawn Assessment indicates very poor spawning behavior, or spawn deposition survey-derived SSB estimates indicate an SSB too small to support fishing.

7.6 Tier 3 Management Areas

If recommendations through a DHAC meeting for quota increases are requested beyond those allowed under Tier 2, and the Department determines it appropriate, permit areas may be managed under a Tier 3 monitoring protocol. A Tier 3 management area utilizes a HCR, informed by both fishery-dependent and fishery-independent monitoring protocols that are implemented annually (Sections 6.1.1 and 6.1.2), to set quotas. The primary indicator of stock status is produced by spawn deposition surveys, from which the total SSB for a season is calculated. Additional monitoring includes sampling the commercial catch to determine age, weight, and length composition, as well as conducting research trawls to determine the age, weight, length, and sex composition of each observed spawning wave. At the time of FMP development, San Francisco Bay is the only area that is considered a Tier 3 management area. In addition, the San Francisco Bay management area uses an annual index of YOY abundance produced with Department's Bay Study Program's midwater trawl survey data.

Setting quotas in Tier 3 management areas requires accurate estimation of the total SSB order to set a quota that will achieve the desired harvest rate. Historically, in San Francisco Bay, the Department has used the observed SSB and/or hydro-acoustic surveys from the previous season to set the quota for the upcoming season. In-season estimates are not available due to the long spawning duration, typically November-March. Given the wide variation in spawn timing and individual spawning wave size, in-season estimates to inform a commercial quota are not practical. This section describes the current empirical method, as well as a new method that uses a predictive model to estimate the next year's SSB for the San Francisco Bay management area.

7.6.1 Empirical Surveys to Estimate SSB

In San Francisco Bay, quotas for next season have been set based on a percentage of the most recent season's SSB. This is the intended harvest percentage, or target harvest rate, for the upcoming season. The intent is to achieve an actual exploitation rate of a given year's SSB that closely approximates the intended harvest percentage. An exploitation rate that closely matches the intended harvest percentage is more achievable when the biomass in the coming season is similar to the biomass observed last season. When this method was first developed in San Francisco Bay, Herring stock sizes were more stable from year to year. However, since the early 1990s the Herring SSB has exhibited higher inter-annual variability. Differences in the SSB from year to year can lead to higher than intended exploitation rates when stock sizes decline sharply between years. Despite the increase in variability of estimated stock size from year to year, determining SSB from observed spawn deposition has been used successfully since the beginning of the fishery, and as the primary quota-setting tool since the early 2000s, when hydro-acoustic surveys were discontinued, as described in Section 6.1.2.3. The spawn deposition method is considered the primary estimation method for quota setting in San Francisco Bay.

7.6.2 Multi-Indicator Predictive Model to Estimate SSB

Prior to FMP development, ecological indicators had been assessed each season and presented as part of annual season summaries to the DHAC and the public in support of Department management recommendations for the upcoming season, as well as to provide context for the SSB estimate. These had not been used, however, to quantitatively predict the SSB to set fishery quotas. As part of the FMP development process, information on correlations between biological indicators of Herring stock health and environmental indicators were used to develop a predictive model to estimate the coming year's SSB (Sydeman and others, 2018) (Section 3.4.1, Appendix E). This model includes three indicators:

1) SSB_{yr-1} – the observed spawn deposition from the previous season
2) YOY_{yr-3} – the CPUE of YOY Herring from April to October three years prior to the upcoming season
3) $SST_{Jul-Sep}$ – The average SST between July and September prior to the upcoming season

Relative to a simple regression that uses SSB_{yr-1} to predict the upcoming season's SSB, the above-described model explains more variability and reduces predictive error by a large margin (Sydeman and others, 2018) (Appendix E). Mechanistically this model supports what is known about Herring stocks. The majority of Herring in the San Francisco stock are thought to mature between ages two and three, and considered fully recruited to the spawning stock by age three. Including YOY_{yr-3}, in addition to SSB_{yr-1}, as an explanatory variable in the model improves the accuracy of the output estimate, because the spawning stock that comes into the bay to spawn is a function of both the survivors from the previous year and the recruiting year class. Additionally, it has long been hypothesized that, in some years, not all Herring come into the bay to spawn, possibly due to environmental cues. The summer and fall SSTs were found to be negatively correlated with the observed spawning biomass later that same winter, suggesting that warmer temperatures may indicate poor conditions for adult Herring, resulting in behavior that results in fewer spawners during the spawning season. The synthesis of different environmental and ecosystem data into a multivariate forecasting equation may promote proactive, rather than reactive, management, and foster an interdisciplinary approach to ecosystem-based fisheries management.

7.6.2.1 Steps to Estimate Biomass Using Predictive Model

This section describes the steps necessary to estimate SSB using the predictive model. All necessary data are available by the end of September each year, and prior to the beginning of the fishing season, which begins in December.

Step 1: Gather and process the necessary indicators

1. SSB_{yr-1} — the total spawn deposition from the previous November-March is summed and converted to metric kilotons.
2. YOY_{yr-3} — YOY abundance data are available from the Department's Bay Study Program, which collects abundance data on pelagic fish using midwater trawls throughout San Francisco Bay at monthly intervals for 52 stations (Section 6.1.2.4); this analysis is based on the original 35 stations that have been sampled since 1980, including those in the central San Francisco Bay region where Herring are common (Baxter and others, 1999). Data on the age zero, one, and two Herring observed in the trawls are routinely provided to Herring managers each year. To summarize YOY_{yr-3} abundance, calculate the mean catch CPUE for three years prior (for example, to make a prediction for the fishing season beginning in 2020, use YOY data from 2017). First select the appropriate stations using only Series = 1 (representing the original 35 stations), and calculate CPUE for each station using the following equation:

$$CPUE = \left(\frac{PACHER_{Age0}}{tow\ volume}\right) * 10{,}000 \qquad [1]$$

   where $PACHER_{Age0}$ represents the number of age zero Herring caught in each tow and is scaled by the tow volume data. Next sum the CPUE data for April-October (months 4-10). Finally, average the summed monthly data.
3. $SST_{Jul-Sep}$ — The SST for July through September is available from offshore buoy N26 at station 46026 provided by the National Data Buoy Center and NOAA[6]. For each month, average the temperature data available, then subtract the mean temperature from each month (based on years 1985-15: July = 13.16°C (55°F), August = 13.97°C (57°F), September = 14.24

[6] http://www.ndbc.noaa.gov/station_history.php?station=46026

°C (58°F)) to calculate the temperature anomaly for each month. Finally, average the anomaly across the three months (July-September).

Step 2: Apply the forecasting model

Insert the formatted indicators into the following equation to calculate the coming year's SSB:

$$SSB_{Next} = 0.2803 * SSB_{Yr-1} + 0.019026 * YOY_{Yr-3} - 7.2582 * SST_{Jul-Sep} + 4.092 \quad [2]$$

Step 3. Model Validation

Model validation should be conducted every year after the spawning season is complete to verify model prediction skill. To validate that the modeled SSB is still performing within the range of deviation described by the regression equation (69%), comparison of predicted and observed SSB (December-March) estimates is required. Calculate the percent deviation using the predicted SSB for the season that has just passed using the following equation:

$$Perc\ Dev = \frac{Observed\ SSB - Predicted\ SSB}{Observed\ SSB} * 100 \quad [3]$$

If the model prediction skill deviates from the mean value (>69%) in one year, no management response is required. If skill deviates by greater than 69% for two sequential years, this should be considered a warning. If it deviates for more than two sequential years, the model should be revaluated and checked for continuing veracity. The model prediction skill should also not stay consistently above or below the mean. In either of these cases, the spawn deposition surveys will be used to estimate biomass and set quotas. Regardless of annual model prediction skill, every five years the Department should test for continuing significance of predictor variables (i.e., the independent variables) in the forecasting model. If terms lose significance or model prediction skill decreases significantly, the Department should consider revision of the forecasting model to verify that the relationships between SSB, YOY abundance, and SST still exist.

7.6.3 Determining Which Method to Use in Estimating SSB in San Francisco Bay

The spawn deposition surveys have been and remain the default method for estimating the SSB in San Francisco Bay to set quotas. While the predictive model provides a promising avenue for incorporating additional indicators into Herring management, as well as for improving predictive accuracy, the model needs to be tested before it is used to set quotas. To do this, the model must have three consecutive years where a) all of the data required are available, and b) demonstrate that over those three years it has greater predictive skill than the spawn deposition survey alone. At that point the Department may decide to use the predictive model in yearly quota setting.

7.7 Harvest Control Rule Framework for San Francisco Bay

Quotas in Tier 3 management areas are set using a HCR to ensure that quotas are appropriate given the current SSB, that the biomass is above the cutoff, and that intended harvest percentages are no more than 10%. Additionally, the status of environmental and ecosystem indicators (Section 7.7.2) will be examined to monitor current ecosystem conditions, and the Department will include information on these indicators and their interpretation in periodic season reports. Each step is described in detail below.

7.7.1 Using the Harvest Control Rule to Determine the Quota

A HCR has been developed to set quotas based on an annual San Francisco Bay Herring SSB input, derived either from the above-described predictive model (Section 7.6.2) or the previous season's estimate from empirical surveys (Section 7.6.1, Figure 7-2). The HCR was developed in consultation with Department staff and stakeholders, and was tested using MSE to understand its performance under various uncertainty scenarios, including climate change scenarios. It was shown to be robust to the scenarios tested, which included a number of reduced productivity situations (Appendix M).

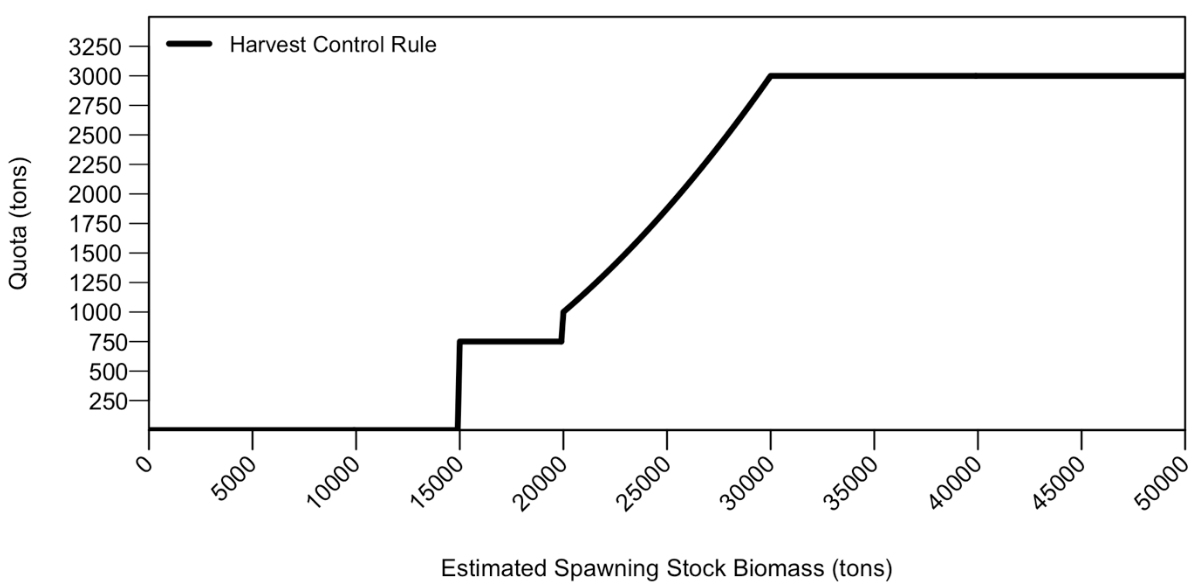

Figure 7-2. HCR describing the relationship between estimated SSB and quota for subsequent season of the San Francisco Bay Herring commercial fishery.

The quota for each season is calculated by inserting the estimated SSB into Equation 4 (also described in Table 7-1).

$$Quota = \begin{cases} 0 & if\ SSB < 15{,}000t \\ 750 & if\ 15000t\ \leq SSB < 20{,}000t \\ SSB * (SSB * 0.000005 - 0.05) & if\ 20{,}000t\ \leq SSB < 30{,}000t \\ 3{,}000 & if\ SSB \geq 30{,}0000t \end{cases} \quad [4]$$

Table 7-1. Prescribed quota (and associated harvest rate) in tons for each estimated SSB in San Francisco Bay.

Spawning Stock Biomass (t)	Harvest Percentages	Quota (t)	Description
<15,000	--	0	No harvest below 15,000t cutoff
15,000	5.00%	750	Low fixed quota to maintain limited fishing opportunity for the commercial fleet
16,000	4.69%	750	
17,000	4.41%	750	
18,000	4.17%	750	
19,000	3.95%	750	
20,000	5.00%	1,000	Harvest rate ramps up from 5% to 10% as stock size increases
21,000	5.50%	1,155	
22,000	6.00%	1,320	
23,000	6.50%	1,495	
24,000	7.00%	1,680	
25,000	7.50%	1,875	
26,000	8.00%	2,080	
27,000	8.50%	2,295	
28,000	9.00%	2,520	
29,000	9.50%	2,755	
30,000	10.00%	3,000	
>30,000	--	3000	Unadjusted quota limit fixed at 3,000t

The HCR includes a cutoff at 15,000 tons (13,600 metric tons), below which no fishing will occur and the quota for the coming season will be zero. The selection of this cutoff was based on a number of different factors. Simulation analysis suggested that continued harvest at low stock sizes (0 – 10,000 tons, depending on the productivity assumptions) delayed the recovery of the stock to healthy levels. Cutoffs above 10,000 tons (9,100 metric tons) had minimal additional benefits to the Herring stock, which diminished quickly as cutoffs increased. However, cutoffs have been suggested as a way to consider forage needs at low stock sizes, and reduce competition between predators and fishermen (Cury and others, 2011; Pikitch and others, 2012). While there is minimal information available to determine what level of cutoff is required to meet the forage needs of Herring predators, this HCR incorporates an additional 5,000 tons (4,500 metric tons) into the 10,000-ton base cutoff level for a total cutoff of 15,000 tons. This higher cutoff provides an additional level of precaution given the lack of information on predator dependency on Herring. The 15,000-ton cutoff was agreed to by fishery stakeholders and may also help to buffer against additional uncertainty in future climate change scenarios.

If the SSB is between 15,000 and 20,000 tons (13,600 and 18,100 metric tons), the quota for the coming season will be set at 750 tons (680 metric tons). This represents an agreement among industry and conservation stakeholders to reduce the number of years with a zero quota, which can have long-lasting implications on market access, while also minimizing the impact on the forage base when stocks are below 20,000 tons. For SSBs from 20,000 tons to 30,000 tons (18,100 to 27,200 metric tons), the harvest rate increases linearly from 5 to 10%. Table 7-1 shows the intended harvest percentages and quotas associated with SSB estimates in this range. MSE testing found that by ramping the harvest up from 5 to 10% across this range rather than starting with a higher harvest rate had slightly higher performance in terms of long-term stock health. For SSBs of 30,000 tons and above, the quota will be capped at 3,000 tons (2,722 metric tons), prior to any ecosystem-based quota adjustment. This cap was developed in consultation with fishing industry representatives and reflects the anticipated capacity of the fleet. This cap may also be beneficial to predator-prey relationships, which are likely to grow in significance during times when the Herring population increases.

7.7.2 Incorporating Ecosystem Considerations into Herring Management

One of the primary goals of this FMP was to formalize the precautionary management approach that Department has been using since 2005. The Department has long considered SSB estimates and annual quota recommendations within the context of available ecosystem indicators, but quota setting procedures did not include a protocol for interpreting the status of these indicators. A secondary goal was to progressively incorporate ecosystem based EFI in compliance with the Commission's forage species policy. In this FMP, ecosystem considerations are incorporated in multiple ways.

The HCR, which includes a precautionary harvest rate, biomass cutoff, and quota cap, is more conservative than the harvest strategies currently used in other Herring stocks (Fisheries and Oceans Canada, 2016), and is designed to ensure that fishery needs do not supersede the forage needs of mid-trophic CCE predators. In addition, the predictive model to estimate SSB improves the Department's ability to proactively manage the Herring stock as it responds to environmental and ecological conditions. This approach helps to ensure that precautionary harvest rates are achieved, and that harvest is reduced or eliminated in low productivity years to meet ecosystem needs. In addition, ecosystem conditions are further incorporated into Herring management in two ways. First, as was the case prior to implementation this FMP, indicators of ecosystem productivity are considered annually alongside SSB estimation and quota recommendation, and this consideration is described periodically in status reports, with a particular emphasis on those indicators that have been linked to Herring productivity (Section 7.7.2.1). Second, the quota may be adjusted as necessary due to concerns about key predators or regional forage conditions using a decision tree (Sections 7.7.2.2 and 7.2.2.3). Together, the indicators identified in each of these tools provide a holistic view of the health and productivity of the system, ensuring that decisions about the Herring stock are placed in the context of the larger ecosystem.

7.7.2.1 Enhanced Status Report

Indicators of ecosystem health and Herring productivity are described in Table 7-2, along with their ecological interpretation and what changes in these indicators may mean for Herring management. To monitor changes in ecosystem health and to place Herring management decisions in an ecosystem context, Department staff should describe ecosystem status at periodic intervals in the Enhanced Status Report. This reports will describe the status of each ecosystem indicator in Table 7-2 and the anticipated effect on the productivity of the Herring stock and the central CCE as a whole, currently and in the coming years. Indicators should be considered individually as well as in concert. It is hoped that, through continued monitoring of these indices as well as future research, this approach will provide a basis for use of these indicators in fishery management and inform future efforts.

Table 7-2 includes indicators on oceanographic and terrestrial conditions, and Herring productivity. These are designed to assist managers in understanding current conditions for the Herring population, as well as how the size of the SSB might change in the coming years.

Table 7-2. Matrix of EFI for assessing ecosystem conditions when setting quotas for the Herring fishery in San Francisco Bay.		
Data	**Interpretation**	**Implications for Herring Management**
Oceanographic Indices		
Pacific Decadal Oscillation (PDO)	Positive PDOs are associated with warmer waters and lower productivity in the CCE, while negative PDOs are associated with cooler waters and higher productivity.	PDO fluctuations affect the primary producers that are food for Herring, so periods of positive PDOs may negatively impact Herring SSB.
Oceanic Niño Index (ONI)	Positive ONI indicates El Niño conditions (warmer and wetter), while negative ONI indicates La Niña conditions (cooler and drier).	El Niño events negatively impact productivity in the CCE, which can indirectly affect food availability for Herring. El Niño events may also reduce larval or juvenile Herring survival, reducing recruitment and impacting Herring year class structure (Sydeman and others, 2018).
Cumulative Upwelling Index	Upwelling results in the transport of cool, high–salinity, nutrient–rich water onshore. Delayed coastal upwelling (known as the Spring Transition) severely depresses the productivity at the base of the CCE.	Strong upwelling provides nutrient-rich water that positively impacts primary producers, which indirectly affects food availability for Herring. Years with weak upwelling may correspond to lower SSB estimates.
SST Anomaly	High SST is associated with lower productivity, while low SST is associated with higher productivity for species such Herring.	A lower SSB might be expected in years where SST anomaly is above average due to lower food availability for cold water species in the CCE.
Buoy N26 SST	Summer SST (Jul-Sep) is negatively correlated with observed spawning deposition in the following season. Warmer waters may mean that conditions for adult Herring are poor, and either survival or spawning may be lower.	Warmer waters may reduce spawning returns in the coming season, while cooler waters may indicate good spawning conditions.
Terrestrial Environmental Indices		
Outflow metric (Sacramento/ San Juaquin delta)	Outflow is affected by precipitation, snow melt, and water diversions, and affects the salinity gradient in the bay. Herring may use freshwater output as an indicator of where to find estuaries with suitable salinity conditions for spawning.	Very high outflow may increase turbidity and lower salinity, which may result in poor spawning conditions for Herring. Very low outflow may result in salinities that are higher than optimal for larval and juvenile survival. Moderate outflow may provide the best conditions for Herring.

Snow Water Equivalent (SWE)	The SWE is a metric of the water stored in the snow pack. Snow melt influences salinity in the Bay during the dry season (summer/fall).	Low SWE may have negative consequences for juvenile Herring survival during the summer months (but see Kimmerer (2002a) for a caveat here).
Biological Indices		
Southern Copepod Index	Higher index of Southern Copepod species usually accompanies periods of lower productivity in the CCE	Southern Copepods are less lipid rich and provide a less desirable food source for forage species in the CCE such as Herring, so a higher index here indicates less favorable conditions.
Northern Copepod Index	Higher index of Northern Copepod species usually accompanies periods of higher productivity in the CCE.	Northern Copepods are more lipid rich and nutrient dense, providing better food for Herring, so a higher index for this species indicates more favorable conditions.
Herring YOY Index	This index measures the number of juvenile Herring in San Francisco Bay during the late spring and summer months. These Herring will leave the bay in the last summer and fall to join pelagic Herring schools.	The YOY index has been shown to be positively correlated with the winter SSB three years later. Herring mature between ages two and three and recruit to the fishery during that time, so a high YOY suggests a larger SSB in three years, and a low YOY suggests a smaller SSB in three years.
Percentage of Age Two and Three Herring in the Catch	The gill net fishery targets primarily age 4, 5, and 6 yr old fish. Between 2005 and 2018, the number of age three or younger fish has been under 20% every year. Tracking the age composition of the catch can be an informative indicator of Herring productivity and survival.	If the percentage of age three- fish is higher than average it may signal a strong recruitment year and larger than average SSB in the next two or three years. However, if the fishery begins to consistently have high numbers of young fish in the catch the gear selectivity should be examined.
Percentage of Age Six and Older Herring in the Catch	The presence of older Herring (age six and older) in the catch suggests low mortality rates that allow some individuals to survive to older ages. These fish tend to be larger and may spawn earlier in the season.	If the percentage of age six and older fish decreases, this suggests that mortality (either fishing or natural mortality) may be higher, preventing survival to old age. If the percentage of age six and older fish is higher than average this may signal a period of decreased recruitment to the fishery.

7.7.2.2 Decision Tree to Adjust the Quota Based on Predator-Prey Conditions

The peer review of this FMP concluded that the HCR described in Section 7.7.1 is likely to ensure that the resource needs of the commercial Herring fishery do not negatively affect Herring's role as forage for mid-trophic predators in the central CCE (Appendix O). However, one of the goals of this FMP was to develop a process to explicitly consider both regional predator population conditions and regional forage availability in quota setting decisions. Given the uncertainty about the needs of predators, as well as concern about recent and potential future changes in the composition of the CCE, additional precaution during years when forage is low may be warranted.

Based on the available information on observed diet composition of predators in the area in and around San Francisco Bay (Chapter 3), a suite of indicators was selected to track the health of key predator populations as well as regional forage availability. To assist Department staff in determining whether quota adjustments may be necessary, and if so, how those adjustments should be applied, a decision tree process was developed (Table 7-3).

Once the SBB is estimated (Section 7.6) and the preliminary quota is determined, Department staff will follow the decision tree to determine whether any quota adjustment should be considered. The first step in the decision tree relates to the size of the estimated Herring biomass, because a quota reduction based on ecosystem considerations is only warranted if the stock is between 20,000 and 40,000 tons. Once the SSB is larger than 40,000 tons, the stock is at 40-50% of the estimated average unfished biomass (Appendices B and M) and is thus considered able to meet forage needs of predators without additional quota reductions. However, at an SSB below 40,000 tons there may be a benefit to reducing harvest if ecosystem conditions suggest that forage conditions in the central CCE are unusually poor. Alternatively, if forage conditions and predator populations are relatively large, the quota may be increased to allow fishermen to take advantage of good conditions when SSB is greater than 20,000 tons. When the stock is between 15,000 and 20,000 tons, a quota of 750 tons is in place to preserve the ability of fishermen to access the fishery while minimizing potential ecological impacts of harvest. Because a lower quota is economically unfeasible, no quota adjustments based on ecosystem conditions are warranted when the SSB is in this range except under emergency conditions, when the quota may be set to zero. When the SSB estimate is below 15,000 tons, the quota is zero.

The next set of criteria (questions 2 through 5; Table 7-3) assess unusually poor conditions in predator populations that may be related to limited forage availability. Incorporating indicators of predator health into management decisions is challenging. Predators are often opportunistic, and tend to eat a wide variety of species depending on availability. While a number of predators are known to eat Herring in the CCE, a comprehensive meta-analysis of all known dietary studies found that there is little information available to link San Francisco Herring to specific predator populations (Szoboszlai and others, 2015). This does not mean that Herring aren't an important dietary source for predators, but few studies are conducted in winter, and so there are few data available during the season when Herring are most abundant in the area in and around San Francisco Bay. A suite of predators that are known to eat Herring in the area (Section 3.3.2) have been included in the decision tree. While it is expected that predator populations will experience natural fluctuations, unusual mass mortality events should be investigated to determine whether the cause is linked to food availability. If so, this may provide an indication of poor forage conditions for local predators.

NOAA tracks marine mammal mortality events in the United States[7], and the United States Geological Survey tracks mass mortality events for terrestrial species[8]. This information should be used by Department staff to determine whether there is a mortality event currently in progress for any of the species listed in question 2. If there is currently no mortality event in progress, Department staff may proceed to question 5. If there is an event affecting one of the indicator predator populations, the information provided on these websites should also be used to assess the location of the mortality event (question 3). It may be difficult to assess the primary location of an ongoing mass mortality event, especially in a species that is migratory or has a very large home range. Department staff will evaluate the best information available at the time when quotas are being set and will decide whether a high proportion of observed mortalities are occurring in the central CCE. Department staff will also need to determine whether the mortality event is caused by a lack of forage (question 4), which may manifest itself with signs of emaciation or starvation. It should be noted that in the past, some mortality events have been inconclusive or caused by non-forage issues, including infectious diseases or exposure to biotoxins such as domoic acid. These events would not warrant a reduction in the quota because they are not caused by a lack of forage in the system. It may take some time to determine the cause of a predator mortality event. In the event of a mortality event where the cause is yet undetermined, no quota reduction is warranted. This is because the HCR is already precautionary, and without direct evidence of forage-related conditions, quota reductions would not be warranted. Should the criteria in questions 2, 3, and 4 all be met, the decision tree directs Department staff to consider a quota reduction (discussed in Section 7.7.2.3).

Chinook Salmon have been directly linked to San Francisco Bay Herring through dietary studies (Merkel, 1957; Thayer and others, 2014). Question 5 compares the forecasted oceanic abundance of the Sacramento River fall-run Chinook Salmon with the upper range for the escapement target that has been set by the PFMC. If the forecasted oceanic abundance is below 180,000 fish, the decision tree recommends considering a quota reduction. This forecast is available in the spring, prior to the time when quotas are set for the Herring fishery. This salmon population is intensively managed, and pre-fishery ocean abundance forecasts are primarily driven by ecological conditions, as fishing is yet to occur (PFMC, 2019). There is no immediate way to know whether low oceanic abundance is specifically due to a lack of forage, but given the direct

[7] https://www.fisheries.noaa.gov/national/marine-life-distress/active-and-closed-unusual-mortality-events
[8] https://www.nwhc.usgs.gov/whispers/searchForm/index

connections between Chinook Salmon and San Francisco Bay Herring that have been observed, should the pre-season ocean abundance salmon forecast fall below the upper end of the escapement target range, care should be taken to consider adequate Herring for forage when population levels are extremely low.

Questions 6-10 aide Department staff in assessing regional forage availability in the central CCE. If the forage indicators suggest that prey conditions in the central CCE are unusually poor (as defined in the decision tree) a reduction in quota may be necessary. Conversely, unusually good conditions might suggest that an increase in quota is warranted. The regional forage indicators identified in questions 6, 7, and 8 rely on variability indices provided by the California Current Integrated Ecosystem Assessment (CCIEA) project, which synthesizes data for the central CCE region (with most data coming from the region around San Francisco Bay). The central CCE forage community includes a diverse array of species and life history stages, each varying in behavior, energy content, and availability to predators, and the relationships between the availability of each type of forage and the Herring stock are not well understood. For this reason, multiple indices are used to provide a holistic look at forage conditions. Krill are important forage for Herring and many other species, and unusually low krill abundances may suggest the potential for reduced productivity, both for the Herring stock and for the entire central CCE. Pacific Sardines and Northern Anchovy are perhaps the most important central CCE prey species because of their high lipid content. The regional indices of relative forage availability of other important forage species such as Market Squid and YOY groundfish such as Pacific Hake, rockfish, and Sanddabs are also tracked (Harvey and others 2017). While these indicators reflect prey conditions during the summer and may represent a spatial distribution that is further offshore than Herring tend to range, these indicators offer the best available science describing the general forage availability within the central CCE.

Table 7-3. Decision tree to assess predator-prey conditions in the CCE.			
Herring	1. Is the biomass estimate greater than 20,000 tons?	**No**	Do not adjust quota.
		Yes	Proceed to 2.
Predators	2. Is there an unusual mortality event in progress in California for one of the following species: Common Murre, Rhinoceros Auklet, Harbor Seals, or California Sea Lions?	**No**	Proceed to 5.
		Yes	Proceed to 3.
	3. Is the mortality event occurring in Central California (e.g., Sonoma, Marin, San Francisco, San Mateo, Santa Cruz, Monterey counties)?	**No**	Proceed to 5.
		Yes	Proceed to 4.
	4. Is the cause of the mortality event attributed to or exacerbated by lack of forage, and the Herring biomass estimate is < 40,000 tons?	**No**	Proceed to 5.
		Yes	Consider reducing quota.
	5. Is the forecasted ocean abundance of Sacramento River fall-run Chinook Salmon < 180,000, and the Herring biomass estimate < 40,000 tons?	**No**	Proceed to 6.
		Yes	Consider reducing quota.
Regional Forage	6. Calculate whether YOY Hake, YOY Rockfish, YOY Sanddab, Market Squid, and krill in the central CCE are more than 1 standard deviation below the long term mean. These indicators are classified as "unusually low".		Proceed to 7.
	7. Calculate whether central CCE regional indices of relative forage availability for Adult Pacific Sardine and Adult Northern Anchovy are below 50% of the long term mean. These indicators are classified as "unusually low".		Proceed to 8.
	8. Calculate the number of forage indicators that are more than 1 standard deviation above the long term mean. These indicators are classified as "unusually high".		Proceed to 9.
	9. Are there currently > 5 forage indicators that are unusually low, and the Herring biomass is < 40,000 tons?	**No**	Proceed to 10.
		Yes	Consider reducing quota.
	10. Are there currently > 3 forage indicators that are unusually high, and the answer to lines 2, 5, and 6 is no?	**No**	Do not adjust quota.
		Yes	Consider increasing quota.

7.7.2.3 Adjusting the Quota Based on Ecosystem Considerations

Should one or more of the criteria in the decision tree recommend that the Department consider reducing the quota, a 300 ton (272 metric ton) reduction in the harvest should be applied (Figure 7-3). If applied to an SSB of 20,000 tons, where the HCR recommends a 5% target harvest rate, resulting in a quota of 1,000 tons, the harvest rate would be adjusted down to 4%, resulting in a quota of 800 tons. At a SSB of 25,000 tons where the HCR recommends a 7.5% target harvest rate, resulting in a quota of 1,875 tons, the target harvest rate would be adjusted down to 6.5%, resulting in a quota of 1,625 tons. At SSBs between 30,000 and 40,000 tons, the quota would be reduced to 2,700 tons. Conversely, if an increase is warranted, a 300 ton increase to the quota should be applied (Figure 7-3). At a SSB of 20,000 tons, the target harvest rate would be adjusted up to 6%, resulting in a quota of 1,200 tons. At a SSB of 25,000 tons, the target harvest rate would be increased from 7.5% to 8.5%, resulting in a quota of 2,125 tons. However, because the target harvest rate is capped at 10%, per an agreement from the SC, increases to the target harvest rate due to ecosystem considerations at estimated SSBs between 28,000 and 32,000 tons are limited. At 33,000 tons or greater SSB, the maximum possible adjusted quota is 3,300 tons.

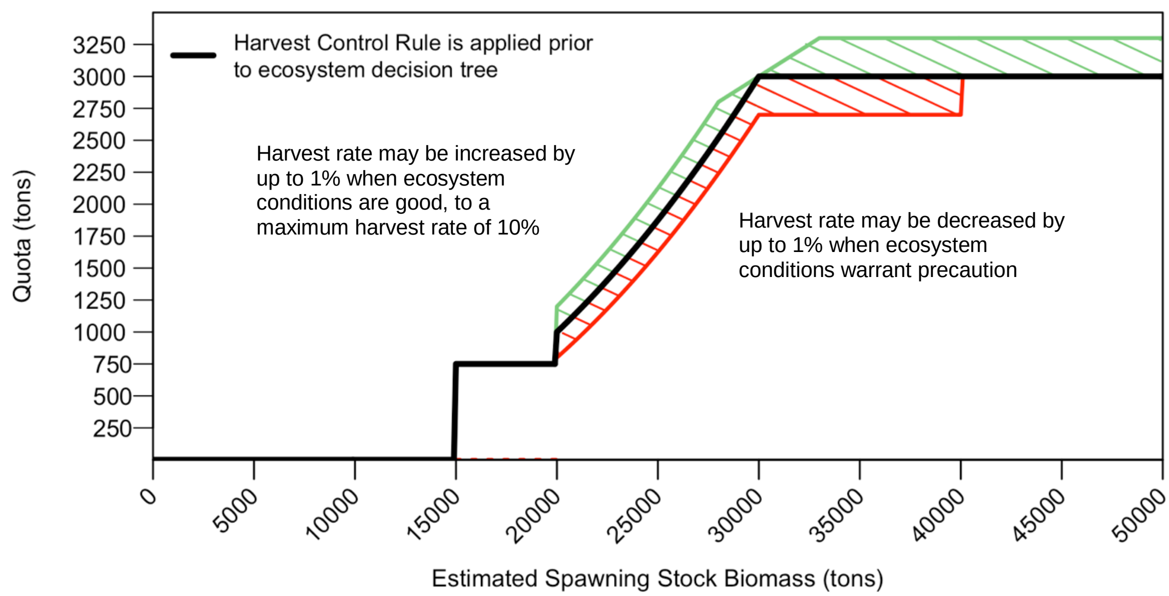

Figure 7-3. Possible range of quotas under the harvest control framework after the ecosystem decision tree is applied.

7.7.3 Application of Management Framework

While there is a desire to have a clearly described and transparent mechanism for setting the quota each year (i.e., the HCR framework described in Sections 7.7.1 and 7.7.2), there is also a need to maintain the ability of Department staff to assess and, if necessary, respond to unforeseen conditions as they arise. This balance between having both a pre-determined process, as well as bounded flexibility in yearly management decisions, is a key component of this FMP, because it is impossible to plan for every possible future scenario that may arise in a complex ecological system.

The Department will follow the previously described quota setting framework but will reserve a level of discretion given the uncertainty related to data availability, as well as resource and staff constraints. Quotas must be announced each year by November 1 to allow fishermen the time to prepare for the season, and quotas must be set using the best available information. The management strategy described in this FMP relies on a number of data that are collected by other projects within the Department (YOY Herring index, forecasted oceanic abundance for Chinook Salmon) as well as other agencies (predator mortality events, regional forage indicators, environmental conditions). It is possible that in some years one or more data streams may be unavailable due to a disruption in sampling. Under that scenario, the Department will apply the HCR framework based on the best available information. Should any of these data become permanently unavailable, the Department will need to develop an alternative method for incorporating ecosystem indicators into quota decisions based on what is available.

Ecosystem-based fishery management is an emerging science and new indicators, as well as methods for incorporating them into fisheries management, are continually in development. In recognition of this, the suite of indicators used to assess ecosystem conditions (Table 7-2) and evaluate the need for ecosystem-based quota adjustments (Table 7-3) may be updated by the Department as needed to reflect the best available science (Section 9.1). As an example, the forage indicators used in the decision tree reflect what is known about forage availability in the central CCE, but may not be the best metric to describe coastal forage, or accurately reflect alternative forage for Herring predators, which is largely unknown due to the limited number of diet studies specific to the winter months. As additional data become available and the science evolves, there may be a better understanding of the linkages between ecological indicators, the Herring stock, and the wider CCE, and Department staff may then update the indicators used in Tables 7-2 and 7-3. When altering or adding indicators it is important to focus on those that overlap geographically and temporally to the extent possible with California's Herring stocks.

The Department retains the discretion to act to protect the Herring resource beyond what is specified in this management strategy. Department staff may set a zero quota or otherwise enact an emergency quota in the event of extreme environmental conditions or disasters, such as in the case of an oil spill or unprecedented environmental or ecological conditions. In this case, the stock should be closely monitored for the season, and conditions should be reevaluated prior to the next season. Closing the fishery for an entire season has economic impacts for the commercial fleet, and should only be considered under poor ecological conditions that would be detrimental to the stock and its ability to recover.

7.8 Management Measures and their Anticipated Impact on the Stock

While quotas are the primary basis for ensuring sustainability in Herring stocks, additional management measures are necessary to provide safeguards for the stock, as well as to mitigate conflicts between user groups to the extent possible. This section describes those additional management measures.

7.8.1 Restrictions on Catch

This FMP requires that commercial catch limits, in the form of annual quotas, be set for each of the four management areas where Herring fishing is allowed. Quotas in the three northern management areas will be set at a precautionary level based on available historical spawning biomass data and/or landings history (Section 7.4). Quotas in the San Francisco Bay management area will be set in accordance with the HCR framework described in the sections above. This framework ensures that: a) quotas are set as a percentage of the total estimated spawning stock for fished stocks that are intensively monitored, b) target harvest rates are low (or zero) when Herring stock sizes are small in order to reduce impacts to the sustainability of the stock and the ecosystem as whole, and c) current forage conditions in the central CCE are tracked and described to provide environmental context. This management framework is comprehensive, adaptive, and based on the best available science.

The HCR framework proposed in this FMP meets the requirements of the MLMA, which state that FMPs must specify criteria for identifying when the stock is overfished, include measures to end or prevent overfishing, and provide a mechanism for rebuilding in the shortest time period possible (FGC §7086). This is achieved by providing clear definitions of when the stock is in a depressed state (which may occur due to either overfishing or natural fluctuations) via the cutoff prescribed in the HCR. It also provides a clear rebuilding plan should the stock be depressed by reducing quotas to zero until the stock recovers to a level above the cutoff, and implements more precautionary target harvest rates at low stock sizes to promote stock growth. The harvest cap is designed to reduce the chance of overfishing.

7.8.1.1 Allocation of Quota between Sectors

In developing this FMP, it is necessary to determine how the quota should be allocated between fishing sectors. Previously, the quota for the HEOK fishery sector was subtracted from the overall gill net quota and transferred to the HEOK sector to reflect the permits that elected to fish using HEOK rather than gill net or round haul gear in that season. This quota in whole fish weight was then converted to the number of eggs that biomass of fish could produce to determine the HEOK product weight. By removing fish from the sac-roe sector and transferring them to the HEOK sector, the Department reduced fishing mortality of adult Herring, because the HEOK fishery removes eggs but does not remove adult fish. This FMP establishes that the gill net sector quota will be set based on the HCR framework described above, and the total HEOK sector quota will be set at a product weight equal to 1% of the total quantity of eggs produced by the most recent estimated SSB (Appendix N).

7.8.2 Effort Restrictions

7.8.2.1 San Francisco Bay

During the FMP development process, a comprehensive review of the permitting system in San Francisco Bay was undertaken. This was one of the primary goals of this FMP and was initiated by fishing industry representatives during annual DHAC meetings. The prior permitting system was originally developed for a much larger fleet, and the platoon system, experience points, restrictions on the number of permits that could be owned, and the dedicated Herring account are no longer necessary or useful given reduced effort and participation in the fishery. The FMP development process provided an opportunity to modernize the permitting system and conform to operational requirements for other fisheries in California.

This FMP establishes the permitting system as follows:

- Odd, Even, and DH gill net permits will be reassigned as Temporary permits. CH permits will be reassigned as two Temporary permits. A Temporary permit allows the permittee to fish one shackle (65 ftms) of gill net during every week of the season from a single vessel. Permittees can hold up to three Temporary permits and these permits are transferable (Section 4.7.2).
- holders of two Temporary permits will be consolidated to a single San Francisco Bay permit. A San Francisco Bay permit allows the holder to fish two nets, each one shackle (65 ftms) in length, during all weeks of the season from a single vessel. Conversion to a San Francisco Bay permit is permanent and these permits are transferable.
- permittees can own a maximum of one San Francisco Bay permit, or one Temporary permit and one San Francisco Bay permit.
- Temporary and San Francisco Bay permits will receive new permit numbers, but will be traceable to the permits/platoons from which they were converted.
- permits will be issued to one permittee each, and may no longer be held in partnership.
- Temporary Substitutes and Experience Points are no longer needed, because a permittee may have any licensed commercial fisherman serve in his or her place on the designated vessel and engage in fishing, provided the permit is aboard the vessel named on the permit(s) at all times during Herring fishing operations.
- HEOK-designated Odd, Even, and DH permits will be reassigned as stand-alone HEOK permits. HEOK-designated CH permits will be reassigned as one HEOK permit and one Temporary permit each. HEOK permits are transferable and royalty payments are eliminated.

- deadline for receipt or postmark of application for renewal of all Herring permits in all management areas, without penalty, is April 30 of each year.

Under the consolidation described in this FMP each vessel can fish two Temporary permits simultaneously or one San Francisco Bay permit. All Temporary permits that are not renewed will be held by the Department until they can be converted to San Francisco Bay permits and reissued once the number of permits drops below the long-term capacity goal described below. Under the authority of this FMP, permittees will have five years from the date of FMP adoption to convert all Temporary permits to San Francisco Bay permits. Once the five-year deadline is reached, all Temporary permits will become non-transferrable and non-renewable. No new San Francisco Bay permits will be issued after the consolidation deadline until the number of permits falls below 30 San Francisco Bay permits.

This FMP also establishes a long-term capacity goal of 30 vessels (or 30 San Francisco Bay permits), with a maximum of two nets per vessel, which will likely be achieved through attrition due to economic conditions in the fishery. With a 3,000-ton (2720 metric ton) unadjusted quota cap in the HCR framework, a fleet of 30 vessels could catch up to 100 tons (91 metric tons) of Herring on average per vessel, though there is no vessel-based allocation of the quota. This level of harvest should maintain the economic viability of the fleet in years where the quota is near the 10% target harvest rate cap. Additionally, the HCR allows a small quota to be available to sustain a reduced fleet in years were SSB is between 15,000 and 20,000 tons (13,600 and 18,100 metric tons).

7.8.2.2 Tomales Bay

Under this FMP the permitting system will remain the same in Tomales Bay (Section 5.3.2), with the only changes being the maximum number of permits issued in this management area and permit application deadline. At the time of FMP development, the maximum number of permits allowed in Tomales Bay was 35. This FMP reduces that number via attrition to 15, (i.e. no new permits issued until the total number of Tomales Bay permits falls below 15). Should conditions change in the future, Department staff may find it necessary to adjust the permit capacity in accordance with the needs of the fleet and the level of catch the resource can support in this management area.

7.8.2.3 Humboldt and Crescent City

Under this FMP there are no proposed changes to the permitting system in the Humboldt Bay and Crescent City Harbor management areas except permit application deadline (Section 5.3.2). The number of permits in these areas specify a permit capacity of four permits. Should conditions change in the future, Department staff may find it necessary to adjust the permit capacity in accordance with the needs of the fleet and the level of catch the resource can support in these management areas.

7.8.3 Gear

At the time of FMP development, the gill net mesh size for San Francisco and Tomales Bays was set at 2-in (50 mm) and the minimum gill net mesh size for Humboldt Bay and Crescent City Harbor management areas was 2.25-in (57 mm). When mesh size for San Francisco and Tomales Bays was reduced in 2005 there was a concern that the reduction from 2.125-in (54 mm) (Section 5.4.3) would lead to a reduction in the size and age of the commercial catch. However, the proportion of fish age two and three in the commercial catch has remained at less than 15% since that time, except during a large recruitment event in 2010-11 and 2011-12, and the catch has primarily consisted of age four and older Herring (Figure 5-2). This is consistent with the Department's goal of ensuring that all Herring are able to spawn prior to becoming vulnerable to the fishery. The maximum mesh size for all management areas is 2.5-in (63.5 mm). No changes to the mesh size used in the gill net fleet are recommended at this time. However, emerging research suggests that selective harvest, in which certain size or age classes are caught at a higher proportion than they naturally occur in the population, may have adverse ecological effects (Garcia and others, 2012), and evolutionary consequences (Law, 2000). The Department will continue to monitor the age structure of the commercial and research catch, and changes to the selectivity of the gear may be warranted if negative trends in the age structure or other adverse effects are detected.

In an attempt to facilitate a local whole fish market for Herring, the Department may consider allowing additional gear types into the commercial Herring fishery (e.g. small cast nets have been proposed to the Commission) (Section 4.7.4). However, any changes in allowed gear must take careful consideration of the efficiency and selectivity of that gear, and its likely impacts on the age and size structure of the stock. A primary component of the Department's Herring management strategy includes allowing gear that primarily targets age four and older Herring. This allows all Herring the opportunity to spawn at least once before they become vulnerable to the fishery. In addition, alternative gear types may increase the rates of bycatch or habitat impacts, and these impacts should be considered prior to allowing new methods of take into the fishery. Any proposed changes in allowable commercial gear should be initially explored through the issuance of an experimental fishing permit through the Commission process. This avenue allows Department scientific staff to assess potential impacts to the stock and ecosystem prior to a regulatory change. See Chapter 9 (Section 9.1) for a discussion of the Commission's role in establishing alternative gear types and issuance of experimental fishing permits under this FMP.

7.8.4 Spatial Restrictions

No changes to the existing spatial restrictions on Herring fishing in San Francisco Bay (Section 5.5, Figure 5-3) are proposed as part of the FMP.

7.8.5 Temporal and Seasonal Restrictions

One of the goals of the FMP is to streamline regulations as appropriate. During the development of this FMP, the Department conducted a review of the existing regulations and sought input from various stakeholder groups, including permit holders, processors, the Department's Law Enforcement Division, recreational fishermen, and the conservation community through surveys, meetings, and public comment periods. Based on the feedback received, changes to the season dates are indicated in Table 7-4.

Table 7-4. Summary of changes to season dates in each management area.

Area	Dates Prior to FMP	Dates Established Under this FMP
San Francisco Bay	1700 on January 1 until 1200 on March 15	Herring fishing in all management areas will run from 1200 on Jan 2 to 1200 on March 15. The weekend closure will remain in effect in San Francisco Bay. If January 2 falls on a weekend, the fishery in San Francisco Bay will open at 1700 on the following Sunday.
Tomales Bay	1200 on December 26 until 1200 on February 22	
Humboldt Bay	1200 on January 2 until 1200 on March 9	
Crescent City	1200 on January 14 until 1200 on March 23	

Previously, each management area had its own season dates. This FMP establishes a single start and end date for all management areas. The start date is moved to January 2 for all management areas, with an end date of March 15. The weekend closure will remain in effect only in San Francisco Bay. If Jan 2 falls on a Friday or Saturday, the fishery in San Francisco Bay will open at 1700 on the following Sunday due to the weekend closure requirement.

7.8.6 Size and Sex

There are currently no limits on the size of Herring that can be retained by the fishery. However, the current mesh size limit begins to select fish at about 160 mm (6 in) body length, and fish are fully selected at about 180 mm (7 in). Given the schooling nature of Herring and the use of gill nets, both males and females are caught in the fishery. The commercial fleet is unable to catch only females, which are the target of the roe fishery. The Commission may choose to adjust the size of the gill net mesh to alter the size composition of commercial landings as a management tool in the future (see section 9.1).

7.8.7 Recreational Fishery

This FMP establishes a daily bag limit for recreational fishing. This FMP recommends a range between 0 and 100 lb (45-kg) daily bag limit, which is equivalent to up to ten gallons, or two 5-gallon buckets of Herring, each containing approximately 260 Herring. Based on input from stakeholders this is considered to be an appropriate amount to provide a reasonable and sustainable amount of recreational harvest for participants. This possession limit is also designed to be clear and easily enforceable. Currently, there are no estimates of the recreational catch available, but this possession limit will provide Department staff with a means of estimating recreational take via counting the number of recreational anglers observed during each spawning event.

Should the recreational sector continue to grow, or should there be additional concerns about the impact the recreational sector is having on the stock, Department staff may consider implementing additional restrictions on fishing effort. These may include only allowing recreational Herring fishing at certain times of the day, on certain days of the week, or establishing a recreational fishing season. Additionally, restrictions on gear types and configurations (such as cast nets) may be an effective and easily enforceable way to reduce the CPUE in the recreational Herring fishery.

7.8.8 Management Measures to Prevent Bycatch and Discards

Given the low levels of bycatch observed in the Herring fishery (Section 5.9), this FMP includes no additional management measures to reduce the amount or impact of bycatch. Bycatch collected in commercial herring samples will be recorded and periodically reported in season summaries or Enhanced Status Reports.

7.8.9 Management Measures to Reduce Habitat Impacts

Gill nets generally are set in shallow muddy bays. Muddy benthic habitats support a wide variety of invertebrate fauna that have varying degrees of susceptibility to and ability to recover from disturbance. Gill nets may also be set in areas with eelgrass and other submerged vegetation, which are vulnerable to disturbance by gill net gear (Section 2.13.3). Existing spatial restrictions on using gill nets to fish for Herring provide protection to roughly 13% of total eelgrass habitat in San Francisco Bay, including the beds in Richardson Bay and Belvedere Cove (Section 5.10.1, Figure 5-3). Other areas, such as Kiel Cove, Paradise, Brooks Island, and Point Richmond have eelgrass beds that may be impacted by gill net fishing. However, given the very short fishing season, which frequently lasts six weeks or less, as well as the established limit on the number of vessels in the gill net fleet, the potential for this type of damage is considered minimal. No additional management measures are proposed to reduce the habitat impacts from fishing activities. The primary threats to Herring habitat are from non-fishing activities that fall outside the scope and authority of this FMP (Section 5.10.2).

7.9 Management Procedure

Under this FMP, the authority for quota changes in all management areas is transferred from the Commission to the Department's Director (Section 9.1). Provided the proposed management change is in line with the management strategy described in this chapter, the Department will be able to adjust quotas as needed without a Commission rulemaking. This allows the Department to be more responsive to changes in the fishery, as well as to reduce the workload associated with routine management (Section 6.1.1). Other changes to the management of the fishery will still require the formal Commission process and approval, providing safeguards for the fishery, as defined in Chapter 9 of this FMP.

7.10 Continued Stakeholder Involvement

The MLMA directs managers to involve stakeholders in management decisions and the Herring fishery has benefited greatly from having a formal process for communication with stakeholders since the early years of the fishery. Yearly meetings with the DHAC should continue to be an integral part of the management cycle. When appropriate, Department staff will continue to meet once a year with the DHAC in order to present the data collected from that season, results of analyses conducted, and a recommendation for the quota based on the HCR. However, under the new HCR framework, some of the ecological and environmental data required for use in the predictive model are not available until late September. Therefore, the timing of DHAC meetings will move to late October or early November to allow Department staff enough time to conduct the necessary analyses and determine the quota for the coming season. Department staff should present the available data and describe the resulting SSB estimate, any quota changes for the next season, and the status of the various ecosystem indicators and their interpretation in periodic Enhanced Status Reports. The DHAC meeting will continue to be a forum for industry and Department discussion as well as exchange of information and ideas.

Chapter 8. Additional Management Needs and Future Research

8.1 Stock Size in Crescent City Harbor

While the stock in Crescent City Harbor was routinely fished between 1973 and 2002, surveys were not been conducted by Department staff to estimate SSB. Anecdotal reports suggest that this stock spawns in Crescent City Harbor along rocky riprap, rather than in shallow subtidal vegetation beds. The total spawning potential and whether the stock utilizes spawning habitat outside the harbor is unknown for this area. The age structure and growth rates are also unknown. These data are important and could be useful for making management decisions in this fishing area.

8.2 Changes in Size at Age and Impacts on Stock Health

Tomales and San Francisco Bays both experienced a decline in the abundance of larger, older fish between the mid-90s through the present. While the age structure in San Francisco Bay has shown some signals of recovery, size at age has continued to decline despite more than a decade of precautionary management (target of 5% or lower) intended harvest percentages. The loss of older fish in a population indicates an increase in mortality rates for those age classes. Increased mortality may arise from fishing or natural processes, and both increased natural mortality and declining size at age have been observed in other Herring stocks (Hay and others, 2012; Schweigert and others, 2002). Given the decrease in fishing pressure in California since the early 2000s it is possible that natural mortality has increased, though the cause of the mortality rate change is unknown.

The location of fishing is often nonrandom relative to spatial distributions of stocks; fishing is typically concentrated where biomass is greatest or most accessible. Fishing mortality is therefore selective with respect to both species and phenotypic variation within species (Jennings and Kaiser, 1998; Stokes and Elythe, 1993). Heavy fishing has been shown to have selective effects on certain phenotypic traits related to yield, most commonly growth rate, length- and age-at-sexual maturation, and fecundity (Law, 2007). Changes in fecundity have been noted in the San Francisco Bay stock. Reilly and Moore (1986) estimated fecundity at 113.5 eggs/g of body weight of female and male Herring, whereas in 2015 Department staff estimated 108.5 eggs/g of body weight. It is possible that larger fish, which are known to spawn earlier in the season, were subjected to higher fishing pressure when fishing was allowed earlier in the season, therefore less likely to reproduce successfully.

Environmental fluctuations may also play a role in the observed changes in length at age in San Francisco's Herring stock. Warmer waters, increased climate variability, pollution, or other unknown variables may have contributed to the reduction in growth rates and condition index that have been observed. Herring populations throughout British Columbia have also displayed a long-term decline in size-at-age, and it has been hypothesized that the food supply in the

CCE may have been reduced over the past two decades (Schweigert and others, 2002). More research is needed to understand the causes of observed changes in size and age distribution. Additional work is also needed to understand the impacts of changes in size and age on the Department's ability to interpret metrics of stock health, which are often based on historical observations.

8.3 Genetics and Stock Structure

Herring populations in California are managed as distinct stocks, though the true underlying population structure has never been verified. San Francisco Bay and Tomales Bay stocks occur within 80 km (50 mi) of one another and some efforts have been made to determine stock structure. Spratt (1981) noted that the growth rate of Tomales Bay Herring was significantly different than that of San Francisco Bay Herring and that this may be evidence that the Herring populations in the two bays are distinct. Reilly and Moore (1986) analyzed morphometric (measurement of body parts expressed as a ratio to total body length) and meristic (count of body parts such as fin rays, vertebrate, etc.) characteristics of California Herring from Fort Bragg Harbor and San Francisco, Tomales, and Humboldt Bays, in an attempt to detect differences in Herring from these locations. Analysis indicated that the northern populations (Humboldt Bay and Fort Bragg) could be separated from the southern populations (Tomales and San Francisco Bays) with an 85-87% success rate, but morphometric differences were not great enough to separate Herring from Tomales and San Francisco Bays. Moser and Hsieh (1992) used parasites as biological tags in a study of juvenile Herring off central California. The results suggested that Tomales and San Francisco Bay Herring are separate spawning stocks and generally remain separate while at sea. As DNA analyses techniques evolve it may be possible to determine the extent to which populations mix or use multiple bays for spawning.

There is a new body of evidence from northern populations of Herring that spawning aggregations separated by several weeks or more in timing exhibit genetic differentiation when using high resolution molecular markers (Petrou and others, in preparation). Given that spawn timing in San Francisco Bay spans months, these new markers may be used to evaluate if there is genetic structure by spawn timing or geography. These may help inform whether additional spatial or temporal considerations in management are necessary.

8.4 Oceanic Phase of California Herring

There is very little information available on the behavior, migration patterns, or distribution of California's Herring stocks when they emigrate from bays after spawning each winter. There is some evidence linking the San Francisco Bay winter spawning stock with Herring populations observed on summer feeding grounds in Monterey (Moser and Hsieh, 1992). This study also concluded that Herring in Tomales Bay are a separate stock that feeds offshore based on the observed parasites load. There is no information on the stocks in Humboldt Bay and Crescent City Harbor. Characterizing these dynamics might be a key future research endeavor that could help to refine the set of ecosystem indicators considered given the spatial overlap of Herring with their prey and predators. The recent development of high resolution, polymorphic single-nucleotide polymorphism markers (Petrou and others, in preparation) may provide information on spatial structure of California's Herring populations, including during oceanic phases.

8.5 Disease

Disease has significant effects on population abundance of some Herring stocks, particularly in Alaska (Marty and others, 2003). Herring are susceptible to epidemic diseases such as viral erythrocytic necrosis virus and viral hemorrhagic septicemia virus (VHSV) (Gustafson and others, 2006; Kocan and others, 1997). In Prince William Sound, Alaska, risk of disease was increased by poor body condition and very high recruitment levels prior to spawning (Marty and others, 2003). Recently, several fish diseases have been implicated as major constraints in limiting age structure and survival of Herring populations in Washington State. Hershberger and others (2002) identified a single-celled protist, *Icthyophonus hoferi,* and VHSV as endemic pathogens in Puget Sound Herring. *I. hoferi* is age dependent, increasing in incidence as the fish grows older. The recent emergence of a disease of this type could potentially explain the lack of older age classes (seven and older) in the San Francisco Bay populations despite very low harvest rates since the early 2000s. VHSV has been found in southern California stocks of Pacific Sardine (Cox and Hendrick, 2001). Herring from San Francisco Bay were tested for VHSV in the early 1990s and the virus was not found (W. Cox, pers. comm.). Updated pathological work in this area would be beneficial to understand the occurrence of disease in California Herring stocks.

8.6 Spatial Variability

Certain regions have been utilized for spawning disproportionately among locations in San Francisco Bay by the observed SSB, and those regions have shifted over time. In the past two decades, the majority of spawning (79% since 2000) has occurred in Marin County, which includes the areas of Richardson Bay and Tiburon Peninsula. Prior to that, from the late 1980s to the early 1990s, the San Francisco Bay Waterfront was the primary spawning region. It is unknown what causes spatial shifts across spawning habitats utilized by Herring in San Francisco Bay. There may be external influences, such as habitat alterations or other environmental cues, or shifts may occur due to the spatial structure of the stock, with certain sub-populations returning to specific locations year after year. For example, Spratt (1992) observed that a large storm in 1981 removed a large proportion of the submerged vegetation in Richardson Bay, and hypothesized that this shift in habitat contributed to the increased spawning along the San Francisco waterfront in the following ten or more years. The closure in Richardson

Bay to the Herring sac-roe fishery may have also contributed to the observed disparity between Marin County and the rest of San Francisco Bay. Populations with high levels of spatial structure may require lower or more evenly distributed harvest rates in order to maintain that structure (Ying and others, 2011), though this requires management at a smaller spatial scale than is usually practical. A Herring stock that spawns in only one location may also be more susceptible to localized disasters such as the 2007 Cosco Busan oil spill, which caused increased Herring embryo mortality (Incardona and others, 2012). A more in-depth analysis focused on spatial population dynamics, spawning habitats, and the diversity of spawning sites will improve management given the current reliance of the population on specific spawning sites, particularly Richardson Bay.

There is also little information on the extent to which Herring stocks utilize spawning grounds outside of San Francisco Bay. Anecdotal reports have indicated that spawning may occur in areas to the north and south of San Francisco Bay each year, as well as just outside of the mouth of San Francisco Bay in high outflow years, and spatial variability on this scale is difficult to detect with current resources. Given that Herring in San Francisco Bay are at the southern end of their range, there is a potential for range shifts in the future due to climate change. Monitoring changes in the spatial distribution of Herring spawns, even if only through anecdotal reports, may be useful in detecting range shifts.

8.7 Relationship between Habitat Availability and Spawning

Herring utilize eelgrass and various algae in addition to other physical and biological spawning habitat. However, the extent to which the availability of these spawning habitats influences spawning behavior and magnitude is unknown. Eelgrass habitat may be an important ecosystem indicator for Herring stocks, especially in Tomales and Humboldt Bays, where it serves as a primary spawning habitat for Herring. Sporadic estimates of eelgrass coverage are available in San Francisco Bay (Merkel and Associates, 2014), as well as for Tomales Bay and Humboldt Bay, but these datasets do not represent a continuous time series. However, the Department has surveyed the biomass of vegetation beds yearly in San Francisco Bay since 1980, and conducted similar surveys every few years in Tomales Bay until 2005. The data from these surveys could be analyzed to understand variability in these bed over time, and to explore correlation between vegetation and environmental conditions as well as vegetation and estimated Herring SSB. In the future, high-resolution satellite data may provide a way to develop a longer-term eelgrass time series that could improve understanding of how Herring biomass and eelgrass co-vary, improving habitat management capabilities.

8.8 Aging Herring Using Scales

In addition to otoliths, scales have been used to reliably age fish (Ricker, 1975), and an independent review of a stock assessment model for San Francisco Bay suggested that the Department explore using scales to estimate the age distribution of Herring stocks. This methodology could be considered by Department staff in the future (Appendix C). Switching to a new aging methodology would require upfront costs in terms of training and validation, but might result in a reliable way to obtain age distributions for Herring stocks over the long term. Age structure is an important indicator of stock health and using an equal or more reliable way to age Herring would be beneficial for the longevity the Herring program.

8.9 Understanding the Impact of Marine Mammal Exclusion Devices in the HEOK Fishery

A representative of the HEOK fishery has petitioned the Commission to allow the use of marine mammal deterrent devices provided they meet NOAA guidelines (marine mammal interactions are primarily governed by Federal statute). California Herring regulations (CCR Title 14 §163 (f)(G)) currently specify that the use of marine mammal deterrents during Herring fishing is not allowed. The Commission issued an experimental gear permit to deploy seal exclusion nets around HEOK rafts during the 2004-05 season and was subject to annual renewal in subsequent seasons. These nets had a rigid structure and large openings in the mesh to minimize bycatch impacts while allowing Herring to freely enter and exit the structure. However, additional trials and directed study are required to optimize the size and configuration of the structures and to understand bycatch and habitat impacts prior to any regulatory change.

8.10 Improving our Understanding of Predator-Prey Relationships

One of the key areas of uncertainty identified in the development of this FMP was the predator-prey dynamics of Herring in California. One of the central questions that arose was whether, and under what circumstances Herring as a specific prey item are a limiting factor for predators in the central CCE. Future research may focus on: 1) whether there is evidence that predator populations fluctuate in response to the Herring population abundance in California, and if so, 2) what predators, and 3) at what levels of Herring abundance do those predators become food limited. Additional research also needs to be conducted to understand the interactions between other small pelagic forage species' relative abundance in relation to Herring. It may be particularly useful to establish winter diet composition data for herring predators in central and northern California (Appendix R).

Chapter 9. Implementation, Review and Amendment

Section 7087 of the MLMA states that each FMP shall include a procedure for review and amendment of the plan, as necessary and shall specify the types of regulations that the Department can adopt without a plan amendment. This section describes those regulations that can be adopted without a FMP amendment, the changes that require an amendment, and the process for plan amendment.

9.1 FMP Implementation: Quota Adjustment and Regulatory Changes Not Requiring Amendment

Upon adoption of the FMP and implementing regulations, the Director of the Department will set annual fishing quotas for all management areas in accordance with the management strategy described in Chapter 7, including the use of the HCR framework in San Francisco Bay (Section 7.7). This does not require changes to the CCR through the formal Commission rulemaking process. Changes, if any, to the San Francisco Bay quota will be set on or before November 1 each year. Herring permit holders and the public will be notified as early as feasible to assist permit holders and buyers with planning for the season. Notification will be posted on the Department's website once a final determination has been made. The notification will provide a summary of how the HCR was applied to determine the quota, and information on the status of additional environmental indicators, if available.

An important component of this FMP is that it provides the Department the ability to respond to changing conditions, both environmental and market driven. Regulation changes may be implemented as necessary to meet the management objectives described in Chapter 7 without FMP amendment. This includes regulations that: 1) manage fishery impacts to Herring habitat, 2) manage bycatch in the fishery, 3) establish record keeping requirements, 4) provide for the orderly conduct of the fishery, and 5) facilitate market access. These changes can only be made if they do not jeopardize the sustainability of the stock or negatively impact the ecosystem. Potential examples of future regulatory changes that may occur are provided in Table 9-1. The anticipated impacts of each regulatory change should be carefully considered, and the changes must maintain consistency with the management objectives and strategies outlined in this FMP. The Department will continue to seek input from various constituents should any management change be considered.

Table 9-1. Descriptions of example management measures (changes) that may be considered by the Commission via a rulemaking process under this FMP.

Type of Change	Potential Rationale	Considerations
Gear changes, experimental fishing permits	There is desire by permit holders to reach new markets via an alternative gear type.	How does this change alter the age and lifetime reproductive capacity of the stock?
		How does this change alter the bycatch levels of the fishery?
		How does this change alter the habitat impacts of the fishery?
Change to season dates	There is a shift in the prime spawning season (earlier or later).	How does this change impact older, larger Herring, which typically spawn early in the season?
		How does this change impact market access?
Change to weekend closure times	There is a desire by permit holders to alter or eliminate the weekend closure.	How does this change impact other activities on the bay?
		How does this change alter the temporal refuge spawning schools may get receive?
		How does this change impact market access?
		How does this change impact the cost of management for the Department?
Additional regulations for recreational fishery	The total recreational catch continues to increase, causing concern for the status of the resource.	How does this regulatory change impact the goal of providing for a satisfying and sustainable recreational experience for participants?
		Are the restrictions consistent with those applied in the commercial fishery?

The goal of this FMP is to provide an adaptive management framework that is applicable to a wide range of future management scenarios (Chapter 7). Unforeseen events may occur that require additional management action by the Department. For example, the HCR framework does include an emergency closure provision for the San Francisco Bay management area. This can be utilized by setting the quota to zero and does not require a Commission rulemaking process. The HCR framework is based on precautionary management principles, therefore this type of management response would only be considered under extreme conditions, such as an oil spill, natural disaster, or severe ecological changes. Under these conditions, the recreational fishery may also be closed to limit all fishery impacts on the stock through an emergency rulemaking process. The Department and the Commission also retain authority to promulgate emergency regulations as needed (FGC §240).

This FMP also allows the Department to continue to adapt the SSB estimation protocol as needed to changing conditions both in the stock as well as in the fishery. Application of the HCR framework in San Francisco Bay requires the use of spawn deposition surveys as the primary assessment method to estimate annual spawning biomass (Table 6-1, Section 7.6). The monitoring procedure has been developed over the last 40 years and has been refined over time to adjust to changes in both the Herring population and staffing availability (Watters and others, 2004). If participation in the Herring fishery continues to decrease or stop all together, the Department may allocate fewer staff to monitoring Herring in San Francisco Bay. Under this scenario, the Department may choose to switch to the Rapid Spawn Assessment Method described in Section 6.2.1.1 without an amendment to the FMP.

9.2 When an Amendment is Required

A change to any components of the HCR framework identified in Section 7.7.1, including the cutoff, minimum quota, line slope, or maximum target harvest rate, will require a FMP amendment. As new information becomes available, MSE analysis used to develop the HCR can be updated to ensure that the desired fishery management objectives continue to be met, and to determine any potential need for a FMP amendment. Updating the MSE analysis however does not require a FMP amendment, and only a change to the HCR framework would require amending the FMP. An updated MSE analysis could help the Department determine if the HCR was performing as expected or to evaluate performance should conditions change in the future.

An important component of this FMP is the inclusion of ecosystem indicators in the decision tree as well as in ecosystem status reports for the San Francisco Bay stock. Ecosystem-based fishery management is an evolving science, and new data and informative indicators on the environmental conditions that affect Herring or their predators may be developed. Additionally, climatic changes may alter the relationships between indicators of Herring population health and indicators that are informative to management. Department staff may choose to include additional and/or remove existing environmental indicators to the decision tree or to the matrix of EFI for understanding ecological and environmental conditions without an amendment to the FMP (Sections 7.7.3). This can be done provided they have been shown to have either: a) direct and significant relationship to metrics of population health through peer reviewed analysis, or b) direct dietary connection at ecologically relevant spatial and temporal scales between the predator and the San Francisco Bay stock. Department staff may also remove indicators that no longer inform stock health. This can happen as ecological conditions change (regime shift as an example) and correlations between indicators and Herring population metrics are no longer present. Additionally, as the science evolves the Department may adjust the magnitude of changes to the quota recommended by the decision tree up to the limits defined in Appendix R provided the supporting science is clearly documented.

This FMP has described options to address management needs outside of the San Francisco Bay management area through a tiered management system. This approach matches the level of Department management effort to the risk posed by the fishery. Chapter 7 outlines how management effort may increase should fishing activity change. Active management in Tomales Bay, Humboldt Bay, or Crescent City Harbor may be required if fishery participation rates increase or to meet a Commission petition for larger quotas.

A significant increase in fishing pressure may require the Department to increase monitoring effort, and to reallocate staff to address monitoring needs in those areas. A FMP amendment would be required if a quota change petition exceeds what is recommended in this FMP for the northern stocks and/or if there is a desire to transition one of these areas to a Tier 3 management area. Development of a HCR for any of the northern management areas would also require an amendment. Many of the features for Tier 3 management areas in this FMP were developed and tested specifically for San Francisco Bay (using location specific data and indicators) and may not be appropriate for the northern management areas. MSE testing would also be necessary to develop a HCR that meets the management objectives for those fisheries, and location-specific environmental and ecological indicators will need to be explored. Thresholds and management objectives would also have to be developed during MSE testing to set levels of harvest beyond what is recommended in this FMP, which is currently based on historical data and landings.

9.3 Process for Amendment

FGC Sections 7075-7078 describe the process required to amend a FMP. The Department, fishery participants and their representatives, fishery scientists, or other interested parties may propose amendments to a FMP to the Department or the Commission. The Commission shall review any proposal submitted and may recommend that the Department develop a plan amendment to incorporate the proposal. Existing Department and Commission workloads and priorities may impact the response to these petitions.

In developing any proposed amendment, the Department will solicit input from California Native American Tribes, stakeholders, the public, and the Commission. Prior to submitting a proposed amendment to the Commission, the Department will submit it to peer review unless the Department determines the amendment may be exempted pursuant to FGC §7075(c). If the amendment is exempt, the Department shall submit reasons to the Commission. The Commission will make any proposed amendment available to the public for review at least 30 days prior to a hearing. The Commission will hear any proposed amendment within 60 days of receipt and will hold at least two public hearings prior to adoption or rejection. The Commission may adopt the amendment at the second public hearing or at any duly noticed subsequent meeting. If the Commission rejects an amendment, it will return it to the Department for revision and resubmission together with a written statement of reasons for the rejection. The Department will revise and resubmit the amendment to the Commission within 90 days of the rejection. The revised amendment shall be subject to the same review and adoption requirements described above.

9.4 List of Inoperative Statutes

This FMP will render the following sections of the Fish and Game code inoperative, as applied to only the Herring fisheries, once the implementing regulations are in place:

8389. Herring Eggs; Taking Restrictions (a) Herring eggs may only be taken for commercial purposes under a revocable, nontransferable permit subject to such regulations as the commission shall prescribe. In addition to the license fees provided for in this code, every person taking herring eggs under this section shall pay a royalty, as the commission may prescribe, of not less than fifty dollars ($50) per ton of herring eggs taken.
(b) Whenever necessary to prevent overutilization, to ensure efficient and economic operation of the fishery, or to otherwise carry out this article, the commission may limit the number of permits which are issued and the amount of herring eggs taken under those permits.
(c) In limiting the number of permits, the commission shall take into consideration any restriction of the fishing area and safety of others who, for purposes other than fishing, use the waters from which herring eggs are taken.
(d) Every person operating under a permit issued pursuant to this section is exempted from the provisions of Chapter 6 (commencing with Section 6650) of Part 1 of Division 6 for aquatic plants taken incidental to the harvest of herring eggs. (AM '88)

8550. Herring may be taken for commercial purposes only under a permit, subject to regulations adopted by the commission. The commission may, whenever necessary to prevent overutilization, to ensure efficient and economic operation of the fishery, or to otherwise carry out this article, limit the total number of permits that are issued and the amount of herring that may be taken under the permits.
The commission, in limiting the total number of permits, shall take into consideration any restriction of the fishing area and the safety of others who, for purposes other than fishing, use the waters from which herring are taken.
(Amended by Stats. 1996, Ch. 870, Sec. 38. Effective January 1, 1997.)

8550.5. (a) A herring net permit granting the privilege to take herring with nets for commercial purposes shall be issued to licensed commercial fishermen, subject to regulations adopted under Section 8550, as follows:
(1) To any resident of this state to use gill nets, upon payment of a fee of two hundred sixty-five dollars ($265).
(2) To any nonresident to use gill nets, upon payment of a fee of one thousand dollars ($1,000).
(b) The commission shall not require a permit for a person to be a crewmember on a vessel taking herring pursuant to this article.
(Amended by Stats. 2000, Ch. 388, Sec. 17. Effective January 1, 2001.)

8552. (a) It is unlawful to take herring for roe on a vessel unless the operator holds a herring permit issued by the department pursuant to commission regulations. The permit may be transferred pursuant to Sections 8552.2 and 8552.6.
(b) No person may be issued more than one herring permit, and the department shall not issue a herring permit to more than one person except as provided in Section 8552.6.
(c) Herring permits shall only be issued to and shall be held only by a natural person.
(d) Herring permits shall not be used as any form of security for any purpose, including, but not limited to, financial or performance obligations.
(e) The permittee shall be on board the vessel at all times during herring fishing operations, subject only to exceptions provided for in this code and regulations adopted under this code.
(Amended by Stats. 1988, Ch. 1505, Sec. 3.)

8552.2. Notwithstanding Section 1052, a herring permit may be transferred from a herring permitholder to a nonpermitholder having a minimum of 20 or more herring fishery points, as follows: The permitholder shall mail, by certified or registered mail, to the department and every individual listed on the department's list of maximum 20 or more point herring fishery participants, his or her notice of intention to transfer his or her herring permit, which notice shall specify the gear type to be used under the herring permit; the name, address, and telephone number of the transferor and proposed transferee; and the amount of consideration, if any, sought by the transferor. Sixty days after mailing the notice, the transferor may transfer the permit to any person having 20 or more experience points without the necessity for giving further notice if the transfer occurs within six months of the date the original notice was given. Transfers after that six-month period shall require another 60-day notice of intention to be given. No person may hold more than one herring permit. A true copy of the notice of intention to transfer a permit shall be filed with the department by the transferor under penalty of perjury and shall be available for public review.

(Amended by Stats. 1989, Ch. 207, Sec. 4. Effective July 25, 1989.)

8552.3. The commission may, in consultation with representatives of the commercial herring roe fishery, and after holding at least one public hearing, adopt regulations intended to facilitate the transfer of herring permits, including, but not limited to, regulations that would do the following:
(a) Allow an individual to own a single permit for each of the different herring gill net platoons in San Francisco Bay.
(b) Eliminate the point system for qualifying for a herring permit.
(c) Allow a herring permit to be passed from a parent to child, or between spouses.
(Amended by Stats. 2016, Ch. 50, Sec. 42. (SB 1005) Effective January 1, 2017.)

8552.4. Herring permits that are revoked or not renewed may be offered by the department for a drawing to persons having 20 or more experience points in the fishery on the first Friday of August of each year.
(Amended by Stats. 1989, Ch. 207, Sec. 5. Effective July 25, 1989.)

8552.5. The commission shall revoke any herring permit if the holder of the herring permit was convicted of failing to report herring landings or underreported herring landings or failed to correctly file with the department the offer or the acceptance for a permit transferred pursuant to Section 8552.2.
(Added by Stats. 1988, Ch. 1505, Sec. 6.)

8552.6. (a) Notwithstanding Section 8552, a herring permit may be issued to two individuals if one of the following criteria is met:
(1) The individuals are married to each other and file with the department a certified copy of their certificate of marriage and a declaration under penalty of perjury, or a court order, stating that the permit is community property.
(2) The individuals meet both of the following requirements:
(A) They are both engaged in the herring roe fishery either by fishing aboard the vessel or by personally participating in the management, administration, and operation of the partnership's herring fishing business.
(B) There is a partnership constituting equal, 50 percent, ownership in a herring fishery operation, including a vessel or equipment, and that partnership is demonstrated by any two of the following:
(i) A copy of a federal partnership tax return.
(ii) A written partnership agreement.
(iii) Joint ownership of a fishing vessel used in the herring fishery as demonstrated on federal vessel license documents.
(b) For purposes of this section, a herring permit does not constitute a herring fishing operation. A herring permit may be transferred to one of the partners to be held thereafter in that partner's name only if that partner has not less than 10 points computed pursuant to paragraph (2) of subdivision (a) of Section 8552.8

and there has been a death or retirement of the other partner, a dissolution of partnership, or the partnership is dissolved by a dissolution of marriage or decree of legal separation. A transfer under this section shall be authorized only if proof that the partnership has existed for three or more consecutive years is furnished to the department or a certified copy of a certificate of marriage is on file with the department and the permit is community property as provided in subdivision (a). The transferor of a permit shall not, by reason of the transfer, become ineligible to participate further in the herring fishery or to purchase another permit.
(c) Notwithstanding subdivision (b), in the event of the death of one of the partners holding a herring permit pursuant to this section, where the partnership existed for longer than six months but less than three years and the surviving partner does not have the minimum points pursuant to subdivision (b) to qualify for a permit transfer, the permit may be transferred on an interim basis for a period of not more than 10 years to the surviving partner if an application is submitted to the department within one year of the deceased partner's death and the surviving partner participates in the fishery for the purpose of achieving the minimum number of points to be eligible for a permit transfer pursuant to Section 8552.2. The interim permit shall enable the surviving partner to participate in the herring fishery. At the end of the interim permit period, the surviving partner, upon application to the department, may be issued the permit if he or she has participated in the fishery and gained the minimum number of experience points for a permit.
(Amended by Stats. 2001, Ch. 753, Sec. 20. Effective January 1, 2002.)

8552.7. The department shall reissue a herring permit which has been transferred pursuant to Section 8552.2 or 8552.6 upon payment of a transfer fee by the transferee of the permit. Before April 1, 1997, the transfer fee is two thousand five hundred dollars ($2,500), and, on and after April 1, 1997, the transfer fee is five thousand dollars ($5,000). The fees shall be deposited in the Fish and Game Preservation Fund and shall be expended for research and management activities to maintain and enhance herring resources pursuant to subdivision (a) of Section 8052.
(Amended by Stats. 1994, Ch. 360, Sec. 1. Effective January 1, 1995.)

8552.8. (a) For purposes of this article, the experience points for a person engaged in the herring roe fishery shall be based on the number of years holding a commercial fishing license and the number of years having served as a crewmember in the herring roe fishery, and determined by the sum of both of the following:
(1) One point for each year in the previous 12 years (prior to the current license year) that the person has held a commercial fishing license issued pursuant to Section 7852, not to exceed a maximum of 10 points.

(2) Five points for one year of service as a paid crewmember in the herring roe fishery, as determined pursuant to Section 8559, three points for a second year of service as a paid crewmember, and two points for a third year as a paid crewmember, beginning with the 1978–79 herring fishing season, not to exceed a maximum of 10 points.
(b) The department shall maintain a list of all individuals possessing the maximum of 20 experience points and of all those persons holding two points or more, grouped in a list by number of points. The list shall be maintained annually and shall be available from the department to all pointholders and to all herring permittees. All pointholders are responsible for providing the department with their current address and for verifying points credited to them by the department.
(c) A herring permittee may use the department's list and rely upon that list in making offers for transfer of his or her permit until the date of the annual distribution of the new list. On and after the date of the annual revision of the list, the permittee shall use the new list.
(d) The point provisions in this section are for purposes of sale of a permit or transfer to a partner of a coowned permit.
(Amended by Stats. 2000, Ch. 388, Sec. 18. Effective January 1, 2001.)

8553. The commission may make and enforce such regulations as may be necessary or convenient for carrying out any power, authority, or jurisdiction conferred under this article.
(Added by Stats. 1973, Ch. 733.)

8554. The commission, in adopting regulations for the commercial herring fishery, shall provide for the temporary substitution of a permittee to take herring, if the permittee is ill or injured, by a crewmember aboard the vessel operated by the permittee. The commission may require that proof of the illness or injury be substantiated to the satisfaction of the department.
(Added by Stats. 1986, Ch. 725, Sec. 3.)

8556. Notwithstanding any other provision of law, the commission shall determine, by regulation, if drift or set gill nets may be used to take herring for commercial purposes. The commission may also determine, by regulation, the size of the meshes of the material used to make such gill nets.
(Added by Stats. 1976, Ch. 882.)

8557. Notwithstanding any other provision of law, the commission shall determine if round haul nets may be used to take herring in Districts 12 and 13 and the conditions under which those nets may be used.
(Amended by Stats. 1987, Ch. 269, Sec. 17.)

8558. (a) There is established a herring research and management account within the Fish and Game Preservation Fund. The funds in the account shall be expended for the purpose of supporting, in consultation with the herring industry pursuant to Section 8555, department evaluations of, and research on, herring populations in San Francisco Bay and those evaluations and research that may be required for Tomales Bay, Humboldt Bay, and Crescent City and assisting in enforcement of herring regulations. The evaluations and research shall be for the purpose of (1) determining the annual herring spawning biomass, (2) determining the condition of the herring resource, which may include its habitat, and (3) assisting the commission and the department in the adoption of regulations to ensure a sustainable herring roe fishery. An amount, not to exceed 15 percent of the total funds in the account, may be used for educational purposes regarding herring, herring habitat, and the herring roe fishery.
(b) The funds in the account shall consist of the funds deposited pursuant to Sections 8558.1, 8558.2, and 8558.3, and the funds derived from herring landing fees allocated pursuant to subdivision (a) of Section 8052.
(c) The department shall maintain internal accountability necessary to ensure that all restrictions on the expenditure of the funds in the account are met.
(Amended by Stats. 2017, Ch. 26, Sec. 32. (SB 92) Effective June 27, 2017.)

8558.1. (a) No person shall purchase or renew any permit to take herring for commercial purposes in San Francisco Bay without first obtaining from the department an annual herring stamp. The fee for the stamp shall be one hundred dollars ($100). The revenue from the fee for the herring stamps shall be deposited into the herring research and management account established pursuant to Section 8558.
(b) This section shall become operative on April 1, 1997.
(Added by Stats. 1996, Ch. 584, Sec. 2. Effective January 1, 1997.)

8558.2. The amount of the difference between fees for nonresidents and resident fees, collected pursuant to Section 8550.5, shall be deposited into the herring research and management account established pursuant to Section 8558, and all fees for San Francisco Bay herring permit transfers, collected pursuant to Section 8552.7, shall also be deposited into the herring research and management account.
(Added by Stats. 1996, Ch. 584, Sec. 3. Effective January 1, 1997.)

8558.3. One-half of all royalties collected by the department from the roe-on-kelp fishery collected pursuant to paragraph (2) of subdivision (f) of Section 164 of Title 14 of the California Code of Regulations shall be deposited into the herring research and management account established pursuant to Section 8558.
(Added by Stats. 1996, Ch. 584, Sec. 4. Effective January 1, 1997.)

8559. The commission, in determining experience requirements for new entrants into the herring fishery after January 1, 1987, shall require that any person seeking a permit to operate a vessel to take herring and claiming crew experience shall demonstrate, to the satisfaction of the department, proof of payment as a crewmember in the herring fishery based on tax records or copies of canceled checks offered and accepted as payment for service on a crew in the California herring roe fishery.
(Added by Stats. 1986, Ch. 725, Sec. 5.)

Chapter 10. Analysis of Management Action and Alternatives

Per CEQA, an environmental document need not consider every conceivable alternative to a project. Rather an environmental document must: consider a range of reasonable alternatives that meet most or all of the project's objectives; substantially avoid or lessen the proposed project's potentially significant negative effects; be feasible to implement based on specific economic, social, legal and/or technical considerations; and foster informed decision making and public participation. It is not required to consider alternatives which are infeasible. The discussion of alternatives in this document will focus primarily on different management actions that could be modified to either improve the economics of the fishery or reduce negative environmental effects of the project. All commercial harvest alternatives contain common elements with the proposed project with only selected elements of the management framework considered as alternatives. This document examines in detail only the alternatives that could feasibly attain most of the basic objectives of the project. The document provides information about each alternative to allow meaningful evaluation, analysis, and comparison with the proposed project and does not consider alternatives whose effect cannot be reasonably ascertained and whose implementation is remote and speculative.

10.1 Summary of Potential Environmental Impacts of the Proposed Project

Overall, the proposed project is not anticipated to have any significant impacts on the environment. Additionally, implementation of the proposed project is expected to benefit natural resources held in trust for the people of California when compared to existing conditions. This section is intended to summarize the analysis contained throughout this document, with a focus on the potential for significant impact.

10.1.1 Effects to the Herring Population

Overall, this FMP is not anticipated to cause any significant impact to the health of the herring population. There is no anticipated change to overall fishing effort. In fact, the season will be shortened a few days from the current regime, and overall fishing effort may decrease due to an anticipated reduction in fleet size. Additionally, the quotas are set at levels anticipated to ensure recovery of stock if needed, buffer against uncertainty in the future due to climate change scenarios, as well as support higher performance in terms of long-term stock health.

While the FMP does anticipate a scheme for allowing increased fishing in areas where fishing (at least in recent history) has not been occurring, for example Crescent City and Humboldt Bay, the management measures put in place by this FMP ensure that fishery will progress only at a level that is sustainable for the herring population. This includes conservative, precautionary initial quotas until monitoring data supports raising the fishing level.

This FMP does not authorize any changes to current gear types. In particular, net mesh size, which has the potential to impact the age of herring targeted by the fishery, will remain the same as currently used.

In sum, the proposed project will not cause any significant impacts on the herring population in California.

10.1.2 Effects on Predator Populations

Herring play a role in the CCE as a forage stock for mid- to upper-trophic level predators. However, this FMP is not anticipated to cause any significant impact on predator populations dependent on herring. The HCR is set to put limitations on herring fishing and minimize any impact on the forage base, even when herring stocks are low. Additionally, the quota cap may be beneficial to predators by allowing them to feed more on herring when Herring are abundant. Furthermore, the CCE is resilient to fluctuations in forage fish abundance because so many species make up the forage base available to predator populations.

In sum, the FMP is designed to ensure that fishing mortality does not negatively affect the stock's role as forage, and will not have any significant impacts on the predator populations in California.

10.1.3 Effects on Marine Habitats

Gill nets may be set in areas with submerged vegetation as well as a variety of invertebrate benthic fauna that may be susceptible to disturbance. Eelgrass is one example of submerged vegetation that could be impacted by Herring fishing activities. However, given the short fishing season as well as the proposed limits on the number of vessels in the fleet, the anticipated damage to benthic habitats is considered minimal. Much of the available eelgrass habitat area is closed to the commercial Herring fishery. While localized areas subject to intense fishing may be vulnerable to short-term effects, no data exists to quantify these impacts, and the limited depths associated with eelgrass beds also limits the fishing activity and potential impact from that activity. Regarding benthic fauna, soft-bottom benthic communities impacted by Herring fisheries are dynamic and anticipated to recover quickly from non-continuous disturbances.

In sum, the FMP is designed to ensure the Herring fishery does not negatively impact marine habitats and associated communities, and will not have any significant impacts on marine habitats.

10.1.4 Effects on Non-Target Sensitive Species

The nets set in the gillnet sector may have interaction with young salmonids in San Francisco Bay, including listed species of salmon and steelhead. However, the peak timing of smolt emigration typically occurs after the Herring fishing season is ended. Additionally, smolts tend to remain in main channels and move quickly through the Bay, and are unlikely to occur in the nearshore areas where gill nets are often set. Salmon smolts that do occur in San

Francisco Bay during the Herring fishing season are also too small to be vulnerable to Herring gill nets due to the allowable mesh size. As a result, the FMP is unlikely to have impacts to non-target sensitive species.

10.1.5 Growth Inducing Effects

The proposed FMP is not expected to result in potentially significant growth inducing affects. The proposed project could foster some very limited economic activity, but that incremental affect would not be of a magnitude that it would stimulate the establishment of new businesses, population growth, or the construction of additional housing. In addition, no project characteristics are likely to remove obstacles to population growth or encourage or facilitate other activities that could significantly affect the environment, either individually or cumulatively. Any increase in fishing activity is not expected to be significant relative to existing conditions in and around the Herring fishery.

10.1.6 Significant Irreversible Environmental Effects

CEQA Guidelines section 15126(f) requires that the proposed project identify potential impacts that could result in significant irreversible environmental changes, including the use of non-renewable resources and the irretrievable commitment of resources. An irreversible commitment of resources is one that cannot be reversed, except perhaps in the extreme long term (millions of years). The classic instance is when a species becomes extinct; this is an irreversible loss. Irretrievable commitments are those that are lost for a period of time. The proposed project would not result in significant irreversible environmental changes or irretrievable commitments of environmental resources. The project is designed to avoid significant adverse impacts to other species, their habitat, and listed or locally unique species.

10.1.7 Short-term Uses and Long-term Productivity

CEQA Guidelines section 15126(e) requires that the cumulative and long-term effects of the proposed project that could affect the state of the environment, could narrow the range of beneficial uses of the environment, or that could pose long-term risks to health or safety be addressed. The proposed project will not affect the variety of short-term uses currently available, nor are any significant impacts expected to occur. In addition, the proposed project will not adversely affect long-term productivity of statewide populations of the targeted species, as this FMP is designed to bring fish populations and fishery participants into a balance that promotes sustainability.

10.1.8 Cumulative Impacts

In this section, the proposed project is analyzed in relation to other major projects in the region. Cumulative effects on environmental resources can result from the incremental effects of the project when added to other past, present, and reasonably foreseeable future projects in the area. Cumulative effects can result from individually minor but collectively significant actions over a period of time.

Dredging and dredge materials are one of the primary threats to herring habitat in the Bay. However, the threat from these activities is minimized and avoided by work windows limiting dredging activities to times when biological resources are not present or least sensitive to disturbance. Additionally, projects not incompliance with the LTMS must consult with the appropriate resource agency for additional recommendations to avoid potential impacts.

Boating activities may reduce vegetation beds that are the preferred spawning habitat of Herring stocks in some locations. In particular, boats can shade and provide light-limiting conditions. Moorings can disturb eelgrass beds, causing barren patches in in eelgrass meadows. Additionally, boat propellers, anchors, and anchor chains can damage vegetation beds. Aquaculture activities may also have a negative impact on eelgrass density. However, aquaculture activities in California are regulated to minimize impacts to eelgrass habitat.

In sum, cumulative effects of the proposed project are not expected to be cumulatively considerable, that is, significant, when compared to the additional proposed projects described above.

10.2 No Project Alternative

The No Project Alternative is the existing regulations governing the Herring fishery at the time of the development of this FMP. These regulations include rules for the harvest of Herring for roe products, harvest of HEOK, and the harvest of Herring for fresh food, bait, and pet food. The No Project Alternative establishes fishing quotas by area and permit type, based on assessments of the spawning populations of Herring in San Francisco Bay. Set quotas for this alternative for Tomales Bay, Humboldt Bay, and Crescent City Harbor management areas are 350 tons, 60 tons, and 30 tons, respectively. Permits in San Francisco Bay in this project are limited and divided into platoons, which the permit holders fish on alternate weeks, which limits the number of vessels on the bay at any given time (Section 5.3.1). Finally, gill nets are the only authorized gear for the commercial fishery in the No Project Alternative.

Biomass surveys are performed during the spawning season in San Francisco Bay, and based on the data collected from these surveys, recommendations were sent to the Commission with quotas ranging from 0-10%. The Commission would set the final quota after considering environmental conditions, the Herring population’s age class structure, and other factors. While prior management policy for Herring had many desirable aspects, when to reduce quotas below a 10% target harvest rate was not defined, nor had harvest limit thresholds been established in regulation.

The No Project Alternative does not have a daily or possession recreational Herring bag limit, therefore the potential for a participant to take hundreds of pounds of fish per day exists. Additionally, the gear types allowed include any method that is legally defined within statute or the regulations, although the primary methods for targeting Herring by sport fisherman are cast net and hook and line. Finally, there are no seasonal restrictions for targeting Herring under the No Project Alternative. For more information on the recreational sector, see Sections 4.6, 4.7.6, 5.8, 6.2.2.5 and 7.8.7.

10.2.1 Environmental impacts of No Project Alternative compared to proposed project (Summary)

The No Project Alternative represents the baseline activity (existing regulations at the time of development of this FMP), and therefore is not anticipated to cause additional environmental impacts. The existing regulations were analyzed per CEQA when they were finalized in 1998. An environmental document was certified and each year in which the Department made recommendations for a fishery quota change a supplemental document was produced to analyze the changes to the quota and these changes had to be approved through amended regulations. The following is a summary of the environmental effects analyzed in those CEQA documents that are relevant to the proposed project. For more detailed information and links to the prior CEQA documents produced on the Herring fishery regulations, please go to the Department website (https://www.wildlife.ca.gov/Fishing/Commercial/Herring).

10.2.2 Biological Effects

Potential environmental impacts to biological resources exist in all geographical areas that support commercial Herring fisheries. This is because Herring populations can fluctuate widely and play an important role in many marine food webs. Additionally, and for the purposes of this analysis, all geographic areas will be treated the same, since Herring utilize similar habitats in each area and sensitive species are fairly comparable due to the biogeographical region in which the fisheries operate. The potential impacts may be divided into four categories: effects on the population, effects of predator populations, effects on marine habitat, and effects on sensitive species.

10.2.2.1 Effects to Herring Population

The primary effects the No Project Alternative has on the Herring population are attributed to fishing pressure and environmental influences. Herring stocks may become unstable under fishing pressure, which could lead to collapsing stocks. The threat from fishing pressure is greatest when fisheries are data limited and managers cannot act quickly enough in the absence of independent stock assessment techniques. Similar to the proposed project, the No Project Alternative addresses these potential stock effects by using a conservative management strategy and employing a variety of independent stock assessment techniques. Annual stock assessment (SSB estimate and determination of population parameters, such as age structure) is conducted in the principal fishing area of San Francisco Bay. If a stock collapse is detected, then fishery closures are implemented to protect the population.

Changing environmental conditions from year to year can pose challenging problems for fishery managers, as Herring stocks could decline or be overtaxed due to fishing pressure in combination with environmental influences, such as El Niño. However, the No Project Alternative uses the Commission's emergency regulatory authority to close a fishery or set provisional quotas to decrease fishing pressure during times of environmental stress. Strictly relying on Commission actions is a less effective conservation strategy than the proposed project, which uses ecological indicators and predictive modeling to adjust the quotas and more proactively manage the stock (Section 7.7.2)

The final effect on the Herring population from the No Project Alternative is fishing mortality from fish caught by lost gill nets and illegal take beyond established quota limits. This Alternative, as with the proposed project, addresses these concerns by providing intensive enforcement effort as a part of Herring management.

10.2.2.2 Effects on Predator Populations

Harvesting Herring not only affects the Herring populations, but potentially affects a number of other species within the ecological food web. These impacts include reduced availability of Herring eggs for predators such as birds, fishes, and marine invertebrates as well as a reduction in Herring consumed by fishes, birds, and marine mammals. The No Project Alternative reduces negative trophic level impacts of Herring as forage by setting conservative exploitation rates as discussed in Section 10.1.2.1. Unlike the proposed project, there is no cap on quotas in the No Project Alternative. However, both the No Project Alternative and the proposed project will have similar and less than significant effects on predator populations due to the conservation measures in place to avoid excessive harvest of the Herring population.

Additionally, Herring are not the sole forage species for any of the predators (principally birds, fish and marine mammals) that utilize Herring for food. For predators that feed on Herring, a reduction in the SSB may lead to increases in effort of predators seeking out alternative sources of food or changing predator movement and behavior patterns. These impacts will be short-term, however, and are expected to be less than significant at the population level. Even though they should be less than significant, these impacts will be slightly greater than the proposed project due to the increase in fishing effort due to the higher number of permits and potential maximum quota.

10.2.2.3 Effects on Marine Habitats

As with the proposed project, gill nets are the only method used by commercial fisherman. Impacts to marine habitats from the No Project Alternative are likely to be greater than the proposed project due to the higher number of potential vessels operating and the larger maximum quota. These potential effects include anchor and net benthic scouring, subtidal disturbance to vegetation such as eelgrass, impacts to benthic infauna, and increased siltation from fishing vessel propeller wash. Due to the limited fishing season, the dynamic nature and ability of soft bottom infauna communities to recover quickly from disturbance, and that most eelgrass beds are closed to the Herring fishery, like the proposed project, the impacts to marine habitats should be limited and will likely be less than significant under this Alternative.

10.2.2.4 Effects on Non-target Species including Sensitive Species

The No Project Alternative would have similar effects on fish and invertebrate communities when compared to the proposed project, due to the use of the same fishing method (i.e., gill net). A number of associated species are accidentally taken during commercial Herring fishing operations (Section 5.9.1). However, the potential exists for any fish or invertebrate in the area to be taken. The species most likely to be taken are relatively small in size and more vulnerable to the mesh size used in Herring gill nets. Because of the very low levels of catch of non-target species, no significant short-term or long-term ecological effects are expected as a result of this rate of take with the No Project Alternative.

10.3 Alternative A: Harvest Guidelines Adjustment

Alternative A would set the HCR structured to have a minimum biomass estimate cutoff at 25,000 tons versus the 15,000 ton cutoff in the proposed project's HCR. Under the Alternative A HCR, in years where the SSB was estimated to be below 25,000 tons, no fishing would occur and the quota for the coming season would be zero. Above 25,000 tons, the target harvest rate would ramp up from 5% to 10% until the SSB reaches 40,000 tons. After that point, the quota would be capped at 4,000 tons.

10.3.1 Environmental impacts of Alternative A compared to proposed project (Summary)

Due to the higher cutoff in the HCR, Alternative A would likely increase the probability that the fishery would be closed more frequently, allowing the population some refuge from fishing pressure. One of the key performance metrics used in modeling a range of cutoff values was the probability of being above a critical low biomass threshold (defined as 10% of unfished biomass, or B0) in the last ten years of a 50 year simulation. Each of the HCRs analyzed with a 15,000 ton cutoff, as provided in the proposed project, had a 96% probability of being above 10% B0 in the last ten years. Whereas, the HCR with a 25,000 ton cutoff had a slightly higher probability being at or above 80% of Bmsy (defined as the biomass that would result in maximum sustainable yield, a commonly used target biomass in fisheries management) than the proposed project's HCR (64% versus 60% in the last ten years of the simulation). Alternative A had the lowest average catch and the highest variability in catch due to the high number of years that the stock biomass was below the cutoff, resulting in fishery closures 38% of the time (the highest closure rate for any HCR analyzed). Therefore, setting a higher cutoff threshold would provide for a more conservative approach to managing the fishing and Alternative A would potentially affect the environment less than the proposed project due to reduction in effort and catch on any given year.

10.3.2 Biological Effects

10.3.2.1 Effects to Herring Population

An analysis of the HCR performance using MSE was conducted for the 25,000 ton cutoff and this resulted in only marginal improvements in the projected SSB in the long term. Reducing effort and catch, an expected outcome of Alternative A, would be slightly more beneficial to the Herring population when compared to the proposed project, although the differences would be negligible as both Alternative A and the proposed project are not expected to cause any significant impacts on the Herring population as both quota systems are set at levels anticipated to allow recovery of stock if needed and buffer against future uncertainty due to environmental changes. Alternative A is not expected to have a significant effect on the Herring population.

10.3.2.2 Effects on Predator Populations

Alternative A would likely have less effect on predator populations than the proposed project due to the difference in effort and catch that could occur when compared to the proposed project. However, as with the proposed project, Alternative A is designed to ensure that fishing mortality does not negatively affect the stock's role as forage and will not have any significant impacts on the predator populations in California.

10.3.2.3 Effects on Marine Habitats

Alternative A would likely have less effect on marine habitats due to the difference in effort and catch that could occur when compared to the proposed project. However, as with the proposed project, Alternative A is designed to ensure the Herring fishery does not negatively impact marine habitats and associated communities and will not have any significant impacts on marine habitats.

10.3.2.4 Effects on Non-Target and Sensitive Species

Alternative A would likely have less effect on non-target and sensitive species due to the difference in effort and catch that could occur when compared to the proposed project. However, as with the proposed project, Alternative A is designed to ensure the Herring fishery does not significantly affect non-target or sensitive species.

10.4 Alternative B: Round Haul Net Authorization and Permitting

Alternative B would allow an additional fishing method (gear) to be permitted for the commercial sector. The addition of round haul gear (purse seine and/or lampara) would be allowed as an option for fisherman that do not fish with gill nets. The permit program for round haul proposed under this project would be limited entry with a cap of five permits. The HCR would still dictate quota for the fishery, but the quota would be spit across the two sectors (gill net versus round haul) and based proportionately on the number of permits issued.

Round haul is a fishing gear that uses a large encircling net (Appendix G), which was eliminated in 1998 (Chapter 4). However, there have been informal requests in recent years from fisherman not participating in the gill net fleet to reinstitute round haul permits to facilitate fishing in San Francisco Bay for the fresh seafood market and for bait for sport anglers.

10.4.1 Environmental impacts compared to proposed project (summary)

Round haul, which consists of purse seine or lampara gear, was previously used in the fishery until 1994, when the Commission adopted regulations stating that all round haul permittees had five years to convert their permit to a gill net permit. At the time, the rationale behind this change was that round haul gear caught smaller, younger, lower value fish, and it was suspected that seiners increased mortality in the fishery by catching and releasing Herring during roe percentage testing. They are also more efficient than gill net gear and can take considerably more fish in a shorter time period. This can mean that Herring schools that spawn early in the season make up a disproportionate amount of the catch each year, and thus may contribute less spawning each year. Round haul gear is also less selective than gill nets and essentially wraps any fish that is encircled. However, catch from round haul nets also can be used as bait for sportfishing or sold in the fresh seafood market, neither of which require quality roe, or a specific sex or age class. This could provide an economic incentive to prevent waste that would exist if the fishery was operating only to harvest the roe. Depending on the time of the season the round haul nets operate, this Alternative, when compared to the proposed project, could have a greater negative effect on the environment, but possibly provide a better economic return to the few operators under the limited permitting system proposed.

10.4.2 Biological Effects

10.4.2.1 Effects to Herring Population

Alternative B would have similar effects on the Herring population as the proposed project in that the total catch via the HCR would not change, therefor leaving the conservative measures in place to allow recovery of stock, if needed, and also shield against uncertainty in environmental changes and influences, such as climate change. However, there are some differences between Alternative B and the proposed project that should be considered. Should round haul net operators choose to target fish for the roe market, then there could be an unquantifiable mortality of Herring due to the practice of wrapping and releasing of inferior-quality roe Herring by round haul vessels. This practice of "high grading" occurs when less desirable fish due to small size or low roe count is discarded to retain higher-value fish and stay within the catch allocation for the year. While this could be mitigated through regulations, past practices have shown that these types of regulations are difficult to enforce.

When compared to gill nets, round haul nets are also less selective, regardless of the which market the fish are sold to (roe, bait, or fresh). Removing younger fish (one and two year olds) from the population is far more likely with Alternative B than the proposed project, which primarily target older fish (three, four, and five year olds). Removing younger age classes from the population negatively effects recruitment which in turn could reduce future populations by decreasing the available spawning biomass on any given year. Given the wrap and release mortality concerns and the ability to capture more age classes, Alternative B would result in impacts to the Herring population that are greater than the proposed project.

10.4.2.2 Effects on Predator Populations

Should round haul nets negatively affect recruitment as described in Section 10.3.2.1, then Alternative B could have a greater impact on predator populations than the proposed project by reducing the amount of fish available for food or to spawn and reducing the number of other forage fish through bycatch. However, conservative quotas will limit the effects to both the Herring population and that of any bycatch species taken. Due to this, Alternative B may not negatively affect the stock's role as forage and will not have any significant effects on the predator populations in California.

10.4.2.3 Effects on Marine Habitats

Adding round haul nets as an additional method would likely not impact marine habitats, because round haul nets do not set anchors. There may be occasions when the lead line of the net drags along the bottom, which could lead to vegetation scouring and siltation as described in the proposed project (Section 10.1.2.3). Benthic infauna communities are not likely to be disturbed as lead lines, unlike anchors, are unlikely to dig deep into the benthos. Therefore, Alternative B would have less than significant effects on the marine habitat and cause slightly less impact than the proposed project.

10.4.2.4 Effects on Non-Target and Sensitive Species

Gear selectivity plays an important part in the amount of incidental catch that occurs in any given fishery. Round haul nets have the possibility of having more discarded catch from bycatch and low value age classes. Sensitive species such as salmon, Steelhead, Longfin Smelt, *Spirinchus thaleichthys*, and

Green Sturgeon, *Acipenser medirostris,* all have the potential to be captured by round haul nets. While fisherman would be prohibited from retaining these fish, there is uncertainty regarding post release mortality rates. When compared to the proposed project, due to the less selective nature of round haul nets, impacts to non-target and sensitive species are likely to be greater with Alternative B. However, due to the short season of the fishery (January through mid-March) and the low number of vessel permits proposed for this Alternative (five), the overall impact to non-target and sensitive species is likely to be less than significant.

10.5 Alternatives Considered but Not Carried Forward

10.5.1 A Recreational Bag Limit of 100 Pounds

In soliciting public comment on the proposed management strategy in the Herring FMP, many recreational participants responded that a 50 pound daily bag limit (one 5 gallon bucket) was sufficient to meet their needs, there were some recreational participants who felt that this amount of catch was too limiting because there are so few spawns during the year that are close enough to a public pier or beach where it is accessible to recreational participants. Some participants commented that they share Herring with family members and would like to see a higher bag limit of 100 pounds (two 5 gallon buckets) to facilitate this. While it is true that not all spawning events are accessible to recreational fishermen, those that are have experienced very intense fishing pressure, with reports of hundreds of fishermen on piers, jetties and in the intertidal zone, fishing with hook and line or cast nets, therefore the recreational fishing pressure on some spawning events may be significant. This alternative is not being analyzed as it is the Department's goal to protect the sustainability of the resource while maintaining a satisfying recreational experience and based on feedback this can likely be achieved with a bag limit of 50 pounds.

10.5.2 Alternative Fishing Methods

During the public scoping and public comment periods of the Herring FMP, the Herring FMP Project Management Consultant Team received a few requests to consider allowing the use of alternative gear types to take Herring. Round haul nets were evaluated as Alternative B above, although there were requests to consider other types of gear, including cast nets. Cast net gear have been discussed because stakeholders have expressed an interest in facilitating a fresh fish fishery for a local market and feel these gears would allow for smaller catches of higher quality fish necessary to fulfill fresh fish market orders, which could evolve into a lucrative market for Herring. However, since this gear has not been used in the commercial fishery previously, leading to a lack of data to analyze, the best venue for considering and evaluating these gears would be through an Experimental Fishing Permit (FGC §1022). Future consideration of these gears could occur within this FMP after an Experimental Fishing Permit for each gear type has been issued and subsequent reports have been filed with the Department.

10.6 Summary of Alternatives Analyzed

Proposed alternatives for management of the Herring fishery have been analyzed in this chapter. A comparison of these alternatives and their effects on the objectives of the Herring FMP enables identification of which alternatives would best meet management needs.

Although each of the alternatives has some benefits for management, only Alternative B addresses most of the objectives of the Herring FMP and MLMA (Table 10-1). Alternative B could provide more economic benefit but would also introduce more risk to the environment and could potentially create competition and develop conflict between the two permitting sectors (gill net versus round haul). The No Project Alternative would also not achieve all the goals outlined in the FMP and the lessons learned from the existing regulations constituting this Alternative were the impetus for the proposed project.

Table 10-1. Alternative analysis matrix.				
Goals Met (y/n)	**Proposed Project (Preferred)**	**No Project Alternative**	**Alternative A**	**Alternative B**
Includes species and fishery related background information	Yes	Yes	Yes	Yes
Includes industry and public's perspective	Yes	Yes	Yes	Yes
Identifies relevant ecosystem indicators	Yes	No	Yes	Yes
Provides adaptive management framework	Yes	No	Yes	Yes
Contains criteria to limit overfishing	Yes	No	Yes	Yes
Creates an efficient permitting system	Yes	No	Yes	Maybe
Uses collaborative fisheries for research	Yes	Yes	Yes	Yes
Minimizes risk to habitats from fishing	Yes	Yes	Yes	Yes
Minimizes bycatch to extent practical	Yes	Yes	Yes	No
Promote a healthy long-term average biomass	Yes	Yes	Yes	No
Minimize the number of years stocks are in a depressed state	Yes	Yes	Yes	No
Maintain a healthy age structure	Yes	Yes	Yes	No
Maintain an economically viable fishery	Yes	Yes	No	Yes
Ensure Herring remain an important component of the ecosystem	Yes	Yes	Yes	Yes

10.7 Environmentally Superior Alternative

CEQA requires a lead agency to identify the "environmentally superior alternative". The environmentally superior alternative would be Alternative A, due to the higher cap set for the HCR which would potentially reduce the overall effort and catch of the fishery due to a higher frequency of seasonal closures from not achieving the 25,000 ton SSB threshold to open the fishery. The lack of a fishery from year to year could have positive effects on the Herring populations and predator interactions. This could also ameliorate any impacts to marine habitats by providing larger recovery times in between seasonal closures. However, Alternative A does not meet the objectives of producing a year-to-year stable fishery and the relatively modest gains in terms of meeting the biomass target and avoiding the biomass limit were deemed by the SC to be not worth an average catch that was 30% lower, a higher variability in year to year catch, and a fishery closure rate that was almost double that of the agreed upon HCR. Due to this, the proposed project is still the preferred project as it meets all the core program objectives while also not significantly effecting the environment.

10.8 Mitigation Measures

Fishing activities will result in the removal of a small proportion of Herring from the population. However, specific safeguards included in this Herring FMP such as management based on a conservative harvest control rule, designed to ensure that removal of those fish will not exceed sustainable levels, reduction in the number of permitted vessels, an adaptive management framework, the use of ecological indicators to buffer against environmental uncertainty, while including industry and public support which should lead to greater compliance with regulations. These provisions allow for the conservation of Herring in California waters. Since no significant negative effect of this proposed project is expected on the Herring population, and no significant effects on the environment overall, mitigation measures are not being provided.

Appendix A Sources and Estimated Rates of Natural Mortality for Pacific Herring

Review of Natural Mortality in Pacific Herring at Each Life Stage

Sources and annual rates of natural mortality for Pacific Herring (Herring), *Clupea pallasii*. differ at various life stages, with mortality typically being greatest during the first year of life. Egg mortality is high, with estimates ranging from 55 to 76 percent (%) (Norcross and Brown, 2001; Rooper and others, 1999) up to 100% (Tester, 1942). Possible causes of egg mortality include wave action, predation, smothering by dense egg deposits, hypoxia, desiccation, air-water temperature differentials, and microorganism invasions (Alderdice and Hourston, 1985; Carls and others, 2008a; Hay, 1985; Norcross and Brown, 2001). Survival of eggs is highly variable from year to year, and thus a large spawning event does not necessarily correlate with a strong year class (Watters and others, 2004).

Mortality of larvae soon after hatching (posthatch) can be caused by starvation due to physiological abnormalities such as underdeveloped jaws, resulting from exposure to unusually warm air temperatures (Norcross and Brown, 2001; Purcell and Grover, 1990). Posthatch mortality appears to vary geographically and interannually, and ranges from 0 to 50% (Norcross and Brown, 2001). Model results indicate that larval mortality increases between 93 and 99% during the dispersal period when larvae are transported from spawning sites to (either favorable or unfavorable) nursery areas (Norcross and Brown, 2001). Between 18 and 36% of larvae may starve during this time (McGurk, 1984). The other major cause of larval mortality is predation by a wide range of organisms (Norcross and Brown, 2001; Purcell and Grover, 1990). As larvae must find suitable, exogenous food during this period, larval survival is likely the major determinant of year class strength (Carls and others, 2008a; Norcross and others, 2001).

Rates and sources of mortality for juvenile Herring depend on the time of year. Estimated mortality of juveniles in Prince William Sound, Alaska, ranges from 79 to 98% from August to October and 1 to 96% during the winter (Norcross and Brown, 2001). From August to October, juvenile Herring survival depends mainly on food availability, competition, predation, and disease (Norcross and Brown, 2001). Juveniles may begin to school during this time to minimize the risks associated with the food availability, competition and predation (Carls and others, 2008b). During the winter season, survival of 1 year (yr) old Herring depends on the conditions in the areas where these fish overwinter (Norcross (Carls and others, 2008b; Norcross and Brown, 2001).

Typical mortality rates for adult Herring worldwide are between 30 and 40% (Stick and others, 2014), though higher (and increasing) mortality rates have been documented in some Herring stocks. For instance, estimates of annual mortality rates for Herring stocks in Washington have increased from less than 40% in the late 1970s to over 60% in the early 1990s (Bargmann, 1998; Gustafson and others, 2006). Natural mortality of adult Herring may be due to predation, disease, starvation, interspecific competition, or senescence, and observed increases in mortality could also be caused by pollution or climatic shifts (Carls and others, 2008a; Stick and others, 2014).

Estimated Survivorship to Maturity

Using the above reported minimum average observed mortality rates for Herring at each life stage (egg, post hatch, larval, juvenile, and 1 yr old Herring) in areas north of California, the percentage of eggs surviving to maturity (at age two or three) is very small (<0.004%) with fewer than four eggs out of every thousand laid reaching maturity. In San Francisco Bay, for the 2003-04 to 2014-15 year classes, survival from egg to mature Herring (3 yr) ranged from a low of 0.0001% to a high of 0.0781% and averaged 0.0125% (Greiner, in preparation) (Figure 1). Survival to maturity in all Herring stocks is highly variable and while the average egg laid in a given year may have a very low probability of survival, a single spawning event may contribute disproportionately to the surviving year class because of favorable environmental conditions at the time and location of spawning.

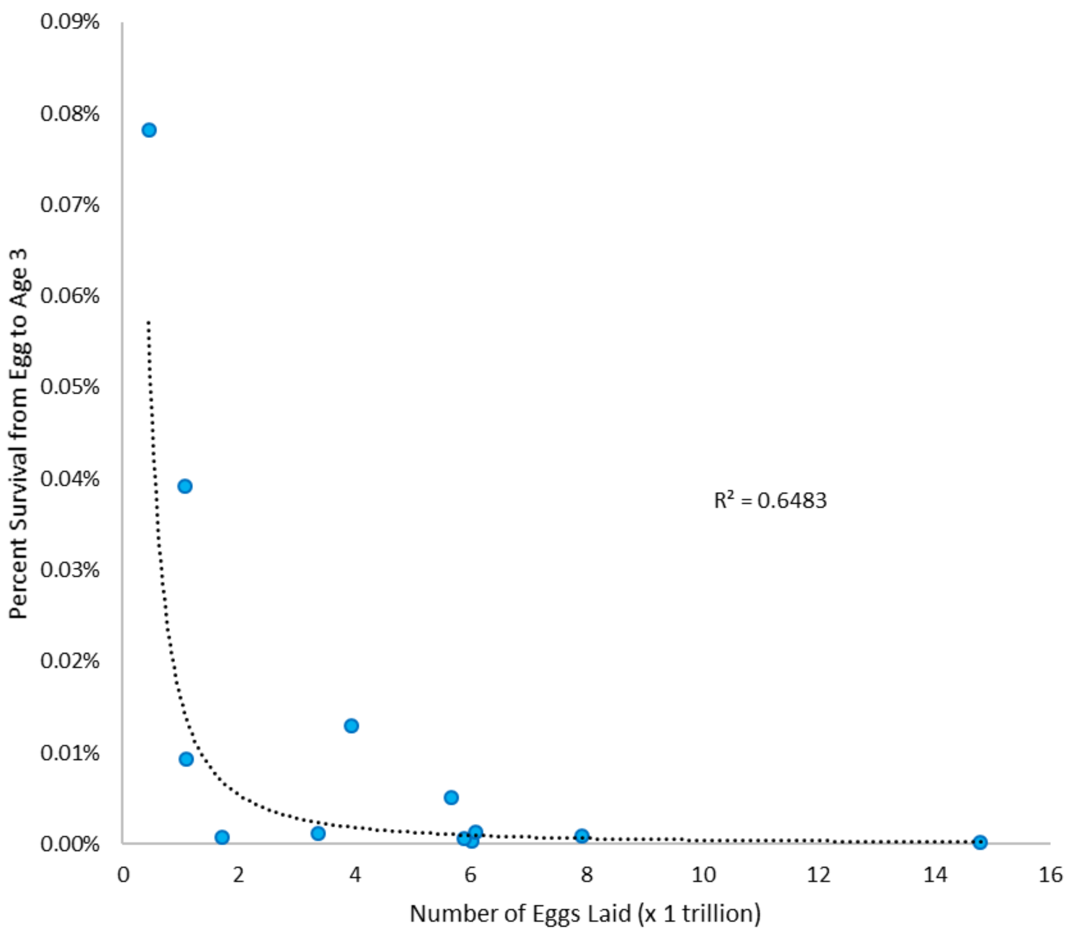

Figure 1. Number of eggs laid (times one trillion) in San Francisco Bay from 2003-04 through 2014-15 and the percent survival of that cohort to age-3. Calculations used for number of eggs spawned and survival from egg to age-3. The number of eggs spawned each season was calculated by multiplying the spawning escapement (short tons) by 102,511,876, which is the number of eggs per short ton of fish (50:50 sex ratio by weight assumed and fecundity of 113 eggs per gram of male and female fish which was multiplied by 907,184.74 grams per short ton). The numbers of age-3 fish in the cohort were taken from the tonnage and number at age spreadsheets produced annually. The number of eggs spawned was divided by to the number of age-3 fish three years later to calculate survival.

Appendix B Cefas Stock Assessment Model Report and Peer Review Response

California Department of Fish and Wildlife Response to Stock Assessment Peer Review for the Pacific Herring Population in San Francisco Bay September 2017

In 2011, with funding provided by the San Francisco Bay Herring Research Association, the Department of Fish and Wildlife (Department) contracted with scientists at the Center for Environment, Fisheries, and Aquatic Science (Cefas) to develop a stock assessment model for the Pacific herring (*Clupea pallasii*) population in San Francisco Bay. The purpose of this work was to develop and fit a population to all available data in order to estimate the status of the San Francisco Bay herring stock. This stock assessment would then form the basis for an operating model that could be used to evaluate the expected impacts of various management decisions going forward as part of a Management Strategy Evaluation (MSE) framework. It was anticipated that this analysis would be used in developing a Harvest Control Rule (HCR) as part of an adaptive management approach during development of a Fishery Management Plan (FMP) for the Pacific herring fishery.

Following the stock assessment peer review, the reviewers concluded that they could not recommend its use as a method for estimating biomass and setting quotas for the commercial herring fishery. This was primarily because the model that best fits the available data (the preferred model) does not reflect current understanding of herring stock dynamics. The modeling exercise and review highlighted the level of uncertainty about the dynamics of the San Francisco Bay stock and the inability to base management decisions on any single model. The reviewers emphasized the following areas of concern with the Cefas model and associated data:

- Inability to establish a defensible stock recruitment relationship
- Lack of empirical support for various mortality factors used
- Unresolved issues related to gear selectivity at age
- Over-weighting of age composition data inputs relative to young-of-year-based recruitment and spawn deposition-based spawning stock biomass indices

The reviewers also recommended that the model not be used as the base model for the MSE analysis, but as one of a number of uncertainty scenarios. The Department accepts the recommendations of the review panel and agrees that the deficiencies in the Cefas model, identified above, could lead to the overexploitation of the herring stock if adopted as a management tool. Instead, the Department is following the review panel's recommendation and using Cefas's preferred model (Model 6) as one of a range of operating models representing alternative hypotheses of how the stock functions as part of an MSE.

The results of Cefas model development and review, as well as the discussions between Department biologists, the review panel and Cefas scientists, have provided valuable insight into San Francisco Bay population dynamics. They have also helped identify which areas still represent major uncertainties, which will ultimately inform the MSE work for testing Harvest Control Rules (HCR). In the interim, based on the peer review recommendation, the Department will continue to use spawn deposition surveys to set quotas, and will be exploring candidate HCRs based on this method using MSE. These steps will help to ensure that the harvest strategy chosen through the FMP process will be robust to uncertainties and continue to provide a sustainable Pacific herring fishery in San Francisco Bay.

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Review of the Stock Assessment for the Pacific Herring Fishery in San Francisco Bay

October 10th and 11th, 2016

Peer Review Panel Members:

Harold J. Geiger (chair)
St. Hubert Research Group
Juneau, Alaska

Jake Schweigert and Nathan Taylor
Fisheries and Oceans Canada
Pacific Biological Station
Nanaimo, B.C.

Background

On October 10th and 11th, the California Department of Fish and Wildlife organized a peer review of the recently completed stock assessment of San Francisco Bay Pacific herring. A peer review panel consisting of Jake Schweigert and Nathan Taylor of Fisheries and Oceans Canada in Nanaimo, B.C., and Hal Geiger of the St. Hubert Research Group in Juneau, Alaska traveled to Santa Rosa California to meet with modeler Jose De Oliverira from Cefas in the United Kingdom. Also participating were Kirsten Ramey, Ryan Bartling, Tom Barnes, Tom Greiner, and Andrew Weltz of the California Department of Fish and Wildlife, and Sarah Valencia, a consultant hired to develop the management plan for the fishery. The review panel, chaired by Hal Geiger, was given the following objectives: (1) review and discuss the stock assessment and operating models for San Francisco Bay Pacific herring, (2) provide recommendations to the stock assessment modeler for any changes to the assessment, (3) determine whether the final product is appropriate and sufficient for use in management of the Pacific herring fishery in San Francisco Bay via incorporation into the Fishery Management Plan, and (4) provide a written panel report to the Department of Fish and Wildlife.

Prior to the meeting in Santa Rosa, the review panel received a written report (San Francisco Bay Herring: Stock Assessment and evaluation of Harvest Control Rules, by Roel et al., March 2016 version), which formed the basis for most of the review. The panel evaluated the technical merits of the approach, but in the broader context of the management strategy evaluation approach (Punt et al. 2014) described in the Roel et al. report, the panel considered whether any new approach would result in improved fishery outcomes. The panel endorses, in principle, the management strategy evaluation approach for analyzing the effect of alternative management strategy choices. As an analytical instrument, the management strategy evaluation provides a process for evaluating and presenting trade-offs between alternative management strategies (i.e. the choices of data, assessment model, and harvest control rule).

Comments Related to the Data Used for the Analysis

At the review meeting, the panel was surprised that the modeling appeared to have been conducted with an incomplete and undocumented data set. The panel recommends that prior to further modeling of the San Francisco Bay Herring population, all data required for model development should be fully reviewed, and that the final data set include all necessary measurements and metrics. If there are any instances where specific years or components of a data series are excluded, then this should be fully explained in a revised report. A process should also be set up to ensure that only a single quality-assured, complete data set is adopted for modeling at a given time. This data set should be maintained for subsequent analyses, and updates or revisions should be tracked by a version-control or report number.

The decision to restrict the analysis of the San Francisco Bay herring population to the years 1992 to 2013 requires further comment and justification in view of the existence of additional earlier data. The data series that was analyzed reflects a period of reduced harvest levels. The reduced harvest provides limited contrast in the data, which constrains the ability to estimate some model parameters. Moreover, by not using a longer time series of data the model relies on assumptions of the depletion level at the beginning of the modeling period.

A description of the process used to acquire age-composition data and its application to the derivation of catch at age for the commercial and research surveys is needed in a revised report. A reviewer attempting to understand the unique problems and issues with the input data, such as the sample sizes, measurement error, non-sampling error, or similar issues, can only find statements as brief as this one from page 3: "Input data for the assessment were provided by Tomas Greiner, California Department of fish (sic) and Wildlife," or "A recruitment index was derived from the Young of the Year surveys."

The panel noted the mention of a herring eggs on kelp (HEOK) fishery in the overview on the San Francisco Bay Pacific herring spawning stock and commercial fishery management. However, no information on the landings from the fishery or information on its relative significance was provided in the Roel et al. report. This should be addressed in a revised report. It was not possible for the panel to assess the impact of this herring removal on the stock assessment.

Comments Related to the Age-Structured Model

The panel agreed that the description of the assessment model in the Roel et al. report was inadequate to allow for complete and thorough review. Additionally, as an aid to review, the panel recommends that a revised report include appendices detailing all parameter estimates for each model run and that additional model runs be included to demonstrate the robustness of the results to varying assumptions and model building decisions.

The panel found the decision to adopt the hockey-stick stock-recruit function equivocal and not well supported by data. Moreover, the implications of this choice were not clearly communicated to the reader. The available data are insufficient to demonstrate the relationship between stock size and subsequent recruitment, especially for small stock sizes. The choice of the hockey-stick model results in predictions of unrealistic resilience in the population dynamics, especially at high levels of fishing mortality.

The formulations chosen for gear selectivity were confusing and do not adequately reflect what is known about herring biology. The selectivity ogives for the commercial fishery indicated a broad range for round-haul nets and a domed pattern for gillnets (Figure 4 in the Roel et al. report), the latter peaking at about 185 mm corresponding to age-4 herring, a pattern that is consistent with the selectivity of the research trawls shown in Figure 11. However, the selectivity function in the model adopts full selection by the fishery (gillnets since 1998–1999) at age 5 and 6+. The panel agreed that further explanation of these decisions is required.

The final operating model[1] developed for the evaluation of harvest control rules implements a sequential approach to the inclusion of flat topped commercial selectivity, a 2007 natural mortality event associated with the oil spill, a fixed natural mortality and mortality multiplier to age 6 and older herring (Table 4 in the Roel et al. report). However, the explanation for the

[1] The term *operating model* is used here to mean an overall model to simulate various management outcomes based on models of the stock dynamics, the management, and the data acquisition.

choice of this version of the model is unconvincing and the mortality multiplier for age 6+ seems ad hoc and arbitrary. It would be helpful to repeat the runs described in Table 4 of the Roel et al. report for all cases with natural mortality fixed at 0.53 as in the final run. The analysts might also consider testing a linear function for mortality from age 3 when fish are fully mature to age 6+. Such an approach could be more readily justified on a biological basis.

Decisions about model selection in this report rely heavily on the total likelihood, the largest component of which relates to the fit of the age-composition data. Table A1.3 in the Roel et al. report presents the catch at age for the commercial fishery and Table A1.5 presents the catch at age for the research survey. The research catch-at-age data presented in this version of the report is an order of magnitude larger than the commercial catch at age. This seems implausible. These data also do not reflect the exceptional 2002 or 2003 year classes that produced the large 2005 spawning stock biomass. As we discuss above, the panel again recommends that these data be carefully reviewed and fully documented before conducting further modeling.

The panel also noted that Figure 7 of the Roel et al. report shows an inability of the model to adequately explain the spawning stock biomass index from 2009 to 2013. This result requires further analysis and comment in a revised report. Similarly, no explanation is provided for the positive trend in recruitment residuals (Figure 9 of the Roel et al. report). Some of these residual patterns are symptomatic of poor goodness of fit to the data and the reasons underlying this pattern need to explored and preferably rectified.

Provided that a defensible operating model can be developed, the panel identified several deficiencies in the way the model described in the Roel et al. report simulated herring population dynamics. In particular, the analysis must include more challenging scenarios with which to test the alternative management procedures. In the Roel et al. report, the scenarios involved routine sampling from well-behaved probability distributions that were expected to reproduce historical conditions over a short time scale. Dynamic species like herring have both variable recruitment and variable natural mortality (as environmental conditions change). More challenging scenarios should include periodic el Nino, infrequent catastrophic events, climate change, induced changes in recruitment, or changes in natural mortality, for example. In addition, the analysis would benefit greatly by imbedding the assessment model into future simulations in order to capture assessment model estimation errors that can be very large (Punt et al. 2014). Failing to consider such factors results in an under-estimation of the uncertainty in the range of future outcomes for the stock and the fishery under a given management strategy. That would mean quantities like the probability of breaching a limit reference point could be much higher in reality than what would have been demonstrated in the simulations.

The panel agreed that a broader range of performance statistics is needed to increase the relevance of the work for decision making. Some of these statistics could be quantities such as the probability of being at a target biomass for the stock, the probability of fisheries closures, and the average annual variability in the catch. Moreover, the presentation would benefit from having the performance statistics partitioned into more time frames. The time horizon for achieving particular objectives or avoiding limits may be particularly important. For example, the application of any particular management strategy may have consequences that are undesirable in the short term (5–10 years) even if in the longer term (over 20 years) performance is good. Performance statistics used in other management strategy evaluations might be useful for application in future analyses (see Taylor et al. 2014, Schweigert et al. 2007, for examples).

Suggested Revisions to a Final Report

The version of the report the panel received appeared incomplete, contained insufficient material and detail for a full and complete review, and the document contained obvious errors that left the panel wondering about errors that were not as obvious. The panel suggests that the main document be rewritten in the standard Introduction-Methods-Results-Discussion format of a scientific report. Each section should be written in sufficient detail to allow a reader not already fully familiar with the subject to understand and be able to critique the analysis.

The Introduction should introduce the reader to the history of the fishery, the history of the management process, and explain how the results of the current analysis and modeling would provide a basis for altering existing management approaches. Importantly, the Introduction should specifically lay out the goals and intent for management and for the study. This context is essential for understanding the decisions about the parameterization of the assessment model and also for understanding the relevance of the management strategy evaluation analysis.

The Methods should contain a complete review of the all data sources (see the section on Comments Related to the Data Used for the Analysis, above). As previously mentioned, this review should allow the reader to understand how far back in time the data series goes, understand the sampling design for the survey index, understand the protocols for the ageing data, understand the sampling design for the commercial age-composition data, understand what data exist from prior to 1992 and why these data were not used, and so forth. Additionally, the Methods should fully introduce the models. The revised report should contain descriptions relating to the choice of the stock-recruitment function, gear selectivity, natural mortality, and the maturity ogive. The Methods should cite authorities, describe where the models came from, and include a narrative that introduces notation and describes the parameters to readers not familiar with the models. This section should tell the readers how the state dynamics are updated at each time step, how the subsequent model fitting procedure occurs (including choice of likelihood function formulation), and so on. In summary, this section should contain sufficient detail for a reader to be able to reproduce the analysis after reference to materials in any appendices.

In the Roel et al. report, the material relating to the methods appears to have been written for someone already fully familiar with the model. In other words, this material appears to have been written for someone that only needs brief reminders of model notation rather than a presentation introducing the material for the first time. A section of the document found under the heading of "Assessment Model" contains a few facts about the model, but no explanation of model development or any of the theory underpinning the model. The reader is incorrectly referred to Appendix 1 of the Roel et al. report for a "generic description of the model."

Appendix 1 contains tables of input data; Appendix 2 does contain over five pages of lists of equations—not a "generic description of the model." The equations in Appendix 2 were introduced without explanation, and equations in Appendix 2 appear before the notation is introduced to the reader.

When the reader does discover Appendix 3 in the report, the reader finds only brief reminders of the meaning of the notation. For example, the notation *F* is commonly used in age-structured models in North America to mean the instantaneous fishing mortality. In Appendix 3, $F_{y,a}$ is defined as fishing mortality at age a in year y. This brief comment fails to clearly tell the reader that *F* is being used to denote a kind of harvest rate. The reader is left to see by inspection of equation A2.1 that if *F* indicates instantaneous mortality then this equation does not make sense. Similarly, C_y^f is described as "Catch of fleet *f* in year *y*." To fully understand the meaning of this notation in equation A2.3 the reader will need to correctly guess that *C* is in units of weight or mass or else carefully inspect the units of the other quantities in equations that contain *C* so as to infer the appropriate units. In North America *C* is often used to denote catch in units of individual fish. Some of the equations may contain errors, but the panel was unable to decode the notation, infer the meaning of the equations, and check the equations in Appendix 2 carefully in the time available. Some narrative walking the reader through the equations should be considered essential in a revised report.

The Results section should lead the reader through the results in a logical manner so that the reader will be able to understand and digest the material in the figures and tables. In most cases, the tables and figures in the version of the report that the panel was given were insufficient for their intended purpose. Most graphics were too small and many had unlabeled axes. Table captions did not describe the table contents adequately. Graphics and tables were usually introduced without any kind of interpretation or context (e.g., "Model fits to the SSB and recruitment indices are shown in Figure 7."). Figure 6 in the Roel et al. report is described in the figure caption as a "Likelihood profile," yet the preferred estimate is shown at some kind of minimum—not the maximum. In this case there is an axis label, but that axis is described with the nonspecific term "Function value." The reader is left to decide whether the figure caption is wrong and "Function value" means the negative log likelihood rather than likelihood, decide whether this is simply the entirely incorrect figure that was included by mistake, or whether something else happened. All of the figures should be reviewed and brought up to the standards that are usually required for a scientific publication. In contrast, note that Figure 12 in the report provides a good example of a helpful graphic. Here the axis labels and the figure caption complement each other. The figure works to allow the reader to understand a complex point about the model fitting that is important to understand the limits of the model's ability to predict.

The panel was surprised to find that the report they reviewed contained essentially no discussion of the important implications for the use of the estimated model in fishery management. This important section of the report should be a place where the model results are placed in context for the reader, a place for synthesis and integration of new information with historical information, and a place where uncertainty and limitations are carefully explained to the reader. A carefully constructed Discussion in the report is the place to try and communicate these limitations to the fishery management, the fishing industry, and other concerned organizations and individuals.

Much more importantly, there is no discussion of the important conflict between predicted yield based on the proposed model and the actual fishery performance in the past. The panel noted that the proposed model predicts that yield will increase as the harvest rate increases from 0.0 all the way to 1.0 (Table 6 and Figure 15 in the Roel et al. report). This result is both surprising and counter-intuitive. Additionally, this result also serves to demonstrate how new models can create a potential liability for management's credibility if the management has not carefully validated the model.

In contrast to the prediction that very high harvest rates are sustainable, the panel that conducted the 2003 review of San Francisco Bay herring (see Appendix A attached to this review) concluded that harvest rates at that time had been too high and were not sustainable. The 2003 panel specifically stated the following: "The current harvest strategy for this stock should be re-evaluated and explicitly documented. The current harvest rate policy of 20% appears to be too aggressive under current levels of stock production. A harvest rate in the range of 10–15% appears to be sustainable with the lower level providing a desirable target for stock rebuilding." The Roel at al. model's prediction that a 100% harvest of the available population in the future would be sustainable and the observation that a 20% harvest in the past had been considered excessive obviously needs to be brought out in a Discussion and reconciled.

There were 10 paragraphs in the Conclusions. Some of these conclusions appeared to be correct but not supported by evidence found in the report (e.g., see the first paragraph in the Conclusions). The panel also questioned whether other statements were correct or not. Either way, the team agreed this section should be revised, expanded, or combined with a new Discussion section.

Final Comments and Recommendations

Before a management agency adopts a complex model into its management strategy, the agency should have a clear understanding of how the model is going to be used. The agency should also have given adequate thought to the consequences of assumptions and choices in model development that might simply be wrong. These considerations should affect any future review.

An age-structured model could be used either to study the effects of various management actions or strategies (i.e., the management strategy evaluation), or the model could be used for short-term decision making, such as setting a total allowable catch. These two uses are not the same. For example, a model of herring dynamics might be quite useful and safe as a way to combine fishery-derived information with fishery-independent information so as to smooth out random fluctuations in a spawn deposition survey to set harvest rates when fishing mortality is low. Yet, this same model may completely fail to predict the stock dynamics at very high fishing mortality—especially when the model is used to predict what will happen far outside the range of the data that was used to construct the model.

Roel et al. cite "Punt et al. (*in press*)" (this should now be cited at Punt et al. (2014), which is how we have cited it) as a key reference on the management strategy evaluation (MSE) approach. Punt et al. stress, "The ability of MSE to facilitate fisheries management achieving its aims depends on how well uncertainty is represented, and how effectively the results of simulations are summarized and presented to the decision-makers." In other words, it is not good enough to simply have an operating model, assessment model, and a set of closed loop simulations. A complete management strategy evaluation involves a careful study of uncertainty—including a careful analysis of "what if we are wrong." At a minimum the assessment must address this question: what if the population dynamics in nature are different from those assumed in the assessment? There are many layers of uncertainty involved in modeling herring dynamics, including uncertainty as a result of a random and possibly changing environment, uncertainty due to estimation and sampling error, uncertainty that could be the result of incorrect assumption or modeling decisions. Prior to further review, the analysis needs a much more sophisticated study of uncertainty. The panel agrees that the cited Punt et al. article could be used as a guide.

The panel recommends that the California Department of Fish and Wildlife at least consider some simpler, more cost effective management tools. Age-structured assessment models can be demanding in terms of both data and in the capacity to use these tools. The capacities to run, update, and explain such models within the agency may be limited, expensive, and may divert resources way from more important needs. In some cases adopting the age-structured modeling approach for annual decision-making may even erode fishery outcomes if the effects of the models are not well understood or if the models poorly predict the dynamics of the population. Many alternative assessment models or management based on smoothed survey estimates could be less costly and potentially more effective. For example, Kalman filtering (Walters 2004) has been evaluated in other herring fisheries (Cleary et al. 2010). Even with these simpler tools in place to set catch limits, management strategy evaluation simulations could be used to illustrate how these alternative models perform in terms of catch, variability and conservation metrics with similar or different harvest control rules. It may be possible to show with a more complete accounting of uncertainty that a harvest control rule based on the annual survey could have a similar, or even better, performance without the cost and complexity of adopting an annual age-structured modeling calculation and evaluation.

In anticipation of future modeling in support of management strategy evaluation, the panel recommends that California Department of Fisheries and Wildlife engage with stakeholders to develop objectives and performance indicators for the management of the fishery. The single factor of breaching the precautionary limit biomass, or the putative limit reference point, with greater than 5% probability, examined in the Roel et al. report, is unlikely to universally satisfy the larger community. For example, the panel heard during the review that some individuals and organizations might be concerned about addressing the broader ecosystem consequences of the fishery on a forage fish like herring. In this case, the metrics identified in some of the forage fish literature (Essington et al. 2015, Smith et al. 2011) may be very important.

Additionally, management strategy evaluations (Hall et al. 1988 for a herring-specific example) have documented that the objectives typically trade off against each other. For example, high average catches occur at the expense of high variability in catch. By failing to consider a broader set of objectives it is not possible to understand the broader set of consequences of applying a given management strategy on the industry, the stock, or the ecosystem.

Given the concerns about aspects of the development of the operating model based on the relatively short time series and outstanding questions about the data and the ability of such a model to reasonably predict the future productivity and resilience of the San Francisco Bay herring population given climate warming and unpredictable catastrophic events, the panel cannot endorse the model described in the Roel et al. report for the development of harvest control rules and reference points at this time.

As a concluding recommendation, the panel again recommends that the California Department of Fish and Wildlife adopt a stronger policy of documentation. Details of each year's surveys and monitoring should be recorded and archived at least in timely internal reports.

Finally, the panel strongly commends the professionalism of the California Department of Fisheries and Wildlife staff. Their dedication to the annual collection of herring assessment data, given their limited resources, is indicative of their vision and commitment. This herring assessment data provides the basis for any rigorous statistical analyses, the modeling effort reviewed here, or any kind of rational management.

Acknowledgement

The panel thanks Jose De Oliveira for his patient help explaining the model, for conducting additional simulations for the panel, and for all his help in the review. We also thank Andrew Weltz and Tom Greiner for their help in understanding the history of spawning survey and the management. We thank Tom Barnes, Ryan Bartling, and Kirsten Ramey for organizing the review and for their warm hospitality while we were in Santa Rosa.

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This document provides brief responses, where appropriate, to some of the comments from the reviewers.

Responses by José A.A. De Oliveira and Beatriz A. Roel, following completion of the final report. Responses are given in bold. References (e.g. to Figures and Tables) relate to the revised final report. The original Appendix to the review report is not included for the sake of brevity.

Review of the Stock Assessment for the Pacific Herring
Fishery in San Francisco Bay

October 10th and 11th, 2016

Peer Review Panel Members:

Harold J. Geiger (chair)
St. Hubert Research Group
Juneau, Alaska

Jake Schweigert and Nathan Taylor
Fisheries and Oceans Canada
Pacific Biological Station
Nanaimo, B.C.

Background

On October 10th and 11th, the California Department of Fish and Wildlife organized a peer review of the recently completed stock assessment of San Francisco Bay Pacific herring. A peer review panel consisting of Jake Schweigert and Nathan Taylor of Fisheries and Oceans Canada in Nanaimo, B.C., and Hal Geiger of the St. Hubert Research Group in Juneau, Alaska traveled to Santa Rosa California to meet with modeler Jose De Oliveira from Cefas in the United Kingdom. Also participating were Kirsten Ramey, Ryan Bartling, Tom Barnes, Tom Greiner, and Andrew Weltz of the California Department of Fish and Wildlife, and Sarah Valencia, a consultant hired to develop the management plan for the fishery. The review panel, chaired by Hal Geiger, was given the following objectives: (1) review and discuss the stock assessment and operating models for San Francisco Bay Pacific herring, (2) provide recommendations to the stock assessment modeler for any changes to the assessment, (3) determine whether the final product is appropriate and sufficient for use in management of the Pacific herring fishery in San Francisco Bay via incorporation into the Fishery Management Plan, and (4) provide a written panel report to the Department of Fish and Wildlife.

Prior to the meeting in Santa Rosa, the review panel received a written report (San Francisco Bay Herring: Stock Assessment and evaluation of Harvest Control Rules, by Roel et al., March 2016 version), which formed the basis for most of the review. The panel evaluated the technical merits of the approach, but in the broader context of the management strategy evaluation approach (Punt et al. 2014) described in the Roel et al. report, the panel considered whether any new approach would result in improved fishery outcomes. The panel endorses, in principle, the management strategy evaluation approach for analyzing the effect of alternative management strategy choices. As an analytical instrument, the management strategy evaluation provides a process for evaluating and presenting trade-offs between alternative management strategies (i.e. the choices of data, assessment model, and harvest control rule).
The Punt et al. 2014 reference is not correct. The correct reference, Punt et al. 2016, can be found in the revised final report {Punt, A. E., Butterworth, D. S., de Moor, C. L., De Oliveira, J. A. A. and M. Haddon. 2016. Management strategy evaluation: best practices. Fish and Fisheries, 17(2): 303-334.}.

Comments Related to the Data Used for the Analysis

At the review meeting, the panel was surprised that the modeling appeared to have been conducted with an incomplete and undocumented data set. The panel recommends that prior to further modeling

of the San Francisco Bay Herring population, all data required for model development should be fully reviewed, and that the final data set include all necessary measurements and metrics. If there are any instances where specific years or components of a data series are excluded, then this should be fully explained in a revised report. A process should also be set up to ensure that only a single quality-assured, complete data set is adopted for modeling at a given time. This data set should be maintained for subsequent analyses, and updates or revisions should be tracked by a version-control or report number.
{CDFW to comment}

The decision to restrict the analysis of the San Francisco Bay herring population to the years 1992 to 2013 requires further comment and justification in view of the existence of additional earlier data. The data series that was analyzed reflects a period of reduced harvest levels. The reduced harvest provides limited contrast in the data, which constrains the ability to estimate some model parameters. Moreover, by not using a longer time series of data the model relies on assumptions of the depletion level at the beginning of the modeling period.
Fair comment, although it should be noted that exploitation in the early- to mid-1990s (a period included in the assessment) was substantially higher than recent levels, with 1996 representing the highest landings since at least the early 1970s, therefore we disagree with the comment that the data set used for this development lacks contrast . {CDFW to comment further}

A description of the process used to acquire age-composition data and its application to the derivation of catch at age for the commercial and research surveys is needed in a revised report. A reviewer attempting to understand the unique problems and issues with the input data, such as the sample sizes, measurement error, non-sampling error, or similar issues, can only find statements as brief as this one from page 3: "Input data for the assessment were provided by Tomas Greiner, California Department of fish (sic) and Wildlife," or "A recruitment index was derived from the Young of the Year surveys."
{CDFW to comment}

The panel noted the mention of a herring eggs on kelp (HEOK) fishery in the overview on the San Francisco Bay Pacific herring spawning stock and commercial fishery management. However, no information on the landings from the fishery or information on its relative significance was provided in the Roel et al. report. This should be addressed in a revised report. It was not possible for the panel to assess the impact of this herring removal on the stock assessment.
A decision was taken early on to ignore the herring eggs on kelp data {CDFW to comment further}

Comments Related to the Age-Structured Model

The panel agreed that the description of the assessment model in the Roel et al. report was inadequate to allow for complete and thorough review. Additionally, as an aid to review, the panel recommends that a revised report include appendices detailing all parameter estimates for each model run and that additional model runs be included to demonstrate the robustness of the results to varying assumptions and model building decisions.
Appendix 2 now provides a detailed description of the assessment model, with all parameters and variables defined, and with a narrative to "walk" the reader through the model (including more information in the main text). Key results for each of the model runs are now included in the report where these models are discussed. All sensitivity runs, including the additional runs requested during the review process, are included.

The panel found the decision to adopt the hockey-stick stock-recruit function equivocal and not well supported by data. Moreover, the implications of this choice were not clearly communicated to the

reader. The available data are insufficient to demonstrate the relationship between stock size and subsequent recruitment, especially for small stock sizes. The choice of the hockey-stick model results in predictions of unrealistic resilience in the population dynamics, especially at high levels of fishing mortality.
The text on stock-recruit modelling has been expanded to clarify that the hockey-stick model is not actually estimated in the assessment, but instead a simpler form is used. For stock-recruit modelling beyond the assessment (e.g. for stochastic projections), a hockey-stick is used; however, the breakpoint of the hockey-stick is not estimated, but instead placed at the lowest SSB estimated (hence it is termed the "fixed hockey-stick"). The reasons for this (following a well-established procedure used for ICES stocks) is explained in the report, and is related to the fact that there is no evidence, from the estimated stock-recruit pairs, of impaired recruitment at lower stock sizes; under these circumstances, it is not unreasonable to place the breakpoint at the lowest estimated SSB (an approach that is followed in ICES). Robustness to this assumption can of course be tested within an MSE.

The formulations chosen for gear selectivity were confusing and do not adequately reflect what is known about herring biology. The selectivity ogives for the commercial fishery indicated a broad range for round-haul nets and a domed pattern for gillnets (Figure 4 in the Roel et al. report), the latter peaking at about 185 mm corresponding to age-4 herring, a pattern that is consistent with the selectivity of the research trawls shown in Figure 11. However, the selectivity function in the model adopts full selection by the fishery (gillnets since 1998–1999) at age 5 and 6+. The panel agreed that further explanation of these decisions is required.
The assessment model has a non-parametric selectivity formulation (a selectivity parameter is estimated separately for each age). The only constraints imposed on the baseline model (model 6) regarding commercial selectivity are that the selectivity parameter for age 5 is equal to that for age 6, and that the maximum selection for any age is 1 – there are no other constraints imposed. The assessment model relies on the proportions-at-age data to estimate these selectivity parameters; admittedly, there are confounding effects between selectivity and natural mortality (e.g. with the plus-group natural mortality factor). The reason for assuming age 5 equals age 6 for commercial selectivity is not a strong one (it avoids the problems introduced by a cryptic biomass), and could be further explored within an MSE to check robustness of HCRs to competing hypotheses regarding selectivity. These issues are discussed in the report.

The final operating model {The term operating model is used here to mean an overall model to simulate various management outcomes based on models of the stock dynamics, the management, and the data acquisition.} developed for the evaluation of harvest control rules implements a sequential approach to the inclusion of flat topped commercial selectivity, a 2007 natural mortality event associated with the oil spill, a fixed natural mortality and mortality multiplier to age 6 and older herring (Table 4 in the Roel et al. report). However, the explanation for the choice of this version of the model is unconvincing and the mortality multiplier for age 6+ seems ad hoc and arbitrary. It would be helpful to repeat the runs described in Table 4 of the Roel et al. report for all cases with natural mortality fixed at 0.53 as in the final run. The analysts might also consider testing a linear function for mortality from age 3 when fish are fully mature to age 6+. Such an approach could be more readily justified on a biological basis.
There is now a Table 4a (as for the original Table 4) and 4b (where all runs are for M=0.53). Regarding the linear function, for mortality from age 3, we feel sensitivity runs using the Tanasichuk formulation already indicate what would happen: namely unrealistically low estimates of M for the younger ages in order to reach the M needed for the plus-group age 6, when the plus-group age 6 mortality factor is omitted (compare model 11 with model 6).

Decisions about model selection in this report rely heavily on the total likelihood, the largest component of which relates to the fit of the age-composition data. Table A1.3 in the Roel et al. report presents the catch at age for the commercial fishery and Table A1.5 presents the catch at age for the research survey. The research catch-at-age data presented in this version of the report is an order of magnitude larger than the commercial catch at age. This seems implausible. These data also do not reflect the exceptional 2002 or 2003 year classes that produced the large 2005 spawning stock biomass. As we discuss above, the panel again recommends that these data be carefully reviewed and fully documented before conducting further modeling.
The explanation for the magnitude of the research catch-at-age data is given in the caption to the Table – essentially the numbers in the table are raised to the spawning wave estimate so they do not reflect the actual numbers caught in the samples; this information is used as relative proportions-at-age within a year, so the scale is of no consequence. Furthermore, the 2005 SSB index estimate is largely ignored in the model fits, and it is difficult to believe that there could have been such a large pulse in SSB with values for the years on either side being much lower.

The panel also noted that Figure 7 of the Roel et al. report shows an inability of the model to adequately explain the spawning stock biomass index from 2009 to 2013. This result requires further analysis and comment in a revised report. Similarly, no explanation is provided for the positive trend in recruitment residuals (Figure 9 of the Roel et al. report). Some of these residual patterns are symptomatic of poor goodness of fit to the data and the reasons underlying this pattern need to explored and preferably rectified.
We acknowledge there are issues related to the fit to the SSB index and the recruitment residuals; the assessment has high uncertainty (Figure 11). However, we also point to the fits that include a further two years' data, where both issues highlighted by the review seem less relevant (Figures 16 and 18).

Provided that a defensible operating model can be developed, the panel identified several deficiencies in the way the model described in the Roel et al. report simulated herring population dynamics. In particular, the analysis must include more challenging scenarios with which to test the alternative management procedures. In the Roel et al. report, the scenarios involved routine sampling from well-behaved probability distributions that were expected to reproduce historical conditions over a short time scale. Dynamic species like herring have both variable recruitment and variable natural mortality (as environmental conditions change). More challenging scenarios should include periodic el Nino, infrequent catastrophic events, climate change, induced changes in recruitment, or changes in natural mortality, for example. In addition, the analysis would benefit greatly by imbedding the assessment model into future simulations in order to capture assessment model estimation errors that can be very large (Punt et al. 2014). Failing to consider such factors results in an under-estimation of the uncertainty in the range of future outcomes for the stock and the fishery under a given management strategy. That would mean quantities like the probability of breaching a limit reference point could be much higher in reality than what would have been demonstrated in the simulations.
We do not pretend that we have produced a full-blown MSE analysis – we were not contracted to do so, and this is made clear in the report. However, we hope that the analyses presented provide a first step in that direction. An MSE framework is the ideal place for exploring the range of situations mentioned (catastrophic events, climate change, el Niño, etc.), and the sensitivity analysis could provide a basis for alternative operating models in such a framework. [Note, as mentioned before, the Punt et al. 2014 reference is not correct.]

The panel agreed that a broader range of performance statistics is needed to increase the relevance of the work for decision making. Some of these statistics could be quantities such as the probability of being at a target biomass for the stock, the probability of fisheries closures, and the average annual variability in the catch. Moreover, the presentation would benefit from having the performance

statistics partitioned into more time frames. The time horizon for achieving particular objectives or avoiding limits may be particularly important. For example, the application of any particular management strategy may have consequences that are undesirable in the short term (5–10 years) even if in the longer term (over 20 years) performance is good. Performance statistics used in other management strategy evaluations might be useful for application in future analyses (see Taylor et al. 2014, Schweigert et al. 2007, for examples).
We agree with these suggestions, and hope that further MSE development will consider them.

Suggested Revisions to a Final Report

The version of the report the panel received appeared incomplete, contained insufficient material and detail for a full and complete review, and the document contained obvious errors that left the panel wondering about errors that were not as obvious. The panel suggests that the main document be rewritten in the standard Introduction-Methods-Results-Discussion format of a scientific report. Each section should be written in sufficient detail to allow a reader not already fully familiar with the subject to understand and be able to critique the analysis.
We hope that the re-structured and expanded report meets these concerns.

The Introduction should introduce the reader to the history of the fishery, the history of the management process, and explain how the results of the current analysis and modeling would provide a basis for altering existing management approaches. Importantly, the Introduction should specifically lay out the goals and intent for management and for the study. This context is essential for understanding the decisions about the parameterization of the assessment model and also for understanding the relevance of the management strategy evaluation analysis.
{CDFW to comment}

The Methods should contain a complete review of the all data sources (see the section on Comments Related to the Data Used for the Analysis, above). As previously mentioned, this review should allow the reader to understand how far back in time the data series goes, understand the sampling design for the survey index, understand the protocols for the ageing data, understand the sampling design for the commercial age-composition data, understand what data exist from prior to 1992 and why these data were not used, and so forth. Additionally, the Methods should fully introduce the models. The revised report should contain descriptions relating to the choice of the stock-recruitment function, gear selectivity, natural mortality, and the maturity ogive. The Methods should cite authorities, describe where the models came from, and include a narrative that introduces notation and describes the parameters to readers not familiar with the models. This section should tell the readers how the state dynamics are updated at each time step, how the subsequent model fitting procedure occurs (including choice of likelihood function formulation), and so on. In summary, this section should contain sufficient detail for a reader to be able to reproduce the analysis after reference to materials in any appendices.
{CDFW to comment on the data part} We hope the re-structured and expanded report addresses these concerns.

In the Roel et al. report, the material relating to the methods appears to have been written for someone already fully familiar with the model. In other words, this material appears to have been written for someone that only needs brief reminders of model notation rather than a presentation introducing the material for the first time. A section of the document found under the heading of “Assessment Model” contains a few facts about the model, but no explanation of model development or any of the theory underpinning the model. The reader is incorrectly referred to Appendix 1 of the Roel et al. report for a “generic description of the model.” Appendix 1 contains tables of input data; Appendix 2 does contain over five pages of lists of equations—not a “generic description of the

model." The equations in Appendix 2 were introduced without explanation, and equations in Appendix 2 appear before the notation is introduced to the reader.
We hope the re-structured and expanded report addresses these concerns.

When the reader does discover Appendix 3 in the report, the reader finds only brief reminders of the meaning of the notation. For example, the notation F is commonly used in age-structured models in North America to mean the instantaneous fishing mortality. In Appendix 3, F(y,a) is defined as fishing mortality at age a in year y. This brief comment fails to clearly tell the reader that F is being used to denote a kind of harvest rate. The reader is left to see by inspection of equation A2.1 that if F indicates instantaneous mortality then this equation does not make sense. Similarly, C(f,y) is described as "Catch of fleet f in year y." To fully understand the meaning of this notation in equation A2.3 the reader will need to correctly guess that C is in units of weight or mass or else carefully inspect the units of the other quantities in equations that contain C so as to infer the appropriate units. In North America C is often used to denote catch in units of individual fish. Some of the equations may contain errors, but the panel was unable to decode the notation, infer the meaning of the equations, and check the equations in Appendix 2 carefully in the time available. Some narrative walking the reader through the equations should be considered essential in a revised report.
There is no longer a notation Appendix. All definitions are included in the narrative provided in revised Appendix 2.

The Results section should lead the reader through the results in a logical manner so that the reader will be able to understand and digest the material in the figures and tables. In most cases, the tables and figures in the version of the report that the panel was given were insufficient for their intended purpose. Most graphics were too small and many had unlabeled axes. Table captions did not describe the table contents adequately. Graphics and tables were usually introduced without any kind of interpretation or context (e.g., "Model fits to the SSB and recruitment indices are shown in Figure 7."). Figure 6 in the Roel et al. report is described in the figure caption as a "Likelihood profile," yet the preferred estimate is shown at some kind of minimum—not the maximum. In this case there is an axis label, but that axis is described with the nonspecific term "Function value." The reader is left to decide whether the figure caption is wrong and "Function value" means the negative log likelihood rather than likelihood, decide whether this is simply the entirely incorrect figure that was included by mistake, or whether something else happened. All of the figures should be reviewed and brought up to the standards that are usually required for a scientific publication. In contrast, note that Figure 12 in the report provides a good example of a helpful graphic. Here the axis labels and the figure caption complement each other. The figure works to allow the reader to understand a complex point about the model fitting that is important to understand the limits of the model's ability to predict.
Improvements have been made throughout to Tables and Figures, as suggested.

The panel was surprised to find that the report they reviewed contained essentially no discussion of the important implications for the use of the estimated model in fishery management. This important section of the report should be a place where the model results are placed in context for the reader, a place for synthesis and integration of new information with historical information, and a place where uncertainty and limitations are carefully explained to the reader. A carefully constructed Discussion in the report is the place to try and communicate these limitations to the fishery management, the fishing industry, and other concerned organizations and individuals.
We hope expansion of the Discussion and improvements to the report addresses this concern.
{CDFW to provide some context for fisheries management?}

Much more importantly, there is no discussion of the important conflict between predicted yield based on the proposed model and the actual fishery performance in the past. The panel noted that the proposed model predicts that yield will increase as the harvest rate increases from 0.0 all the way to

1.0 (Table 6 and Figure 15 in the Roel et al. report). This result is both surprising and counter-intuitive. Additionally, this result also serves to demonstrate how new models can create a potential liability for management's credibility if the management has not carefully validated the model.
Figures 25a and b, and the text around them deals with this concern. There is also text on why it is that we are seeing this "resilient" behaviour, related to the evaluating the maturity ogive relative to the commercial selectivity pattern (Figure 24).

In contrast to the prediction that very high harvest rates are sustainable, the panel that conducted the 2003 review of San Francisco Bay herring (see Appendix A attached to this review) concluded that harvest rates at that time had been too high and were not sustainable. The 2003 panel specifically stated the following: "The current harvest strategy for this stock should be re-evaluated and explicitly documented. The current harvest rate policy of 20% appears to be too aggressive under current levels of stock production. A harvest rate in the range of 10–15% appears to be sustainable with the lower level providing a desirable target for stock rebuilding." The Roel at al. model's prediction that a 100% harvest of the available population in the future would be sustainable and the observation that a 20% harvest in the past had been considered excessive obviously needs to be brought out in a Discussion and reconciled.
We have a paragraph in the Discussion that specifically deals with this.

There were 10 paragraphs in the Conclusions. Some of these conclusions appeared to be correct but not supported by evidence found in the report (e.g., see the first paragraph in the Conclusions). The panel also questioned whether other statements were correct or not. Either way, the team agreed this section should be revised, expanded, or combined with a new Discussion section.
The Discussion section has been expanded and revised, and any conclusions should be substantiated by the results shown earlier in the report.

Final Comments and Recommendations

Before a management agency adopts a complex model into its management strategy, the agency should have a clear understanding of how the model is going to be used. The agency should also have given adequate thought to the consequences of assumptions and choices in model development that might simply be wrong. These considerations should affect any future review.

An age-structured model could be used either to study the effects of various management actions or strategies (i.e., the management strategy evaluation), or the model could be used for short-term decision making, such as setting a total allowable catch. These two uses are not the same. For example, a model of herring dynamics might be quite useful and safe as a way to combine fishery-derived information with fishery-independent information so as to smooth out random fluctuations in a spawn deposition survey to set harvest rates when fishing mortality is low. Yet, this same model may completely fail to predict the stock dynamics at very high fishing mortality—especially when the model is used to predict what will happen far outside the range of the data that was used to construct the model.

Roel et al. cite "Punt et al. (in press)" (this should now be cited at Punt et al. (2014), which is how we have cited it) as a key reference on the management strategy evaluation (MSE) approach. Punt et al. stress, "The ability of MSE to facilitate fisheries management achieving its aims depends on how well uncertainty is represented, and how effectively the results of simulations are summarized and presented to the decision-makers." In other words, it is not good enough to simply have an operating model, assessment model, and a set of closed loop simulations. A complete management strategy evaluation involves a careful study of uncertainty—including a careful analysis of "what if we are wrong." At a minimum the assessment must address this question: what if the population dynamics in

nature are different from those assumed in the assessment? There are many layers of uncertainty involved in modeling herring dynamics, including uncertainty as a result of a random and possibly changing environment, uncertainty due to estimation and sampling error, uncertainty that could be the result of incorrect assumption or modeling decisions. Prior to further review, the analysis needs a much more sophisticated study of uncertainty. The panel agrees that the cited Punt et al. article could be used as a guide.
We have not attempted a full MSE – we were not contracted to do this. However, as indicated before, we hope the work done can form the initial steps for further development. Again, note the incorrect reference to Punt et al. 2014 here (as highlighted before).

The panel recommends that the California Department of Fish and Wildlife at least consider some simpler, more cost effective management tools. Age-structured assessment models can be demanding in terms of both data and in the capacity to use these tools. The capacities to run, update, and explain such models within the agency may be limited, expensive, and may divert resources way from more important needs. In some cases adopting the age-structured modeling approach for annual decision-making may even erode fishery outcomes if the effects of the models are not well understood or if the models poorly predict the dynamics of the population. Many alternative assessment models or management based on smoothed survey estimates could be less costly and potentially more effective. For example, Kalman filtering (Walters 2004) has been evaluated in other herring fisheries (Cleary et al. 2010). Even with these simpler tools in place to set catch limits, management strategy evaluation simulations could be used to illustrate how these alternative models perform in terms of catch, variability and conservation metrics with similar or different harvest control rules. It may be possible to show with a more complete accounting of uncertainty that a harvest control rule based on the annual survey could have a similar, or even better, performance without the cost and complexity of adopting an annual age-structured modeling calculation and evaluation.
Note, however, that the evaluation of these potentially simpler approaches still require the more complex operating models, a point that is often made in the MSE "literature" (see e.g. Geromont and Butterworth 2015 {Geromont, H. F., and D.S. Butterworth. 2015 Complex assessments or simple management procedures for efficient fisheries management: a comparative study. ICES Journal of Marine Science, 72: 262–274.}).

In anticipation of future modeling in support of management strategy evaluation, the panel recommends that California Department of Fisheries and Wildlife engage with stakeholders to develop objectives and performance indicators for the management of the fishery. The single factor of breaching the precautionary limit biomass, or the putative limit reference point, with greater than 5% probability, examined in the Roel et al. report, is unlikely to universally satisfy the larger community. For example, the panel heard during the review that some individuals and organizations might be concerned about addressing the broader ecosystem consequences of the fishery on a forage fish like herring. In this case, the metrics identified in some of the forage fish literature (Essington et al. 2015, Smith et al. 2011) may be very important.

Additionally, management strategy evaluations (Hall et al. 1988 for a herring-specific example) have documented that the objectives typically trade off against each other. For example, high average catches occur at the expense of high variability in catch. By failing to consider a broader set of objectives it is not possible to understand the broader set of consequences of applying a given management strategy on the industry, the stock, or the ecosystem.

Given the concerns about aspects of the development of the operating model based on the relatively short time series and outstanding questions about the data and the ability of such a model to reasonably predict the future productivity and resilience of the San Francisco Bay herring population given climate warming and unpredictable catastrophic events, the panel cannot endorse the model described in the Roel et al. report for the development of harvest control rules and reference points at this time.

It is possible to deal with future productivity and resilience scenarios, given e.g. climate change and unpredictable catastrophic events, within an MSE framework without needing to deal with it directly in the assessment model (often difficult or impossible to do), so we are not sure that this is an argument to reject the models presented(see e.g. Punt et al. 2014, which is a different paper to Punt et al. 2016 {Punt, A. E., A'mar, T., Bond, N. A., Butterworth, D. S., de Moor, C. L., De Oliveira, J. A. A., Haltuch, M. A., Hollowed, A. B. and C. Szuwalski. 2014. Fisheries management under climate and environmental uncertainty: control rules and performance simulation. ICES Journal of Marine Science, 71: 2208–2220.}).

As a concluding recommendation, the panel again recommends that the California Department of Fish and Wildlife adopt a stronger policy of documentation. Details of each year's surveys and monitoring should be recorded and archived at least in timely internal reports.

Finally, the panel strongly commends the professionalism of the California Department of Fisheries and Wildlife staff. Their dedication to the annual collection of herring assessment data, given their limited resources, is indicative of their vision and commitment. This herring assessment data provides the basis for any rigorous statistical analyses, the modeling effort reviewed here, or any kind of rational management.

Acknowledgement

The panel thanks Jose De Oliveira for his patient help explaining the model, for conducting additional simulations for the panel, and for all his help in the review. We also thank Andrew Weltz and Tom Greiner for their help in understanding the history of spawning survey and the management. We thank Tom Barnes, Ryan Bartling, and Kirsten Ramey for organizing the review and for their warm hospitality while we were in Santa Rosa.

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San Francisco Bay Herring

Stock Assessment and Initial Evaluation of Harvest Control Rules

Report prepared by B. A. Roel, N. D. Walker and J. A. A. De Oliveira
Revised by J. A. A. De Oliveira and B. A. Roel

March 2016 (revised January 2017)

Cefas

EXECUTIVE SUMMARY

The modelling work presented consists of an assessment of the San Francisco Bay herring stock, using a statistical catch-at-age model fitted to data supplied by the California Department of Fish and Wildlife. A number of model explorations and sensitivity tests were conducted, which included investigating aspects related to the stock-recruit relationship, fishery selection and natural mortality. The development of the assessment model, which formed the backbone of the project, was followed by the development of an operating model to test simple harvest control rules. The operating model was conditioned on the assessment. Precautionary and MSY reference points for management were investigated. A harvest control rule, based on a constant exploitation rate with a precautionary reduction when the stock was low, was evaluated by simulation. The model-estimated commercial gear selectivity resulted in a substantial proportion of mature individuals always surviving the fishery, even in the case of high fishing pressure. This resulted in the associated risk (probability of spawning stock biomass falling below the limit biomass reference point, Blim) not exceeding 15.2%, even under maximum fishing pressure. However, the uncertainty in model parameters was large, which resulted in 4.1% risk of falling below Blim in the absence of exploitation. Harvest rates between 10 and 20% had associated risks between 5.6 and 7.0%. Summary statistics for a range of exploitation rates are presented for managers' consideration.

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Introduction

In July 2011 Cefas was contracted by Mr Nick Sohrakoff, President of the San Francisco Bay Herring Association, to develop an assessment model for California Bay herring and to provide tools to better manage the stock. A peer review process was anticipated to take place once Cefas had finalised the agreed (contracted) work and submitted their Report to the California Department of Fish and Wildlife (CDFW). Subsequent to the physical peer review process that took place in Santa Rosa, California, on 10 and 11 October 2016 (with one of the Cefas team present) and the production of the formal review report in November 2016, Cefas and the client agreed that, for the purposes of addressing certain of the requests made in the review, detailed descriptions of the data used in the study, the history of the fishery and the management process would be provided by CDFW. Cefas would then focus on development of the assessment model and stochastic projections that could be used to evaluate basic harvest control rules.

The goals of the study were originally agreed between Cefas and the scientific staff from the California Department of Fish and Wildlife (CDFW) during the early stages of negotiation of the Contract between the two organisations. Currently, the stock is managed on the basis of a total allowable catch (TAC) set at the start of the fishing season. The TAC is computed as a fixed percentage of the spawning stock biomass (SSB) as estimated from an egg survey conducted during the previous year's spawning season. The survey results are, however, considered to be rather noisy, so the TAC tends to be highly variable between years. Further, uncertainty in the survey results is not taken into account in the process of determining the TAC. The present study proposes a management approach that takes into account all existing and available sources of data, both commercial and research. This proposal would be achieved by annually assessing the stock using an analytical model developed by Cefas that would integrate all appropriate data sources provided by CDFW. The outcome from the assessment would constitute the input into a harvest control rule derived from a management strategy evaluation (MSE) process.

In the study, Cefas first examined the data made available by CDFW and provided guidance to process the data required by the assessment model. In short, Cefas' scientists worked with CDFW on criteria and procedures to compute catch-at-age data by allocating age composition samples to sampled and unsampled landings for both commercial and research catches; research data and Young of the Year (YoY) surveys were examined and a recruitment index based on the YoY surveys was constructed. The development and implementation of an age-structured production model formed the core of this study; a range of analyses to test the sensitivity of the results to model key assumptions was subsequently performed. Finally, stochastic projections conditioned on the assessment model were conducted to test the performance of alternative, simple harvest control rules. This (revised) Report reflects all the scientific work carried out by Cefas during the original contract period (up to presenting the first report) and subsequently, following production of the formal review.

Material and Methods

Data

The data used in the assessment consists of landings, maturity data and mortality data, commercial numbers at age landed and research numbers at age caught (catch-at-age data), mean weights at age, spawning biomass estimates from the egg deposition surveys and a recruitment index derived from Young of the Year (YoY) surveys. A full description of the data used in the model is being provided by CDFW. The model input data set is shown in Appendix 1.

Recruitment index

A recruitment index was derived from the YoY surveys (Baxter *et al*. 1999, Watters and Oda 1997). Figure 1 shows length frequencies for the YoY surveys, summed over the period 1980-2012, for the midwater trawl gear. A clear feature of this plot is that age 0 fish are most prevalent in the Bay during the months of April to July, and less prevalent from August on, when they are likely to have started leaving the bay.

Figure 2 shows within-cohort consistency between the YoY survey at age 0, and the research catch-at-age at ages 1–6. When using a recruitment index made up of the average of the YoY surveys for the months April–September, there is almost no consistency between the recruitment index and the research catches (left panel, Figure 2); however, when the index averages the months April–July of the YoY surveys, then consistency improves somewhat, and significantly positive correlations are found between age 0 (the recruitment index) and ages 2 and 3, with positive (but not significant) correlations between age 0 and ages 4 and 5. These features support the use of a recruitment index calculated as the average of the YoY surveys for the months April–July, which is what is used for the results presented in this document. This is consistent with the use of these data by Watters and Oda (1997). Note that there is no correlation between age 0 and age 1; this is because juveniles move out of the bay and only come back to spawn once they mature at age 2.

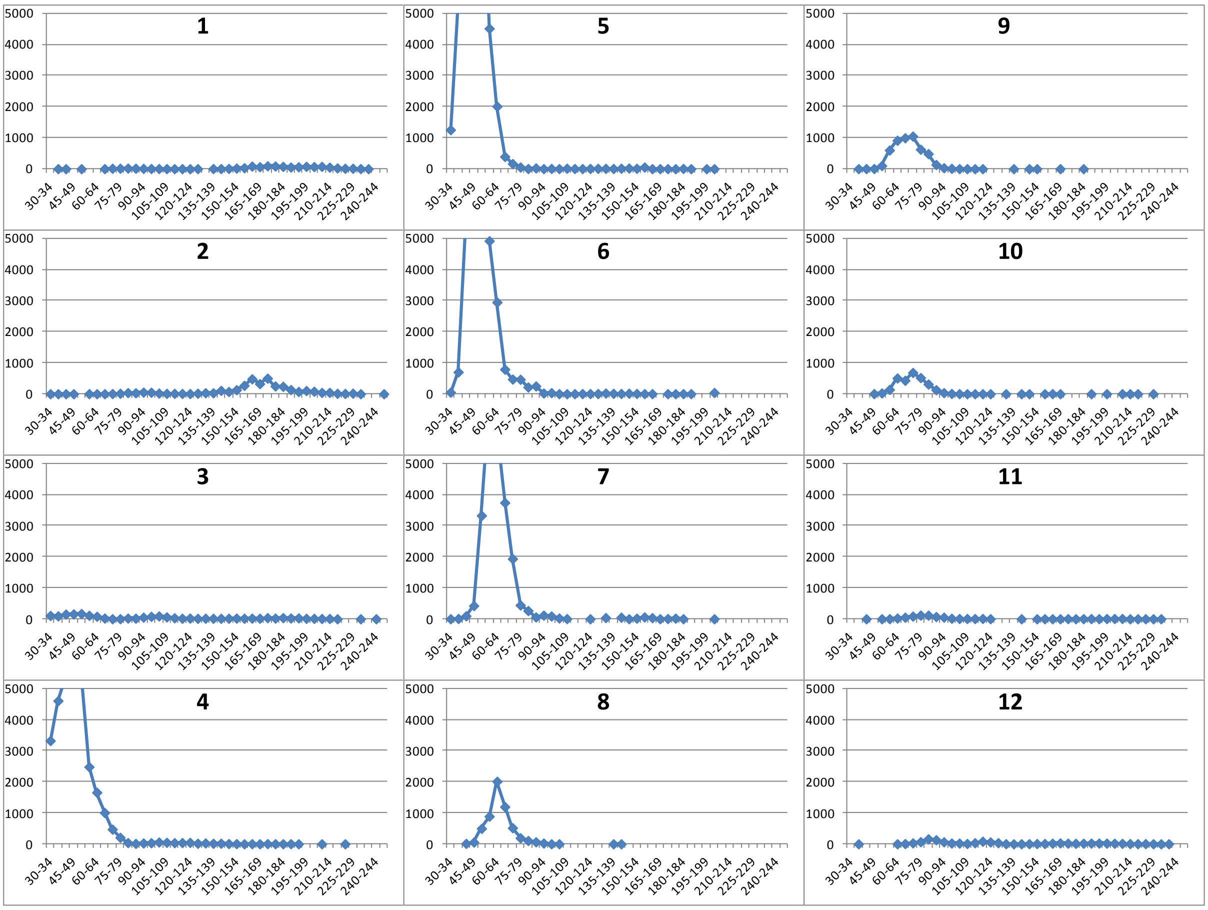

Figure 1. Length frequencies by month for the YoY surveys summed over 1980–2012 for the midwater trawl gear.

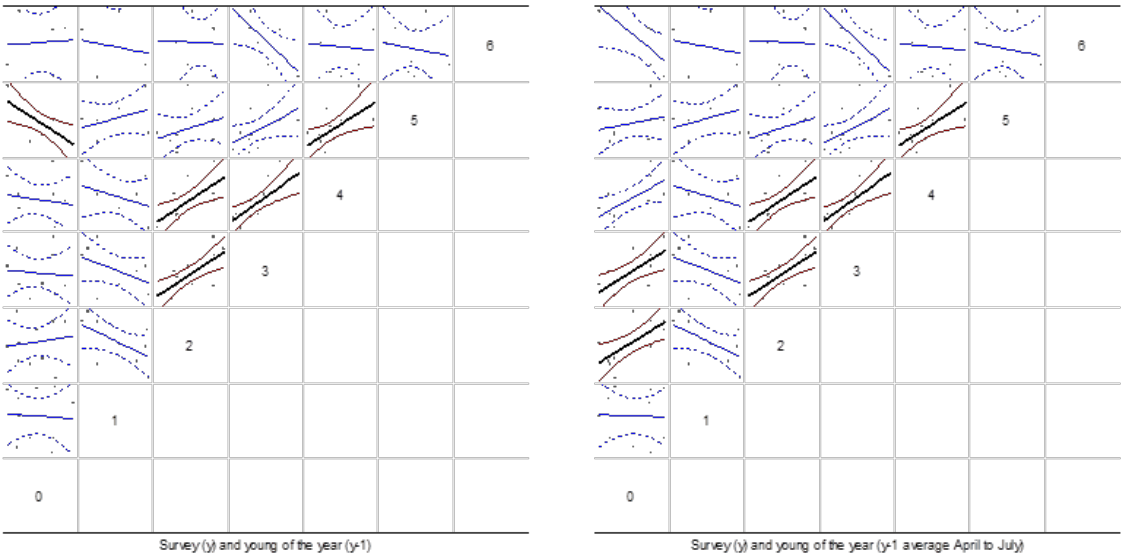

Figure 2. Within-cohort consistency in the research catch-at-age matrix (ages 1-6) and the YoY survey (age 0), shown by plotting the log-catch of a cohort at a particular age against the log-catch of the same cohort at subsequent ages. Regression and 95% confidence intervals included. Left panel gives the YoY survey averaged over April–September, the right panel gives the same index but averaged over months Apri–July. Thick black lines (with confidence intervals in red) represent a significant ($p<0.05$) regression and the curved lines are approximate 95% confidence intervals.

Assessment Model

The model is an age-structured production model (ASPM), introduced by Hilborn (1990) as an extension of age-aggregated production models (e.g. that of Schaefer, 1957). ASPMs essentially replace the estimation of the Schaefer model r and K with parameters of the stock–recruit relationship, and if that function has a stochastic component and catch-at-age data (either from commercial or research survey catches) are used in the fitting process, the ASPM is essentially a statistical catch-at-age model. This is the model that is used for San Francisco Bay herring, and is similar to the approach described by Butterworth and Rademeyer (2008; see Section B of their Supplementary Material).

Appendix 2 provides a detailed mathematical description of the model. The model is fitted using maximum likelihood estimation and relies on a number of data sources. The model fits directly to an SSB index (from an egg deposition survey), a recruitment index (from a Young of the Year survey), catch-at-age data (converted to proportions-at-age) from a commercial fishery, and catch-at-age data (also converted to proportions-at-age) from research catches. Details of the likelihood components for each data source are provided in Appendix 2. In addition to these data sources, a penalized likelihood term is included to model recruitment deviations from an estimated stock–recruit relationship.

Population dynamics follow the usual exponential decay equations, commencing from recruitment, through a stock–recruit relationship (Appendix 2, A2.1-A2.10), and using Pope's approximation (Pope 1972), which assumes pulse fishing in the middle of the fishing season. Instead of modelling instantaneous fishing mortality, harvest rates are used (restricted to be no less than zero and no more than 1; Appendix 2, A2.2-A2.3), calculated using the actual total catch tonnage (assumed without error; Appendix 2, A2.3). An initial unfished age structure is used, but because a fishery already existed in 1992, this is reduced by a proportion (p_{virgin}; Appendix 2, A2.11-A2.12). Fishery and survey selectivity-at-age is modelled through a non-parametric formulation (Appendix 2, A2.15 and subsequent text), and model estimates that correspond to the data observed are obtained for the surveys (Appendix 2, A2-17a-b) and proportions-at-age (Appendix 2, A2.18-A2.19), with the survey indices scaled to the observations by estimating constants of proportionality (Appendix 2, A2.21). The model relies on likelihood formulations for each data source (Appendix 2, A2.26-A2.29) and a penalized likelihood term for recruitment (Appendix 2, A2.30-A2.31). Quasi-Newton minimisation (using AD Model Builder; Fournier et al. 2012) is applied to estimate model parameters by minimising the total negative log-likelihood function (Appendix 2, A2.33).

Stock–recruitment relationship

The assessment assumed a stock and recruitment relationship to initialise recruitment. Three functional forms were investigated: Beverton–Holt, Shepherd, and a simple form based on virgin recruitment. Parameterisation is described in Appendix 2 (A2.5-A2.10). These initial investigations were carried out using natural mortality estimates for North Sea herring; this was later abandoned for the baseline assessment in favour of deriving natural mortality estimates based on the San Francisco Bay herring assessment. Nevertheless, the conclusions of this section regarding which stock–recruitment function to use should be robust to the natural mortality values used (since all stock–recruit functions will use the same natural mortality assumption).

Beverton-Holt:
The Beverton–Holt stock–recruit function is a special case of the Shepherd function (obtained when γ=1; Appendix 2, A2.5). Stock and recruitment parameter estimates obtained are shown in Table 1a. The fit to the data is shown in Figure 3.

Table 1a. Beverton and Holt functional form, parameter estimates (K^{sp} in tonnes). The negative log-likelihood (-ln$L$) is included. [Note, this is identical to γ=1 in Table 1b.].

Parameter	value	stdev	CV
$\ln K^{sp}$	11.10	0.19	0.02
h	0.79	0.39	0.49
K^{sp}	65898	12607	0.19
α	494920	122520	0.25
β	4545	11657	2.56
$-\ln L$	355.83		

Shepherd:
The shape parameter, γ, of this function could not be estimated; therefore, the approach taken was to fix γ at values from 0.5 to 2.0, at 0.1 intervals; γ values less than 0.9 resulted in unrealistic parameter estimates (β became negative). Steepness was better estimated as γ increased while K^{sp} slightly deteriorated. Results for a set of γ values are shown in Table 1b and in Figure 3:

Table 1b. Shepherd functional form, parameter estimates for a range of γ values between 0.9 and 2 (K^{sp} in tonnes). The negative log-likelihood (-ln$L$) is included.

Parameter	γ = 0.9			γ = 1			γ = 1.1			γ = 1.5			γ = 2		
	value	stdev	CV	value	stdev	CV	value	stdev	CV	value	stdev	CV	value	stdev	CV
$\ln K^{sp}$	11.09	0.19	0.02	11.10	0.19	0.02	11.10	0.19	0.02	11.11	0.21	0.02	11.14	0.23	0.02
h	0.83	0.43	0.52	0.79	0.39	0.49	0.76	0.36	0.47	0.66	0.27	0.41	0.56	0.21	0.37
K^{sp}	65743	12369	0.19	65898	12607	0.19	66080	12863	0.19	67050	14082	0.21	68676	16030	0.23
α	153600	35282	0.23	494920	122520	0.25	1583500	422770	0.27	159440000	57156000	0.36	49303000000	24638000000	0.50
β	182	3581	19.70	4545	11657	2.56	24907	37962	1.52	5331500	4363700	0.82	2300900000	1733600000	0.75
$-\ln L$	355.72			355.83			355.95			356.46			357.13		

Simple stock–recruit function based on virgin recruitment:
A simple stock–recruit function, based on virgin recruitment alone (Appendix 2, A2.8) was fitted. If an SSB breakpoint is included at an appropriate SSB value (i.e. where the curve starts to decline linearly to zero), such a relationship is called a "hockey-stick" formulation (see e.g. Mesnil and Rochet 2010). Because the use of a relationship that is completely independent of SSB is not sensible when conducting stochastic projections or evaluating harvest control rules (see Appendix 2), the simple stock–recruit function can be formulated as a hockey-stick model, but it is important to note that the SSB breakpoint is not estimated in the assessment results presented (and we therefore refer to it as the "fixed hockey-stick form here on). The fixed hockey stick shown in Figure 3 (bottom right plot) places the SSB breakpoint at the lowest estimated SSB, because there is no evidence in the stock–recruit plot of reduced recruitment at low stock sizes – this is standard practice in ICES for this type of stock–recruit plot (ICES 2016b). Virgin recruitment (R_{virgin}) was estimated at 467 210 (thousands of fish) with a CV of 0.20 (the associated K^{sp} estimate was 66 499 tonnes with a

CV of 0.20). The simple stock–recruit function is formulated as a fixed hockey-stick model in comparisons below.

Comparison between functional forms:
Likelihood values were similar for all options (Table 2). The fits to the data under the different functional forms considered are shown in Figure 3.

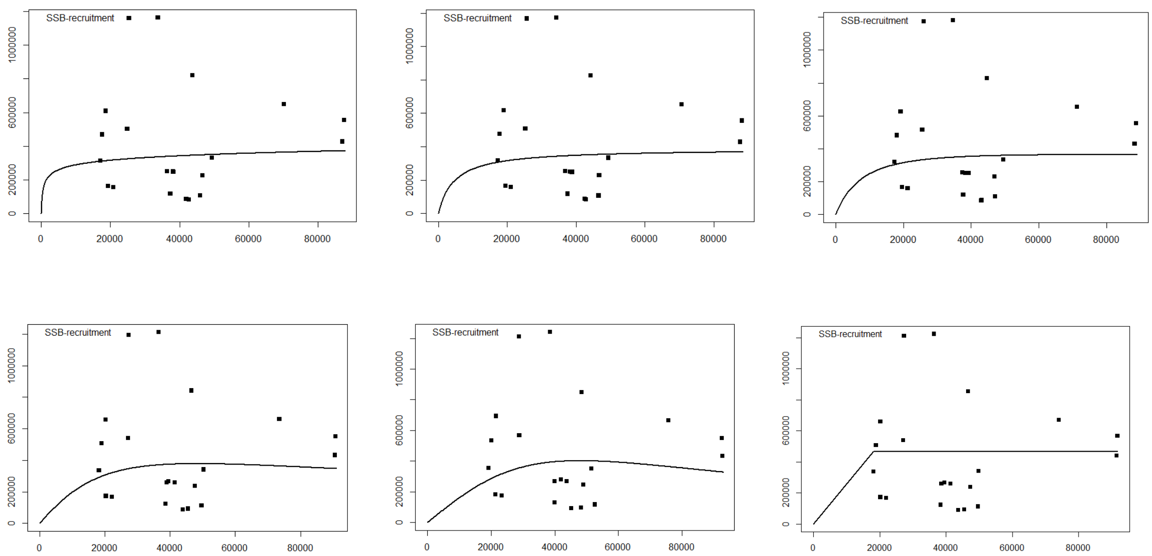

Figure 3. Fits to the stock and recruitment pairs fixing the Shepherd gamma parameter to 0.9, 1 (equivalent to Beverton–Holt), 1.1, 1.5 and 2 (from top left to bottom centre). Bottom right plot illustrates the fixed hockey stick fit (note here that the SSB breakpoint of the hockey stick is not fitted, but placed at the lowest estimated SSB – only the recruitment level, indicated by the horizontal line, is estimated). SSB (horizontal axis) in tonnes, and recruitment (vertical axis) in thousands.

Table 2. Comparison between the three functional forms investigated. "Maximum gradient" is the maximum absolute value of the gradient vector (which has one element per estimable parameter) associated with the negative log-likelihood function ($-\ln L$; Appendix 2, A2.33).

	Beverton-Holt	Shepherd γ = 1.1	Fixed Hockey-stick
Negative log-likelihood	355.83	355.95	355.92
Maximum gradient	4.15E-05	4.39E-05	5.05E-05
Estimable parameters	40	40	39

Goodness-of-fit considerations did not provide a basis for a choice between the functional forms investigated (see Table 2 above; note that other values for the γ Shepherd parameter resulted in similar likelihood, as shown in Table 1b). However, subsequent trials conducted to estimate M indicated that the uncertainty in the steepness parameter present in both Beverton–Holt and Shepherd forms resulted in an unstable minimum when trying to estimate natural mortality (see sensitivity tests below). This feature favoured the use of the simple stock–recruit form, which we term fixed hockey stick for convenience and to reflect the fact that only the level is estimated, with the breakpoint fixed (after the model is fitted, so it has no influence on the model fit) at the lowest SSB in the assessment. The fixed hockey-stick is the form that is adopted in the baseline model.

Selectivity

Fishery selectivity:
There has been a change in selection for the commercial fishery, evident in the length frequencies from commercial catches for round-haul and gillnet (Figure 4). The use of round-haul was phased out gradually and was no longer in use from the 1998/9 season on. The inclusion in the analysis of catch-at-age data from 1992 on has allowed two periods of selection to be estimated in the baseline model, namely 1992–1997 and 1998–2013. Further sensitivity tests are described below.

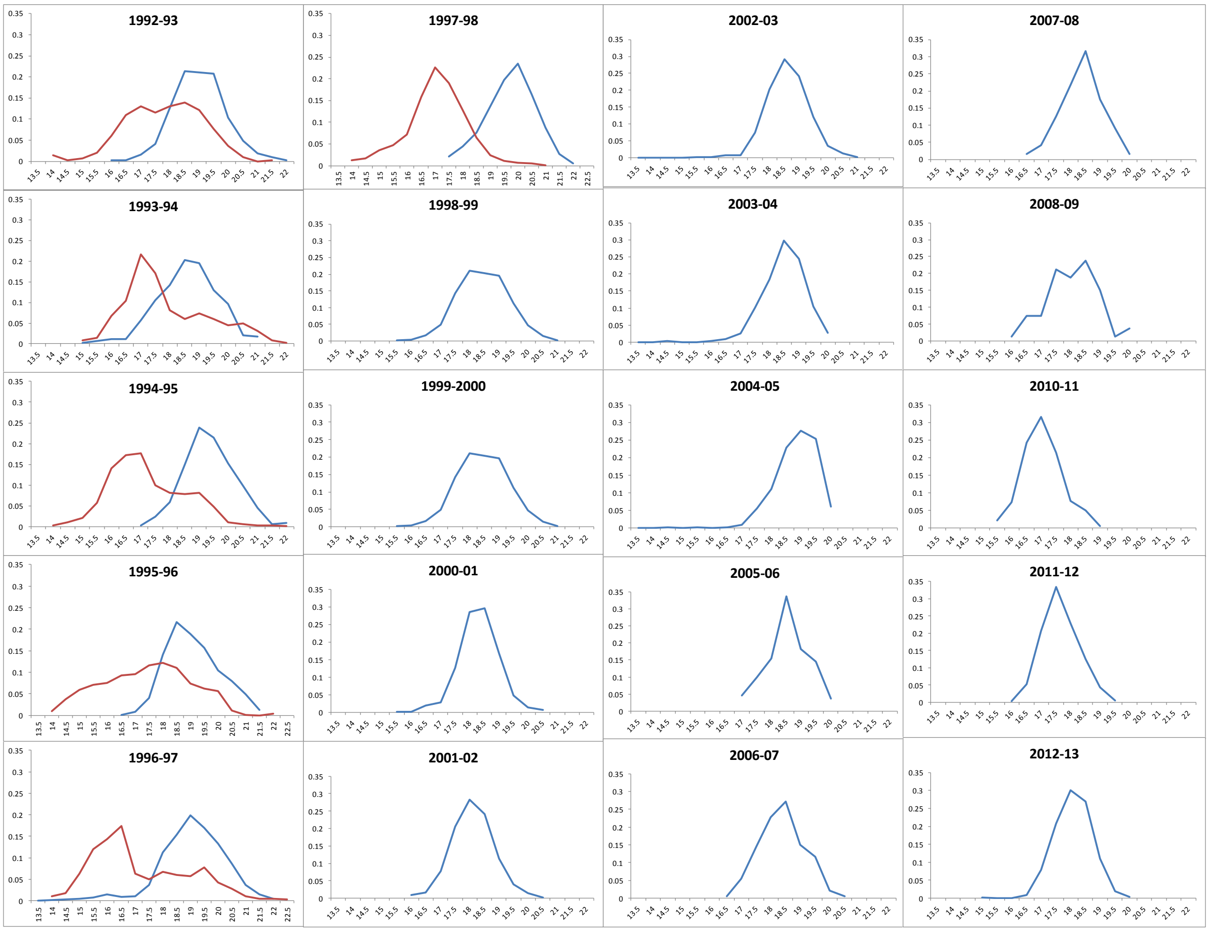

Figure 4. Commercial catch : relative length frequencies (vertical axis) in standardised half cm length bins (horizontal axis) by season, where red corresponds to round-haul and blue to gillnet. [Note that the round-haul gear ceased to operate after the 1997-98 season.]

Survey selectivity:
Samples are usually taken once per week throughout the spawning season. Trawling is the preferred sampling method for research catches, but gillnet samples are used if the trawl vessel is not available or the fish are in shallow water not accessible to the trawl gear; this happens during most seasons. The number of samples taken by each gear type varies from year to year, but trawl samples always dominate numerically. The proportion of fish caught by the two sampling methods is fairly similar from year to year, with no time trend evident in the proportion of trawl vs. gillnet sampling.

Setting up the initial model

Model runs were initially based on values of natural mortality taken from North Sea herring (e.g. the stock–recruit results above; see Table A1.2). This process was later abandoned, and a single value for natural mortality, M, estimated, because North Sea herring values were only being used as a proxy for those for San Francisco Bay herring to initiate the modelling, and therefore were potentially inappropriate. All subsequent results avoid the use of the North Sea herring natural mortality values.

Input values for the recruitment variability σ_R, and the depletion level relative to the virgin stock at the start of the assessment, p_{virgin}, were needed to run the model. The methodology used to derive values for these two parameters was to perform a likelihood profile over these parameters jointly with values selected being σ_R=0.7 and p_{virgin}=0.75, which gave negative log-likelihood values close to the minimum. This was done early in the modelling process, and all subsequent modelling used these two values. The minimum for p_{virgin} (close to 1) was not selected because the fishery was already well-established in 1992, the starting year for the assessment. Nevertheless, the values chosen were within the 95% confidence intervals for these parameters. This is illustrated for the baseline model (model selected after examination of alternative model configurations, see Results section) in Figure 5 and Table 3 which show negative log-likelihood values for a range of σ_R and p_{virgin} value.

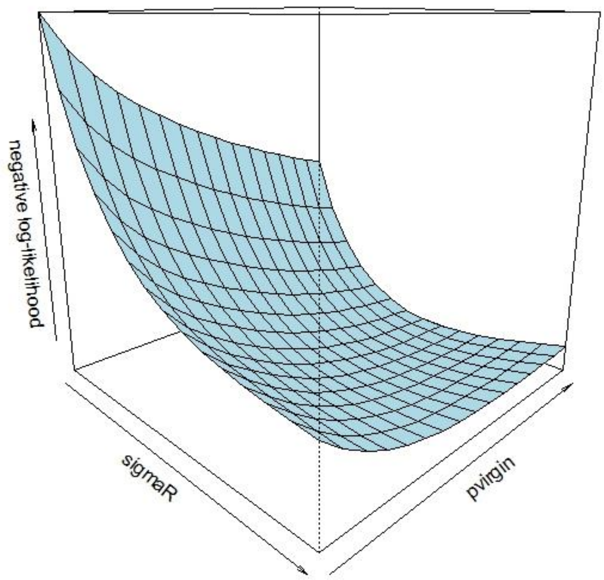

Figure 5. Negative log-likelihood surface for recruitment variability (σ_R, indicated as “sigmaR” in the plot) and proportion of virgin biomass (p_{virgin}). Corresponding values are shown in Table 3.

Table 3. Negative log-likelihood values associated with different combinations of parameters σ_R and p_{virgin}, as shown in Figure 5. The shaded region reflects combinations that fall within minimum (the cell with surrounding border) + 1.92, which represents the 95% confidence region for these parameter combinations (likelihood ratio criterion). The parameter combination in bold and darker shade are the values used for all modelling (i.e. σ_R=0.7 and p_{virgin}=0.75).

	p_{virgin}															
σ_R	0.25	0.3	0.35	0.4	0.45	0.5	0.55	0.6	0.65	0.7	0.75	0.8	0.85	0.9	0.95	1
0.3	388.57	385.66	383.49	381.84	380.54	379.39	378.35	377.40	376.52	375.71	374.97	374.28	373.63	373.03	372.47	371.95
0.35	382.60	379.78	377.68	376.09	374.85	373.78	372.79	371.88	371.04	370.27	369.55	368.89	368.27	367.70	367.18	366.71
0.4	378.17	375.46	373.46	371.94	370.77	369.74	368.79	367.92	367.11	366.37	365.69	365.06	364.50	363.98	363.53	363.13
0.45	374.85	372.27	370.37	368.94	367.82	366.82	365.90	365.05	364.27	363.57	362.93	362.35	361.85	361.40	361.01	360.68
0.5	372.34	369.89	368.10	366.76	365.68	364.69	363.79	362.96	362.22	361.55	360.97	360.45	360.01	359.63	359.31	359.05
0.55	370.42	368.11	366.43	365.18	364.11	363.13	362.24	361.44	360.74	360.12	359.59	359.14	358.76	358.45	358.19	357.99
0.6	368.94	366.77	365.21	364.02	362.94	361.97	361.11	360.35	359.69	359.13	358.67	358.28	357.96	357.71	357.51	357.36
0.65	367.81	365.78	364.33	363.14	362.07	361.12	360.29	359.58	358.98	358.49	358.08	357.75	357.50	357.30	357.16	357.05
0.7	366.94	365.05	363.68	362.48	361.41	360.49	359.71	359.06	358.53	358.10	**357.76**	357.49	357.29	357.15	357.05	356.99
0.75	366.28	364.53	363.17	361.97	360.93	360.06	359.34	358.76	358.30	357.93	357.65	357.44	357.29	357.19	357.13	357.12
0.8	365.78	364.15	362.77	361.58	360.59	359.79	359.14	358.63	358.23	357.93	357.70	357.54	357.44	357.39	357.37	357.39
0.85	365.42	363.83	362.45	361.30	360.38	359.65	359.08	358.64	358.30	358.06	357.89	357.78	357.72	357.71	357.73	357.78
0.9	365.17	363.55	362.20	361.12	360.28	359.63	359.13	358.76	358.49	358.30	358.18	358.12	358.10	358.12	358.18	358.26
0.95	364.93	363.31	362.02	361.03	360.27	359.71	359.28	358.98	358.77	358.64	358.57	358.54	358.56	358.62	358.70	358.81
1	364.71	363.13	361.93	361.03	360.36	359.87	359.53	359.29	359.13	359.05	359.02	359.04	359.09	359.18	359.29	359.42

Sensitivity tests

The sensitivity of the assessment model results to assumptions and modelling decisions regarding fishery selection, natural mortality, maturity, recruitment variability, the form of the stock–recruit relationship and the nature of the SSB index (whether it was a relative or absolute index) was tested. Some of the sensitivity tests resulted from requests made during the Review Workshop (held in October 2016 in Santa Rosa, California). The Review Workshop was followed by a Training Workshop (12–14 October 2016, same venue), during which the baseline model was updated with data for 2014/15 and corrections made to the SSB index for 2012/13; results for this update were included as a sensitivity test.

Stochastic projections

Stochastic projections conditioned on the baseline assessment model were conducted to estimate MSY reference points and to explore the response of the stock to increasing harvest rates.

Operating model

An operating model conditioned on the baseline assessment was developed for the purpose of the evaluation of alternative simple harvest control rules. Thus, the operating model reflects the historic and current status of the stock as well as the associated uncertainty. The uncertainty was derived from the variance-covariance matrix (based on the delta-method in ADMB; Fournier *et al*. 2012). A matrix of 1000 parameter sets, including the stock and recruitment function parameters, was used to generate 1000 historic populations, which were then projected forward for 50 years under alternative management rules. The parameter sets were drawn from a multivariate normal distribution with means equal to the model parameter estimates and the variance-covariance matrix derived from the parameter correlations and standard deviations estimated in the assessment.

An issue encountered with the variance-covariance approach was that some of the drawn parameters fell outside the bounds specified in the assessment model (ASPM). A Markov chain Monte Carlo (MCMC) approach was therefore considered to incorporate assessment uncertainty, because this approach will only sample within the constraints. However, issues were also encountered with this method; the CVs of the MCMC drawn parameters were very high and there were large differences between the averages from MCMC sampling and the fitted model parameter estimates. In particular, the parameter estimates from the best fit often fell to the edge of MCMC parameter distributions that were highly skewed to the right. This behaviour is likely related to high correlations between the estimable parameters, and was considered unsatisfactory, because large parameter draws from MCMC sampling may lead to an underestimation of risk.

To overcome the issue of multivariate normal sampled parameters falling outside the bounds specified in the ASPM, 2000 sampled parameter sets were drawn and any sets containing one or more values falling outside of the bounds were rejected. Out of 2000 draws 1144 parameter sets were accepted. The first 1000 of these were used in the ASPM to obtain starting points for the stochastic projections. To justify this method of obtaining assessment uncertainty, the distributions from the full set of parameter draws were compared with the distributions of the truncated set (Appendix 4, Figure A4.1). The point estimates from the original assessment are included for comparison, and estimates of precision reflected by two standard deviations are also included as a check that input distributions are consistent with these uncertainty estimates from the original assessment. Apart from the bounded parameters which were truncated, the distributions were consistent with each other. Hence the multivariate normal runs were considered a reasonable characterisation of the assessment uncertainty.

Management strategy evaluations (MSE, Punt *et al.* 2016) were conducted using R (R Core Team, 2014). The assessment model was run without fitting for each of the 1000 input distributions and the numbers-at-age and spawning biomass for each population in 2013 were taken as the starting point for simulations (year 0 of the projections). Each population was projected forward into the following year using A2.1–A2.4 (Appendix 2). Recruitment in each year of the projection was modelled using A2.8 (Appendix 2) but with a breakpoint at the minimum biomass (prior to projections) for that population, giving a fixed hockey-stick stock–recruit formulation (see e.g. Figure A4.2).

Length of the projection period:
Forward projections under constant harvest rates were conducted to inform on the length of the projection period. A period of 50 years for forward projections was considered appropriate because the SSB stabilises after approximately 25 years under constant harvest rates (Figure 6). Therefore, performance statistics were computed for the last 20 years of the projections to ensure that the results were not influenced by starting conditions in the simulations.

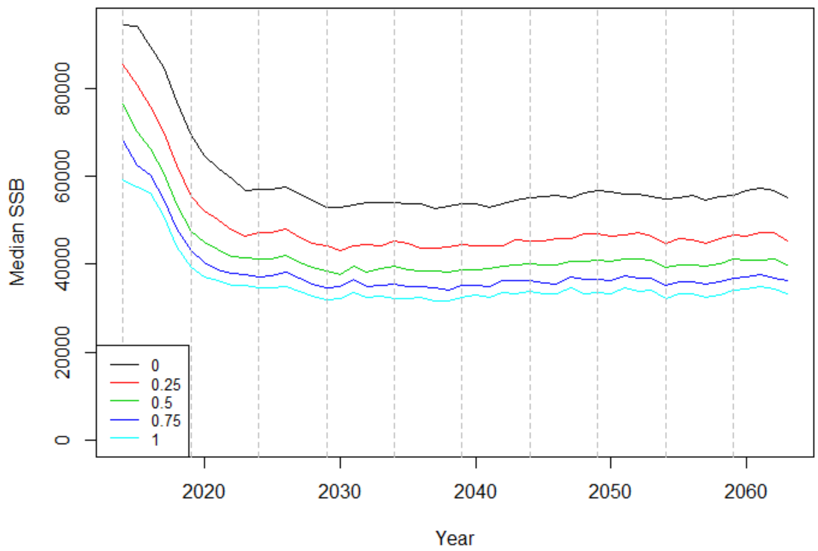

Figure 6 Forward 50-year projections under constant harvest rates: F = 0, 0.25, 0.5, 0.75 and 1.

Modelling recruitment:
It is essential to model future recruitment in a way that is consistent with what has been estimated for historic recruitment. Recruitment was generated on the basis of a fixed hockey-stick formulation (Appendix 2, A2.8-A2.10), where the SSB breakpoint was fixed at the lowest estimated SSB, and virgin recruitment (R_{virgin}) and serial correlation (ρ) were estimated based on the assessment (see Appendix 2, A2.32a for ρ). For the simulations, recruitment residuals were derived as described in Appendix 2 (A2.32b and subsequent text).

Figure A4.2 (Appendix 4) compares future recruitment generated with corresponding (i.e. based on the same SSB) historic recruitments and fixed hockey-stick fit, for a set of iterations. A combination of all populations and a cumulative recruitment distribution provides an overall comparison of historic (red) and corresponding future (black) recruitment (Figure A4.3, Appendix 4) and indicates that the approach followed provides a plausible basis for generating recruitment; therefore, it was adopted for subsequent work.

Mean weights, maturity, natural mortality and selection:
For the simulations, future weights at age were fixed equal to those measured in 2013 (Appendix 1, Table A1.4). Examination of the historic series suggest a slight decline in weight for ages 3 and older from 2000 on. The time-series for age 2 is noisier. The uncertainty in SSB may be marginally under-represented as a result of this assumption of fixed future weights.

Maturity values used for the assessment are shown in Table A1.2 (Appendix 1). Simulations assume that maturity will remain constant for future years at those values. Natural mortality M is assumed to be 0.53 per year (age- and year-invariant for ages 1 to 5) and is 1.95 for age 6 due to the application of μ^{pgp} ($M_{y,6} = \mu^{pgp} M$; Table 4a). These assumptions are maintained for future years in the simulations.

Each population in future simulations has its own selection pattern with parameters drawn from the multivariate distributions shown in Appendix 4, Figure A4.1 (reflecting the uncertainty of the selection pattern from the 1998–2013 separable period of the baseline assessment), which remains constant going forward.

Converting the HCR into realised catch:
No implementation error is assumed. The TAC from the HCR is assumed to be fully taken, apart from cases where, at high exploitation levels, the TAC is set higher than the amount of fish available to the fishery, in which case the realised catch will be smaller than the TAC. A2.2 and A2.3 (Appendix 2) are used (replacing the catch tonnage C_y^f with the TAC, and capping the harvest rate F_y^f to be no greater than 1) to convert the TAC to a harvest rate by age, which is then implemented in the operating model (through A2.1, Appendix 2).

Performance statistics:
In order to evaluate the performance of the HCRs tested, a set of performance indicators was defined. The performance statistics used to evaluate the different HCRs were as follows:

Risk – average probability of Spawning Stock Biomass (B_y^{sp}) being below Blim, where the average is taken across the years of the projection periods.

$$\text{risk} = \frac{100}{N_{yr}} \sum_{y=1}^{N_{yr}} \left[\frac{\sum_{it=1}^{N_{iter}} I[B_{it,y}^{sp} < \text{Blim}]}{N_{iter}} \right]$$

where y indicates the year in the final 20 years of the projection period (N_{yr}=20), it the iteration number (N_{iter}=1000) and

$$I[B_{it,y}^{sp} < \text{Blim}] = \begin{cases} 1 & , B_{it,y}^{sp} < \text{Blim} \\ 0 & , B_{it,y}^{sp} \geq \text{Blim} \end{cases}$$

Mean SSB – median of the mean Spawning Stock Biomass of the projection period across iterations.

$$\text{Mean SSB} = P_{50}^{it}\left(\sum_{y=1}^{N_{yr}} B_{it,y}^{sp} / N_{yr} \right)$$

where y, N_{yr} and it are as above, and $P_{50}^{it}()$ calculates the median of the 1000 iterations.

Mean Yield – median of the mean of the total catch (C_y^f) for different projection periods across iterations.

$$\text{Mean Yield} = P_{50}^{it}\left(\sum_{y=1}^{N_{yr}} C_{it,y}^{f} / N_{yr} \right)$$

where y, N_{yr}, it and $P_{50}^{it}()$ are as above.

The harvest control rule

A harvest control rule (HCR) was defined where a pre-set fraction of the exploitable biomass (harvest rate F) can be taken when the SSB is greater than Bpa. This fraction is reduced linearly to zero when the SSB is less than Bpa:

$$TAC_y = \begin{cases} F\hat{B}_y^{ex} & , \hat{B}_y^{sp} > \text{Bpa} \\ F\hat{B}_y^{ex}\hat{B}_y^{sp}/\text{Bpa} & , \hat{B}_y^{sp} \leq \text{Bpa} \end{cases} \qquad (1)$$

where

$$\hat{B}_y^{ex} = \left(\sum_{a=0}^{a_{pg}} w_{a+\frac{1}{2}} S_a^f N_{y,a} e^{-M_a/2} \right) e^{\hat{\varepsilon}_y}$$

and

$$\hat{B}_y^{sp} = B_y^{sp} e^{\hat{\varepsilon}_y}$$

The quantities $B_y^{sp}, w_{a+\frac{1}{2}}, S_a^f, N_{y,a}$ and M_a are all taken from the operating model (note that the y subscript is no longer needed for selectivity and natural mortality because only the most recent selection pattern is used for the former, and the oil-spill factor is not used in projections for the latter), whereas the exploitable biomass $\hat{B}_y^{ex}$ and SSB $\hat{B}_y^{sp}$ are "perceived" quantities as a result of application of the assessment model. (In the simulations presented, the assessment model is not actually applied, but its application is approximated by adding assessment error, where $\hat{\varepsilon}_y$ above [same for perceived exploitable biomass and SSB] is taken from a normal distribution with mean zero and standard deviation 0.3.) One thousand 50-year-forward simulations were conducted to evaluate the HCRs proposed in terms of mediane recruitment, SSB and yields.

Results

From initial model to baseline model

Preliminary runs were carried out with the fixed hockey stick to initialize recruitment, with natural mortality fixed at 0.27 (which was the best estimate based on a likelihood profile), and allowing the model to estimate all selectivity parameters. This constituted the initial model (model 1 in Table 4a and Appendix 3). However, the approach resulted in domed selection for the commercial fleet (model 1 in Appendix 3, first "estimates" plot), and as a result, in an accumulation of older ages in the population, which appeared to be unrealistic. An additional concern was the oil spill in late 2007 that may have had a detrimental effect on San Francisco Bay herring (although it must be stressed that there is no direct evidence for this). Several trials were carried out to investigate these concerns.

(a) Oil spill factor

In order to address the potential effects of the oil spill on the herring population, a mortality factor (μ^{oil}) for the 2007/8 season, constant across all ages, was introduced (model 2 in Table 4a and Appendix 3). Introduction of this factor led to a significant improvement in model fit (compare $-\ln L$ for models 1 and 2 in Table 4a).

(b) Flat-topped commercial selectivity

Dome selection is estimated for both the commercial and research catches because there are fewer fish in the plus-group (fish aged 6 and older) than expected given the level of natural mortality M (Figure 7, model 1). Dome selection in commercial catches can imply a "cryptic" biomass, not seen by either the fishery or surveys, which nevertheless contributes towards production (through the SSB–recruit relationship), potentially making the stock resilient to fishing. Assuming flat-topped selection for at least one of the selectivity curves is one way of reducing problems introduced by cryptic biomass. Commercial catches were selected for mimicking flat-topped selection because Figure 7 (model 1) shows a stronger dome effect for research catches (predominantly trawl) than for commercial catches (gillnet in recent years).

To investigate the effect of flat-topped selection in the commercial catches, selectivity at age 6 was set equal to that at age 5 ($\Phi^f_{y,6} = \Phi^f_{y,5}$) for both selectivity periods (1992–1997, 1998–2013). This is the only additional constraint imposed on model 1, resulting in model 3 (Table 4a) which has two fewer parameters than model 1 (one fewer selectivity parameter per selectivity period). Selectivity associated with research catches continued to be freely estimated, and continued to indicate dome selection (Figure 7, right plot).

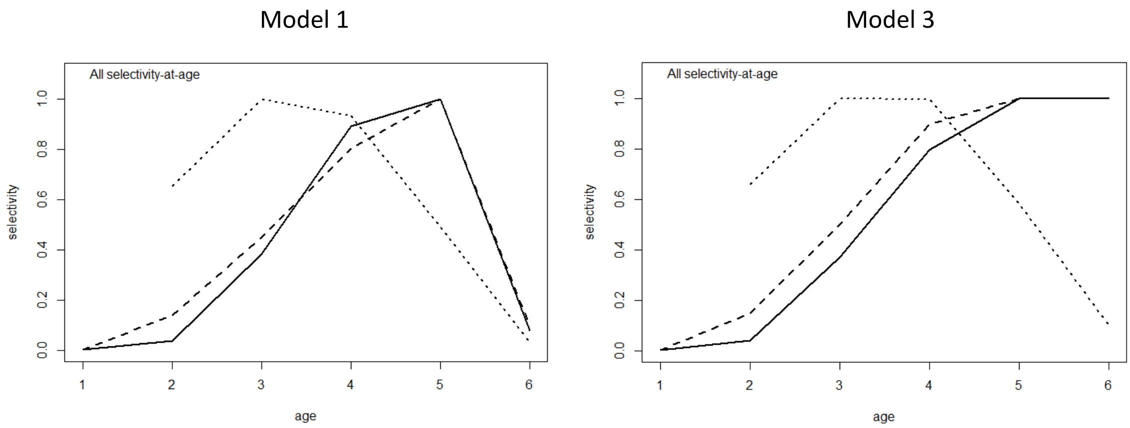

Figure 7 Selectivity-at-age for commercial (dashed = 1992–1997, solid = 1998–2013) and research (dotted) catches for models 1 and 3.

(c) Plus-group natural mortality

Another feature of model 3 is a strong deterioration in model fit (compare $-\ln L$ between models 1 and 3 in Table 4a, but also the poor fits to the commercial proportions-at-age data in Appendix 3 for model 3). This is because the model expects to see many more plus-group (age 6) fish than are available in the data, given M and flat-topped selection. One way around this is to introduce a multiplicative factor, μ^{pgp}, which can be applied to age 6 (Appendix 2). This factor does not necessarily indicate additional natural mortality, but could indicate that the older fish disappear from the area, for example. With the introduction of μ^{pgp}, model 4 shows a significant improvement in fit relative to model 3

(Table 4a), with a large improvement in the fits to the commercial proportions-at-age data (Appendix 3, model 4).

Model 5 combines (a)–(c), showing a significant improvement in model fit over model 4 (Table 4a). However, the M value is still the same as model 1 (M=0.27), and has not been optimized (in likelihood terms) for this model configuration. In order to do so, a likelihood profile over M was performed, indicating a minimum negative log-likelihood at M=0.53 (Figure 8). This is adopted as the M value for model 6 (Table 4a, Appendix 3). In order to better facilitate comparisons with models 1–4, these latter models were re-run for M=0.53, with results shown in Table 4b (models 1b–4b, along with model 6).

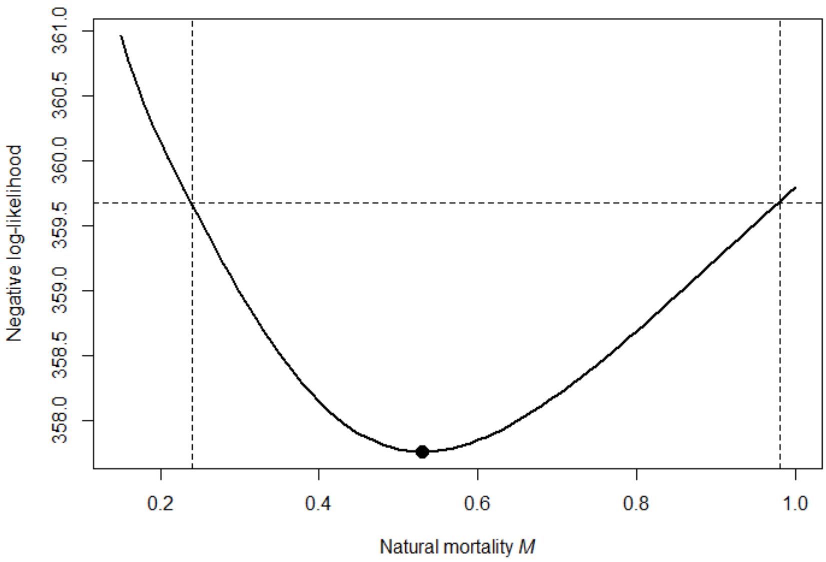

Figure 8 Likelihood profile for natural mortality (M), model 5/6 in Table 4a. Best M=0.53; 95% confidence intervals (minimum function value+1.92): 0.24 – 0.98.

Table 4a. Key model outputs for model 1: the initial model; model 2: model 1 + multiplicative factor (μ^{oil}) for M in 2007; model 3: model 1 + flat topped selection in the commercial fishery (by setting $\Phi^f_{y,6} = \Phi^f_{y,5}$); model 4: model 3 + multiplicative factor (μ^{pgp}) for M at age 6; model 5: model 4 + μ^{oil}; and model 6: the baseline model, which is model 5 but with M fixed at 0.53 (as shown in Figure 7). Values in parentheses are CVs (standard deviation over mean).

Settings/Parameters/Diagnostics	Initial Model 1	Model 2	Model 3	Model 4	Model 5	Baseline Model 6
Settings						
2007 M factor, μ^{oil}		✓			✓	✓
Age 6 M factor, μ^{pgp}				✓	✓	✓
Flat topped commercial selectivity (set $\Phi^f_{y,6} = \Phi^f_{y,5}$)			✓	✓	✓	✓
M obtained by likelihood profile (optimum value)	✓					✓
Input parameters						
M	0.27	0.27	0.27	0.27	0.27	0.53
σ_R	0.7	0.7	0.7	0.7	0.7	0.7
p_{virgin}	0.75	0.75	0.75	0.75	0.75	0.75
Estimated general parameters						
K^{sp}	64162 (0.19)	46218 (0.14)	31670 (0.10)	84448 (0.42)	56964 (0.24)	74370 (0.23)
R_{virgin}	228433 (0.19)	164549 (0.14)	112754 (0.10)	461683 (0.42)	308786 (0.25)	861149 (0.23)
μ^{oil}	-	5.898 (0.23)	-	-	2.415 (0.26)	2.614 (0.23)
μ^{pgp}	-	-	-	9.769 (0.10)	8.076 (0.14)	3.676 (0.14)
Recruitment serial correlation ρ	0.715 (0.038)	0.722 (0.072)	0.705 (0.064)	0.704 (0.060)	0.729 (0.058)	0.739 (0.059)
Estimated constant of proportionality parameters						
SSB index $q^{s=ssb}$	0.583 (0.27)	1.024 (0.19)	1.358 (0.11)	0.367 (0.49)	0.612 (0.31)	0.449 (0.28)
Recruitment index $q^{s=rec}$	1.264 (0.22)	1.654 (0.16)	2.219 (0.11)	0.625 (0.46)	0.952 (0.27)	0.336 (0.26)
Estimated variability parameters						
SSB index $v^{s=ssb}_{adv}$	0.722 (0.15)	0.758 (0.16)	0.754 (0.15)	0.662 (0.15)	0.650 (0.15)	0.617 (0.16)
Recruitment index $v^{s=rec}_{adv}$	0.634 (0.16)	0.707 (0.17)	0.696 (0.16)	0.623 (0.16)	0.640 (0.16)	0.672 (0.17)
Commercial proportions σ^f_p	0.122 (0.062)	0.113 (0.048)	0.236 (0.033)	0.142 (0.041)	0.133 (0.047)	0.135 (0.042)
Research proportions σ^s_p	0.106 (0.086)	0.112 (0.072)	0.102 (0.045)	0.095 (0.059)	0.100 (0.068)	0.097 (0.060)
Likelihood contributions						
Total (-ln$L$)	**355.81**	**349.85**	**437.97**	**363.38**	**359.32**	**357.76**
SSB index	24.10	25.16	25.05	22.19	21.81	20.67
Recruitment index	20.30	22.56	22.23	19.94	20.48	21.52
Commercial proportions	223.07	213.51	306.54	242.27	234.66	236.62
Research proportions	62.95	67.65	59.94	53.78	57.79	55.24
Stock-recruit	25.39	20.96	24.21	25.21	24.58	23.71
Other diagnostics						
Estimable parameters	39	40	37	38	39	39
Maximum gradient component	3.511e-5	6.679e-5	5.096e-5	7.256	2.790e-5	5.961e-5

Table 4b. As for Table 4a, but M is set equal to 0.53 for all models. [Note, model 5 is not repeated because model 6 is in effect model 5 with M=0.53.]

Settings/Parameters/Diagnostics	**Initial Model 1b**	**Model 2b**	**Model 3b**	**Model 4b**	**Baseline Model 6**
Settings					
2007 M factor, μ^{oil}		✓			✓
Age 6 M factor, μ^{pgp}				✓	✓
Flat topped commercial selectivity (set $\Phi^f_{y,6} = \Phi^f_{y,5}$)			✓	✓	✓
M obtained by likelihood profile (optimum value)					✓
Input parameters					
M	0.53	0.53	0.53	0.53	0.53
σ_R	0.7	0.7	0.7	0.7	0.7
p_{virgin}	0.75	0.75	0.75	0.75	0.75
Estimated general parameters					
K^{sp}	97278 (0.36)	74068 (0.19)	44751 (0.13)	143316 (0.74)	74370 (0.23)
R_{virgin}	1002020 (0.36)	762938 (0.19)	460963 (0.31)	1671320 (0.74)	861149 (0.23)
μ^{oil}	-	2.942 (0.25)	-	-	2.614 (0.23)
μ^{pgp}	-	-	-	4.627 (0.11)	3.676 (0.14)
Recruitment serial correlation ρ	0.708 (0.060)	0.750 (0.057)	0.708 (0.057)	0.693 (0.065)	0.739 (0.059)
Estimated constant of proportionality parameters					
SSB index $q^{s=ssb}$	0.318 (0.44)	0.490 (0.25)	0.737 (0.12)	0.198 (0.82)	0.449 (0.28)
Recruitment index $q^{s=rec}$	0.292 (0.41)	0.385 (0.22)	0.603 (0.12)	0.169 (0.79)	0.336 (0.26)
Estimated variability parameters					
SSB index $v^{s=ssb}_{adv}$	0.641 (0.15)	0.638 (0.16)	0.641 (0.15)	0.625 (0.15)	0.617 (0.16)
Recruitment index $v^{s=rec}_{adv}$	0.629 (0.16)	0.697 (0.17)	0.670 (0.16)	0.620 (0.16)	0.672 (0.17)
Commercial proportions σ^f_p	0.135 (0.043)	0.131 (0.041)	0.190 (0.036)	0.144 (0.039)	0.135 (0.042)
Research proportions σ^s_p	0.095 (0.058)	0.096 (0.058)	0.097 (0.051)	0.093 (0.055)	0.097 (0.060)
Likelihood contributions					
Total (-ln$L$)	**357.54**	**353.96**	**402.38**	**362.69**	**357.76**
SSB index	21.50	21.40	21.49	20.95	20.67
Recruitment index	20.14	22.26	21.43	19.82	21.52
Commercial proportions	236.64	232.44	279.46	244.81	236.62
Research proportions	53.67	54.18	55.08	52.10	55.24
Stock-recruit	25.60	23.67	24.92	25.00	23.71
Other diagnostics					
Estimable parameters	39	40	37	38	39
Maximum gradient component	8.066e-5	9.445e-5	2.215e-5	8.453e-5	5.961e-5

Baseline model

Model 6 was adopted as the baseline model in this study (Table 4a). This was based on the difficulty in justifying the cryptic biomass present in models 1 and 2, which was reduced by the introduction of flat-topped commercial selection and plus-group mortality factor, μ^{pgp} (to counteract the deterioration in fit caused by forcing flat-topped selection), and the fact that inclusion of the oil spill factor, μ^{oil}, for 2007 significantly improved the overall model fit.

Model fits and residuals:
Model fits to the SSB and recruitment indices are shown in Figure 9. The fit to the SSB index is acceptable, although the model is still unable to follow some of the rapid year-to-year changes in the index. Variability in the survey index is large given factors such as environmental conditions, predation, variability in temporal and spatial spawning activity that would influence the survey estimates (Spratt 1976, Watters and Oda 1997), which are not factored into the assessment model. However, we agree with MacCall *et al.* (2003) in their assessment review that the spawning survey should be the primary abundance estimate for stock assessment. Similar considerations regarding variability apply to the fit to the recruitment index. No obvious residual patterns are apparent.

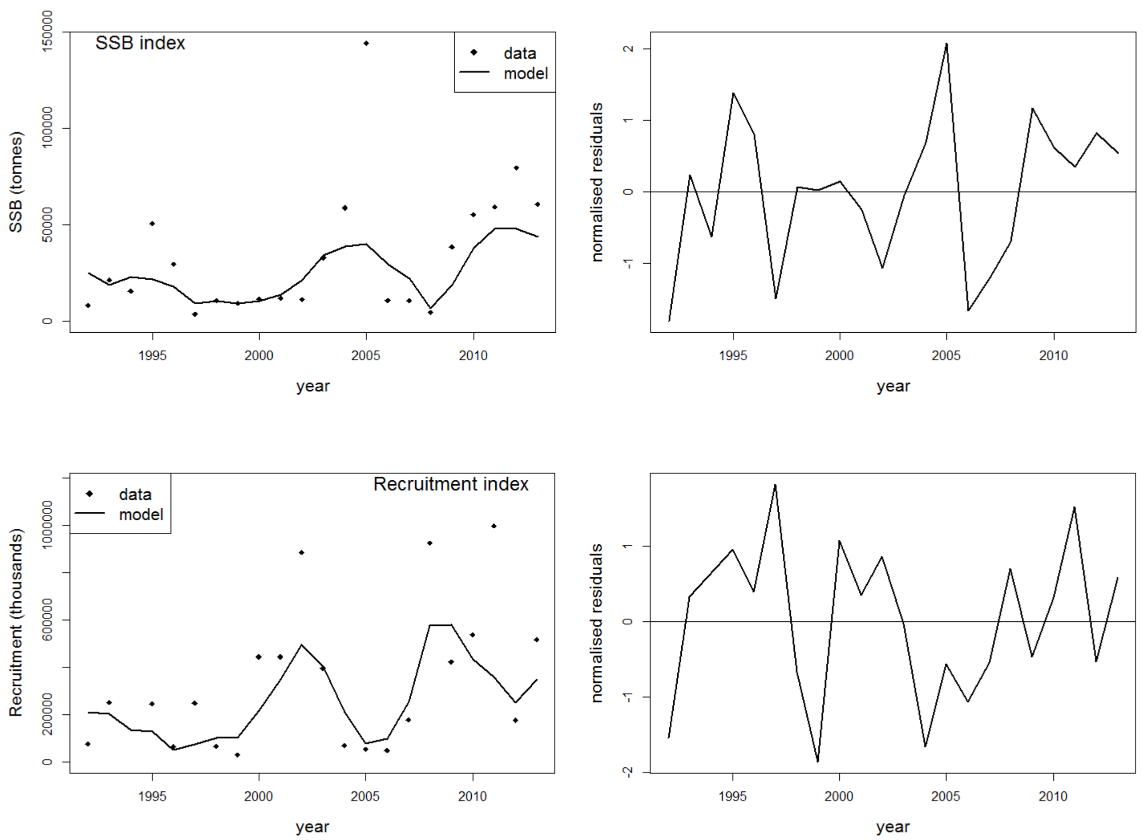

Figure 9 Baseline model 6 fits to the SSB (top) and Recruitment (bottom) indices, with model fits to the data on the left and residual plots on the right. The normalized residuals are $L^{s}_{U,nres}(y)$ (Appendix 2, A2.27).

Fits to the commercial and research catch-at-age data, expressed as proportions-at-age, are shown in Figure 10. Model averages agree well with the data averages (left plots in Figure 10). Although some residual patterns are evident in the case of the commercial catch-at-age, those have been reduced by the assumption of two separable periods. The SSB–recruitment pairs are shown in Figure 11, together with residuals from the stock-recruit fit (see Appendix 2, A2.8). The residual patterns indicate the presence of auto-correlation (estimated at $\rho = 0.739$, Table 4a).

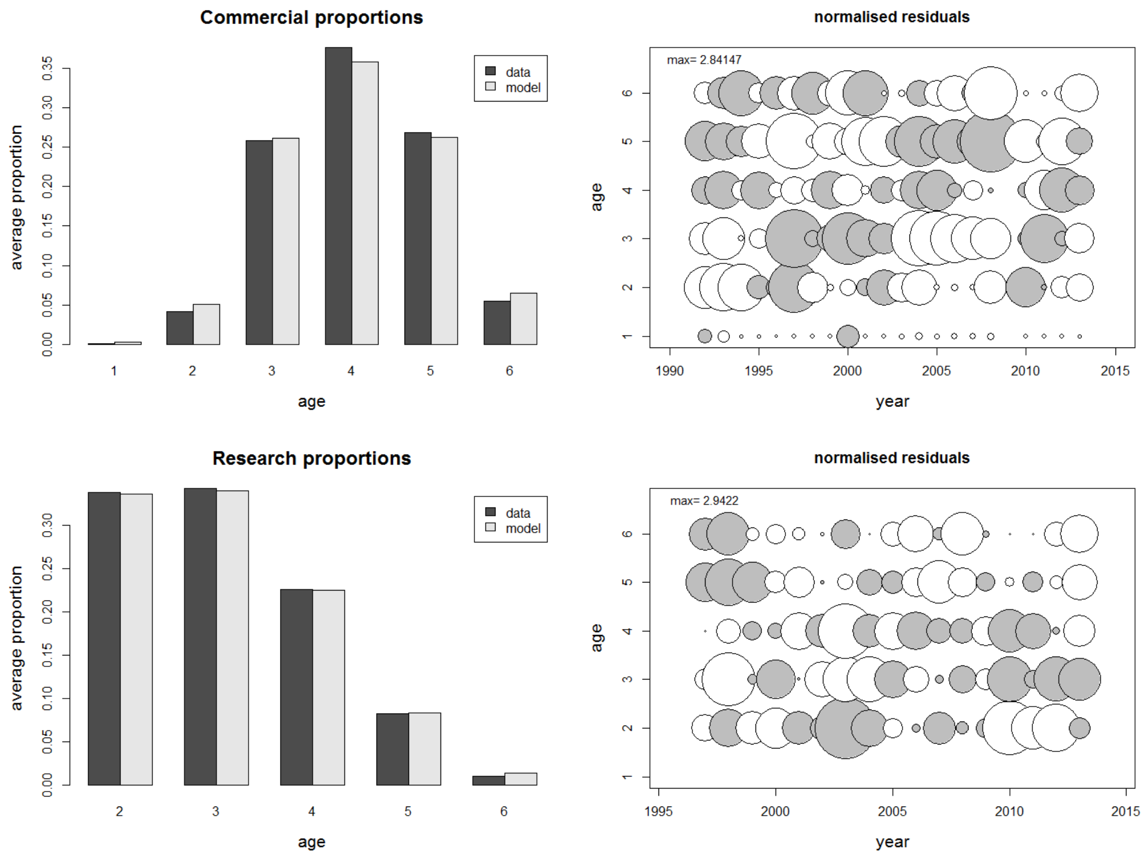

Figure 10 Baseline model 6 fits to the Commercial (top) and Research (bottom) catch-at-age data, with model fits on the left (shown as average over the period for which data are available) and residual bubble plots on the right. In the bubble plots white bubbles indicate negative residuals, and grey bubbles positive; furthermore, the area of bubbles is proportional to the size of the residual, and the "max" value indicated in the top left of the plot relates to the maximum absolute value of residuals shown in the plot (i.e. the size of the largest bubble). The normalized residuals are $L^{j}_{p,nres}(y,a)$ (Appendix 2, A2.29).

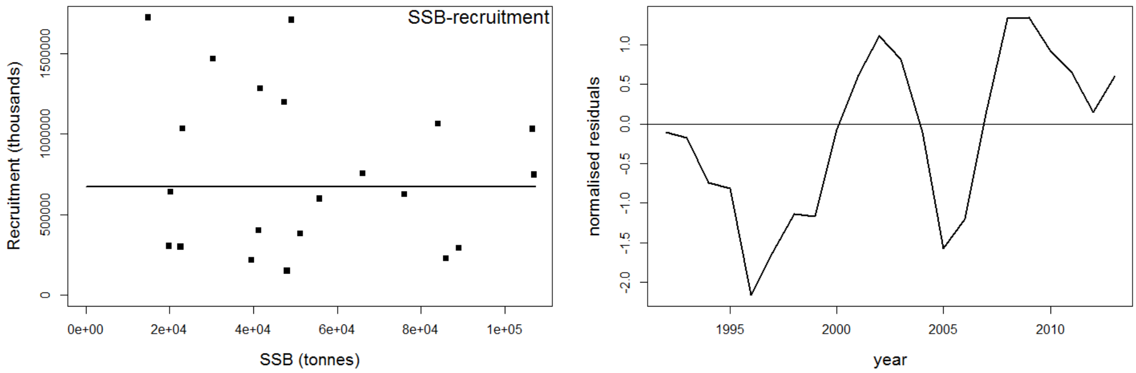

Figure 11 Baseline model 6: SSB-recruitment pairs with stock–recruit relationship estimated by the simple stock–recruit form (Appendix 2, A2.8) and corresponding residuals (right). The normalized residuals are $L_{R,nres}(y)$ (Appendix 2, A2.31), but note ρ is set to zero for the estimation (so $L_{R,nres}(y) = \varepsilon_y / \sigma_R$), and only calculated after the model fit (via Appendix 2, A2.32a).

Model estimates:

Figure 12 provides estimates of population trends with confidence intervals estimated as ±2 standard deviations (approximately 95% confidence limits). The stock biomass seems to have recovered after low recruitment in 2005/06 and the potentially detrimental effects of the oil spill in late 2007. Uncertainty is, however, large in recent years. The harvest rate is estimated to be low in the recent period.

Retrospective plots corresponding to Figure 12 are shown in Figure 13. These are obtained by “shaving” off one year of data at a time and re-running the assessment; this was done for five years. These retrospective plots show reasonably good behaviour, with retrospective curves well within the 95% confidence limits. SSB has a slight tendency for under-estimation, which is more pronounced for recruitment.

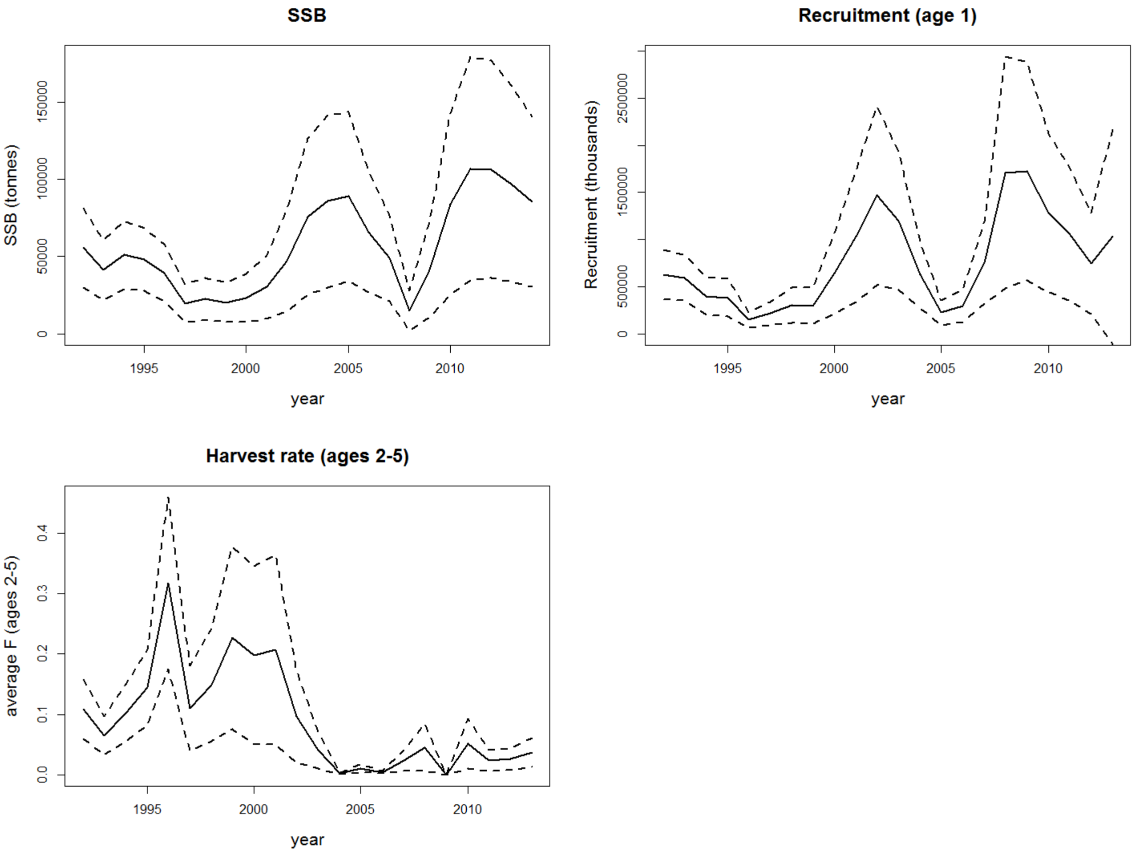

Figure 12 Baseline model 6 population estimates with ± 2 standard deviations: SSB (top left) in tonnes, Recruitment at age 1 in thousands (top right) and harvest rate F averaged over ages 2–5 (bottom). [Note, the SSB plot includes one more year than the others.]

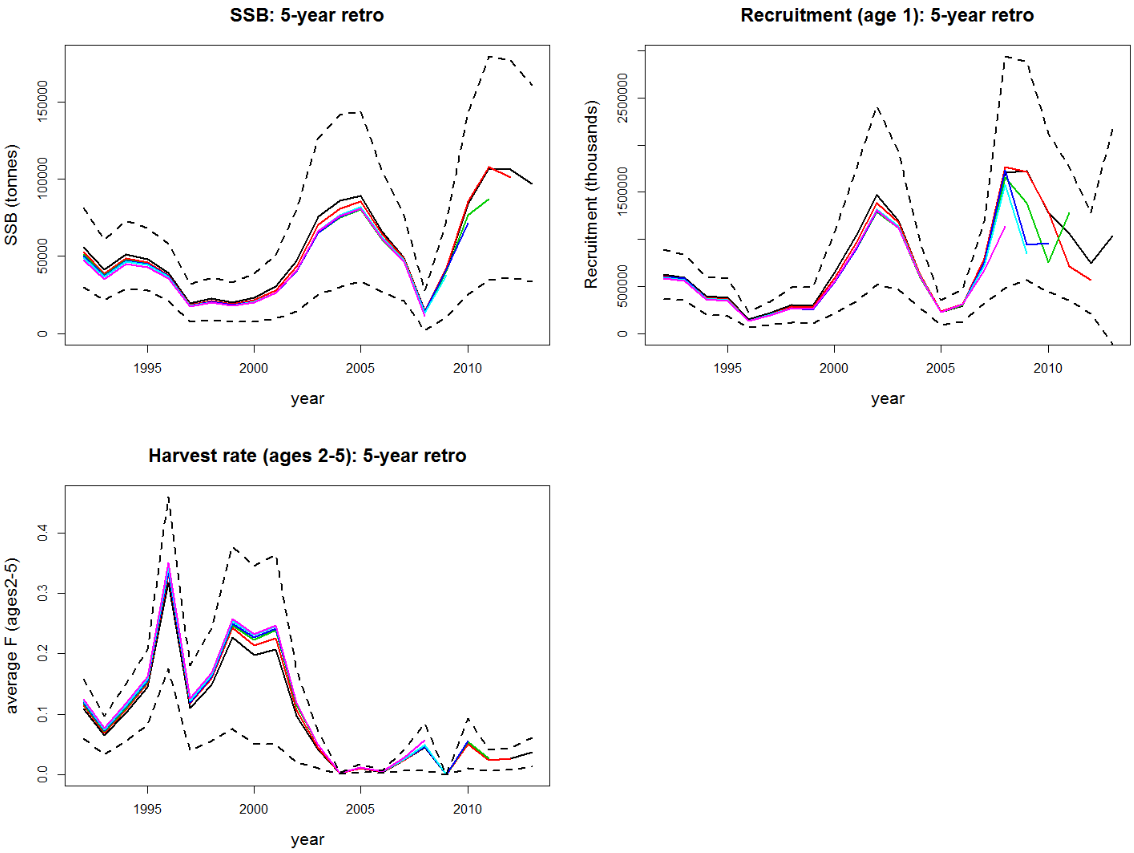

Figure 13 Baseline model 6 five-year retrospective plots corresponding to Figure 12. [Note, the SSB plot has one less year than the corresponding curve in Figure 12, so that only years for which data exist are shown.]

Estimates of the commercial and research catch selectivity curves are provided in Figure 14. The numbers of plus-group age 6 fish in the research catch are very low relative to the numbers expected by the model, so selection is estimated to be rather low for this age group.

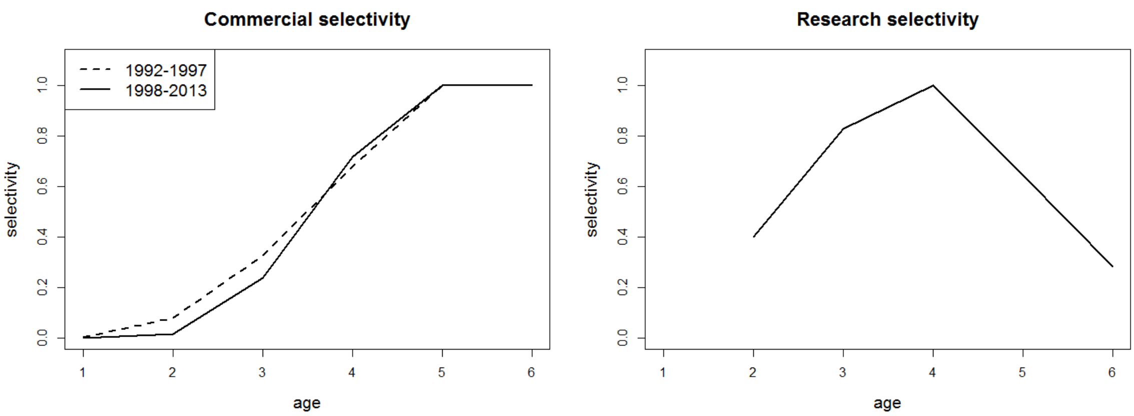

Figure 14 Baseline model 6 estimates of selectivity-at-age for commercial (left) and research catches (right). Two separable periods were fitted to the commercial data, where the dashed line corresponds to the period 1992-1997 and the solid line corresponds to fishery selectivity for 1998-2013.

Sensitivity tests

Results from sensitivity tests relative to fishery selection, natural mortality, maturity, recruitment variability, the form of the stock–recruit relationship and the nature of the SSB index (whether it was a relative or absolute index) are presented in the following sections.

Fishery selection:
The baseline model (model 6) only accounts for a commercial selectivity change between 1997 and 1998. However, apart from the cessation of round-haul catches in 1998, there was also a mesh-size reduction, implemented from 2004 on, for commercial catches, and these sensitivity runs attempted to account for this change and to assess its impact. Model 7 shifts the selectivity change to between 2003 and 2004 (ignoring the earlier change between 1997 and 1998). This leads to a deterioration in model fit, and much greater uncertainty in model outputs relative to the baseline model (Table 5). Model 8 includes both changes (i.e. between 1997 and 1998, and between 2003 and 2004), where the selectivity in the period between these two changes (covering the years 1998–2003) is modelled as a linear interpolation between the selectivity of the first period (1992–1997) and that of the last period (2004–2013). There is a slight deterioration in model fit relative to the baseline model, and parameters (particularly those dealing with scale) are less precisely estimated (Table 5). Model 9 optimizes model 8 for M (through likelihood profiling), resulting in an increase in M from 0.53 to 0.64; although the model fit is slightly improved, precision of estimated parameters deteriorates slightly, and both elements (model fit and precision) are slightly worse than the baseline model (Table 5). There was therefore no justification for changing the baseline model.

Table 5 Key model outputs for sensitivity runs investigation commercial selectivity. Model 6: baseline model (see Table 4a); model 7: model 6 but selectivity period change occurs in 2003–2004 instead of 1997–1998; model 8: model 6 but with three selectivity periods, the first 1992–1997, the third 2004–2013, and the second a linear interpolation between the first and third; model 9: model 8 but with M fixed at 0.64 (optimum value based on a likelihood profile). Values in parenthesis are CVs.

Settings/Parameters/Diagnostics	**Baseline Model 6**	**Model 7**	**Model 8**	**Model 9**
Settings				
Selectivity periods	1992-1997 1998-2013	1992-2003 2004-2013	1992-1997 linear interpolation 2004-2013	1992-1997 linear interpolation 2004-2013
M obtained by likelihood profile (optimum value)	✓			✓
Input parameters				
M	0.53	0.53	0.53	0.64
σ_R	0.7	0.7	0.7	0.7
p_{virgin}	0.75	0.75	0.75	0.75
Estimated general parameters				
K^{sp}	74370 (0.23)	119727 (0.72)	74762 (0.29)	94128 (0.32)
R_{virgin}	861149 (0.23)	1389550 (0.73)	864627 (0.29)	1459840 (0.33)
μ^{oil}	2.614 (0.23)	2.452 (0.25)	2.830 (0.24)	2.649 (0.22)
μ^{pgp}	3.676 (0.14)	3.925 (0.14)	3.559 (0.15)	2.940 (0.14)
Recruitment serial correlation ρ	0.739 (0.059)	0.718 (0.068)	0.750 (0.058)	0.748 (0.060)
Estimated constant of proportionality parameters				
SSB index $q^{s=ssb}$	0.449 (0.28)	0.253 (0.82)	0.459 (0.37)	0.351 (0.40)
Recruitment index $q^{s=rec}$	0.336 (0.26)	0.195 (0.77)	0.339 (0.35)	0.199 (0.36)
Estimated variability parameters				
SSB index $v_{adv}^{s=ssb}$	0.617 (0.16)	0.628 (0.16)	0.616 (0.16)	0.610 (0.16)
Recruitment index $v_{adv}^{s=rec}$	0.672 (0.17)	0.642 (0.17)	0.669 (0.17)	0.676 (0.17)
Commercial proportions σ_p^f	0.135 (0.042)	0.138 (0.043)	0.136 (0.042)	0.137 (0.041)
Research proportions σ_p^s	0.097 (0.060)	0.098 (0.063)	0.097 (0.060)	0.096 (0.059)
Likelihood contributions				
Total (-ln$L$)	**357.76**	**359.58**	**358.03**	**357.83**
SSB index	20.67	21.05	20.65	20.41
Recruitment index	21.52	20.55	21.42	21.63
Commercial proportions	236.62	239.09	236.90	237.75
Research proportions	55.24	56.34	55.52	54.67
Stock-recruit	23.71	22.56	23.54	23.36
Other diagnostics				
Estimable parameters	39	39	39	39
Maximum gradient component	5.961e-5	3.141e-5	4.634e-5	3.506e-5

Natural mortality:

Natural mortality is assumed to be constant by age and over time, apart from mortality factors in 2007 (μ^{oil}) and for plus-group age 6 (μ^{pgp}). The former is because of the possibility that the oil spill in late 2007 may have had a detrimental effect on herring in San Francisco Bay, and the latter because plus-group age 6 fish are less abundant in both the commercial and research catches than expected for a natural mortality of around 0.5, under the assumption that the commercial selectivity is flat-topped (based on commercial selectivity considerations).

Excluding the 2007 mortality factor (μ^{oil}) leads to significantly poorer model fits in likelihood terms (compare e.g. model 4 to model 5 in Table 4a), to higher estimates of M when selecting M based on profiling the likelihood (0.73 for model 4 [results not shown] compared with 0.53 for model 5), and to substantially greater model uncertainty. Even though there is no direct evidence for the detrimental effect the oil spill may have had on herring mortality, the inclusion of μ^{oil} significantly improves the model fit and reduces model uncertainty; μ^{oil} was therefore kept. It should be noted that the cohorts that would have been affected by this mortality factor are no longer present in the population.

Tanasichuk (1999) uses a particular formulation for estimating natural mortality-at-age, namely:

$$M_a = \alpha e^{\beta a}$$

where α and β are parameters, and *a* represents age. The values for α and β estimated by Tanasichuk for adult Pacific herring off southern British Columbia were 0.14 and 0.18 respectively, and hypothesise increasing natural mortality with age for adult fish. In order to check whether this approach could deal with the high natural mortality factor the model needs for plus-group age 6 in order to fit the data, two additional sensitivity runs were performed where α and β were estimated (by simultaneously profiling the likelihood over these parameters) with (model 10) and without (model 11) the plus-group age 6 mortality factor (μ^{pgp}; Table 6). It is clear from these results that omitting μ^{pgp} leads to unrealistically low estimates of natural mortality for ages 1–3, and a high natural mortality for plus-group age 6 still results, so introducing the Tanasichuk formulation for M does not solve the need for a high natural mortality for plus-group age 6. The simpler formulation of M=0.53 with a higher natural mortality for plus-group age 6 (through application of μ^{pgp}) was therefore kept. Model outputs for the three models (6, 10 and 11) are given in Table 7 (along with two other models dealing with M discussed below)

Table 6 Natural mortality for the baseline model 6, and for two versions of the Tanasichuk (1999) formulation (one with μ^{pgp}, and one without).

	1	**2**	**3**	**4**	**5**	**6**
Baseline model 6	0.53	0.53	0.53	0.53	0.53	1.95
Model 10: Tanasichuk with μ^{pgp} (α=0.25, β=0.18)	0.30	0.36	0.43	0.51	0.61	1.81
Model 11: Tanasichuk without μ^{pgp} (α=0.03, β=0.67)	0.06	0.11	0.22	0.44	0.86	1.67

Table 7 Key model outputs for sensitivity runs investigating alternative natural mortality formulations. Model 6: baseline model (see Table 4a); model 10: model 6, but natural mortality follows the Tanasichuk formulation, including μ^{pgp}; model 11: model 10, but excluding μ^{pgp}; model 12: model 6, but M is directly estimated (instead of being fixed or obtained by likelihood profile); model 13: model 6, but excluding μ^{pgp}. Models 12 and 13 were requested as part of the Review Workshop. Values in parentheses are CVs.

Settings/Parameters/Diagnostics	**Baseline Model 6**	**Model 10**	**Model 11**	**Model 12**	**Model 13**
Settings					
Tanasichuk formulation for M		✓	✓		
μ^{pgp} included	✓	✓			
M estimated (i.e. not fixed are obtained by likelihood profile)				✓	
Input parameters					
M	0.53	Table 6	Table 6	0.530 (0.30)	0.53
σ_R	0.7	0.7	0.7	0.7	0.7
p_{virgin}	0.75	0.75	0.75	0.75	0.75
Estimated general parameters					
K^{sp}	74370 (0.23)	67350 (0.21)	64821 (0.19)	74367 (0.37)	45478 (0.12)
R_{virgin}	861149 (0.23)	507089 (0.21)	274280 (0.19)	861079 (0.76)	468448 (0.12)
μ^{oil}	2.614 (0.23)	2.962 (0.24)	2.675 (0.18)	2.614 (0.24)	3.892 (0.18)
μ^{pgp}	3.676 (0.14)	2.452 (0.15)	-	3.676 (0.34)	-
Recruitment serial correlation ρ	0.739 (0.059)	0.734 (0.056)	0.711 (0.053)	0.739 (0.059)	0.724 (0.076)
Estimated constant of proportionality parameters					
SSB index $q^{s=ssb}$	0.449 (0.28)	0.502 (0.26)	0.511 (0.23)	0.449 (0.44)	0.812 (0.11)
Recruitment index $q^{s=rec}$	0.336 (0.26)	0.573 (0.23)	1.061 (0.22)	0.337 (0.78)	0.558 (0.12)
Estimated variability parameters					
SSB index $v_{adv}^{s=ssb}$	0.617 (0.16)	0.620 (0.16)	0.621 (0.15)	0.617 (0.16)	0.648 (0.16)
Recruitment index $v_{adv}^{s=rec}$	0.672 (0.17)	0.663 (0.16)	0.636 (0.16)	0.672 (0.17)	0.767 (0.17)
Commercial proportions σ_p^f	0.135 (0.042)	0.136 (0.042)	0.138 (0.041)	0.135 (0.045)	0.180 (0.030)
Research proportions σ_p^s	0.097 (0.060)	0.096 (0.059)	0.094 (0.057)	0.097 (0.064)	0.095 (0.048)
Likelihood contributions					
Total (-ln$L$)	**357.76**	**357.41**	**358.08**	**357.76**	**393.30**
SSB index	20.67	20.79	20.82	20.67	21.73
Recruitment index	21.52	21.23	20.37	21.52	24.27
Commercial proportions	236.62	236.89	238.68	236.62	272.53
Research proportions	55.24	54.33	52.56	55.24	53.32
Stock-recruit	23.71	24.18	25.65	23.71	21.45
Other diagnostics					
Estimable parameters	39	39	38	39	38
Maximum gradient component	5.961e-5	9.779e-5	4.675e-5	7.193e-5	2.811e5

Additional sensitivity tests (conducted during review):

A number of additional sensitivity tests were requested during the Review Workshop. These related to natural mortality (models 12 and 13), increased age 2 maturity (model 14), stronger flat-topped commercial selectivity (model 15), increased recruitment variability (model 16), a change to Beverton–Holt stock-recruit formulation (model 17) and forcing the constant of proportionality for the SSB index to be 1. These are discussed below and model outputs shown in Tables 7 and 8.

(a) Estimate natural mortality M
Instead of M being a fixed input (which could be derived by likelihood profiling), model 12 treats M as an estimable parameter. Not surprisingly, estimating M leads to almost the same model outputs (because M was originally derived by likelihood profiling, and then treated as a fixed input), but also increases model uncertainty substantially (estimates of precision deteriorate markedly for a number of model estimates; Table 7).

(b) Omit estimation of the plus-group mortality factor (μ^{pgp})
Omitting the estimation of μ^{pgp} (model 13) leads to the same result seen previously (compare models 1 and 3 in Table 4a and Appendix 3), namely that the model is not able to fit the older age groups in the commercial proportions-at-age data (note the deterioration in $-\ln L$ compared to baseline model 6 shown in Table 7, and particularly the component associated with commercial proportions).

(c) Increase age 2 maturity from 0.36 to 0.60
Apart from some re-scaling, the increase in age 2 maturity (model 14) has a negligible impact on model fits (Table 8), although it is more difficult to compare model fits because of the change in underlying data. However, this change will have an impact on model projections, because it means that a greater proportion of the population matures earlier compare to the commercial selectivity. This topic is discussed in more detail later.

(d) Force stronger flat-topped commercial selectivity ($\Phi^f_{y,6} = \Phi^f_{y,5} = \Phi^f_{y,4}$)
Forcing a stronger flat-topped commercial selectivity (by setting $\Phi^f_{y,6} = \Phi^f_{y,5} = \Phi^f_{y,4}$ for model 15, instead of only $\Phi^f_{y,6} = \Phi^f_{y,5}$ for baseline model 6) leads to a significant deterioration in model fit and a substantial increase in population scale (Table 8).

(e) Increase recruitment variability (σ_R) from 0.7 to 1.0
An increase in recruitment variability to σ_R =1.0 for model 16 (instead of 0.7 for the baseline model 6) is not warranted on model-fitting considerations (it is outside the 95% confidence region shown in Table 3); there is a deterioration in model fit (compare $-\ln L$ for models 6 and 16) due to the larger stock–recruit residuals that result (Table 8).

(f) Change the stock–recruit model to Beverton–Holt
A change in the stock–recruit model from the simple stock–recruit formulation (baseline model 6; Appendix 2, A2.8) to a Beverton–Holt formulation (model 17; Appendix 2, A2.5-A2.7) leads to a very similar model fit and estimates (Table 8), but the steepness parameter h for model 17 is not well estimated (the estimate runs into the bound set at h=0.99; Table 8). The fits are compared in Figure 15).

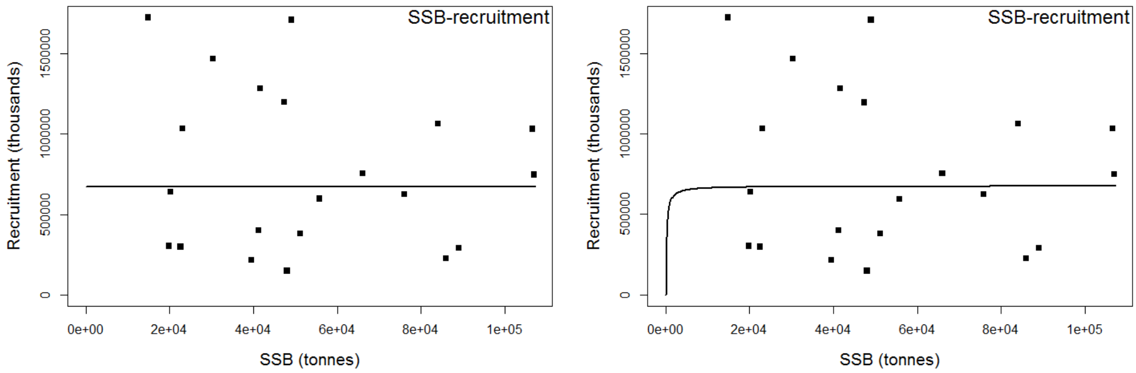

Figure 15 Stock–recruit fits for the simple stock-recruit curve (baseline model 6, left) and the Beverton–Holt curve (model 17, right)

(g) Force the constant of proportionality parameter for the SSB index ($q^{s=ssb}$) to be 1
Forcing the constant of proportionality for the SSB index to be 1 ($q^{s=ssb}$ =1) implies the SSB index is an absolute index of abundance (model 19). As expected, this leads to a deterioration in model fit, which is significant (compare models 6 and 18 in Table 8), because the model forces the parameter away from its maximum likelihood value; the population is also re-scaled.

Table 8 Key model outputs for sensitivity runs investigating a series of alternative model settings, as requested during the Review Workshop. Model 6: baseline model (see Table 4a); model 14: increase age 2 maturity to 0.6; model 15: force stronger commercial flat-top selection (by forcing the final 3 ages to be equal); model 16: increase recruitment variability to 1; model 17: change to a Beverton–Holt stock–recruit model; model 18: force the SSB index to have a constant of proportionality of 1 (instead of estimating it). Grey cells indicate the feature that has changed compared to the baseline model 6. Note, model 14 is not strictly comparable to the other models because the underlying maturity data has changed. Values in parentheses are CVs.

Settings/Parameters/Diagnostics	**Baseline Model 6**	**Model 14**	**Model 15**	**Model 16**	**Model 17**	**Model 18**
Settings						
Age 2 maturity	0.36	0.60	0.36	0.36	0.36	0.36
Flat-topped commercial selection: ages forced to be equal	last 2 ages	last 2 ages	last 3 ages	last 2 ages	last 2 ages	last 2 ages
Stock-recruit model	simple	simple	simple	simple	Bev-Holt	simple
Input parameters						
M	0.53	0.53	0.53	0.53	0.53	0.53
σ_R	0.7	0.7	0.7	1.0	0.7	0.7
p_{virgin}	0.75	0.75	0.75	0.75	0.75	0.75
Estimated general parameters						
K^{sp}	74370 (0.23)	79849 (0.22)	582440 (3.54)	84387 (0.22)	74412 (0.23)	55818 (0.12)
R_{virgin}	861149 (0.23)	841521 (0.22)	6773120 (3.54)	978143 (0.22)	h=0.99* (0.004)	641708 (0.12)
μ^{oil}	2.614 (0.23)	2.700 (0.22)	1.894 (0.26)	2.422 (0.23)	2.613 (0.23)	3.296 (0.18)
μ^{pgp}	3.676 (0.14)	3.620 (0.14)	4.176 (0.13)	3.781 (0.13)	3.676 (0.14)	3.100 (012)
Recruitment serial correlation ρ	0.739 (0.059)	0.740 (0.059)	0.690 (0.071)	0744 (0.060)	0.739 (0.059)	0.723 (0.070)
Estimated constant of proportionality parameters						
SSB index $q^{s=ssb}$	0.449 (0.28)	0.408 (0.26)	0.048 (3.63)	0.452 (0.25)	0.449 (0.28)	1
Recruitment index $q^{s=rec}$	0.336 (0.26)	0.347 (0.24)	0.040 (3.59)	0.346 (023)	0.336 (0.26)	0.503 (0.11)
Estimated variability parameters						
SSB index $v_{adv}^{s=ssb}$	0.617 (0.16)	0.611 (0.16)	0.642 (0.16)	0.615 (0.16)	0.617 (0.16)	0.748 (0.16)
Recruitment index $v_{adv}^{s=rec}$	0.672 (0.17)	0.676 (0.17)	0.639 (0.17)	0.664 (0.17)	0.672 (0.17)	0.711 (0.17)
Commercial proportions σ_p^f	0.135 (0.042)	0.135 (0.042)	0.149 (0.036)	0.135 (0.041)	0.135 (0.042)	0.135 (0.40)
Research proportions σ_p^s	0.097 (0.060)	0.097 (0.060)	0.092 (0050)	0096 (0.061)	0.097 (0.060)	0.099 (0.059)
Likelihood contributions						
Total (-ln$L$)	**357.76**	**357.49**	**365.01**	**359.02**	**357.76**	**363.16**
SSB index	20.67	20.45	21.54	20.60	20.67	24.87
Recruitment index	21.52	21.63	20.46	21.27	21.52	22.70
Commercial proportions	236.62	236.46	248.46	236.11	236.62	236.65
Research proportions	55.24	55.31	50.87	54.72	55.22	56.94
Stock-recruit	23.71	23.63	23.69	26.32	23.73	22.00
Other diagnostics						
Estimable parameters	39	39	37	39	40	39
Maximum gradient component	5.961e-5	4.296e-5	7.345e-5	1.429e-5	5.839e-5	5.208e-5

*This value is not R_{virgin} but h (because this is a Beverton–Holt model; see Appendix 2, A2.5-A2.7) which hits the bound of 0.99 on estimation

Update of baseline assessment (conducted during the training workshop):
The baseline assessment model was updated with two more years of data during the Training Workshop (held 12–14 October immediately after the Review Workshop). This section presents the updated assessment (model 19; Figures 16-22 and Table 9). Apart from two more years of data, corrections were also made to the SSB index for the years 2012 (79509 tons was changed to 77002 tons) and 2013 (60626 tons was changed to 57428 tons). The updates have led to a higher profile likelihood estimate of M (Figure 16, Table 9), and an up-scale of the population as a result (Table 9). The retrospective under-estimation of SSB is slightly more pronounced (compare Figures 13 and 21), but the series of positive residual for recent SSB index values (leading to a perception of model misfit of recent SSB index values; Figure 9) is no longer continued with the addition of two more years of data (Figure 17).

The Training Workshop gave the opportunity for participants to carry out further sensitivity tests, and one of the issues that arose was how relatively insensitive the model was to changes in the SSB and recruitment indices. This can be seen from the variability parameters, which give the proportion-at-age data lower variances and hence greater weight in the model fit compared with the SSB and recruitment indices (Table 9).

Likelihood profile:

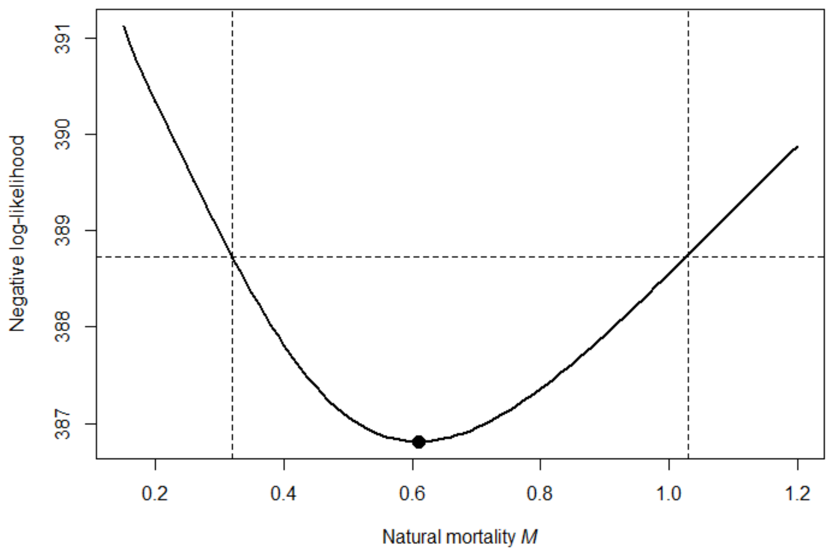

Figure 16 Updated model 19 likelihood profile for natural mortality (M). Best M=0.61; 95% confidence intervals (minimum function value+1.92): 0.32 – 1.03.

Model fits and residuals:

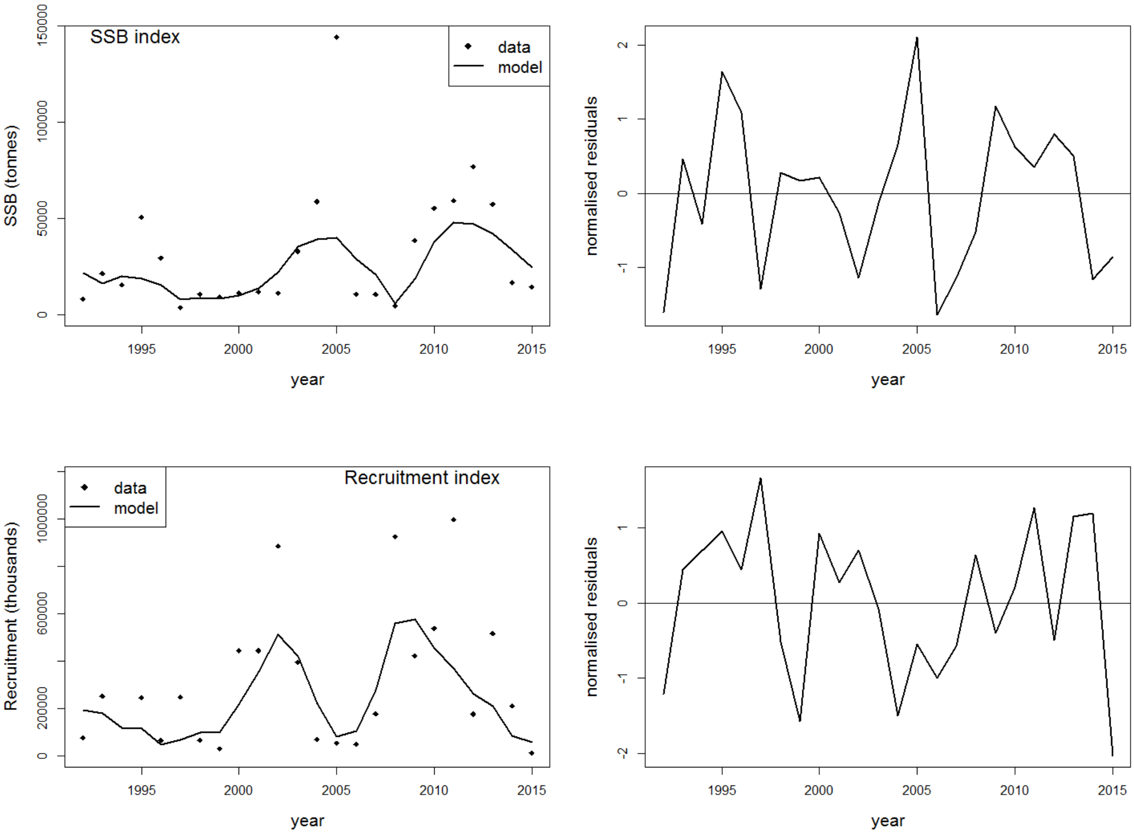

Figure 17 Updated model 19 fits to the SSB (top) and Recruitment (bottom) indices, with model fits to the data on the left and residual plots on the right. The normalized residuals are $L^{s}_{U,nres}(y)$ (Appendix 2, A2.27).

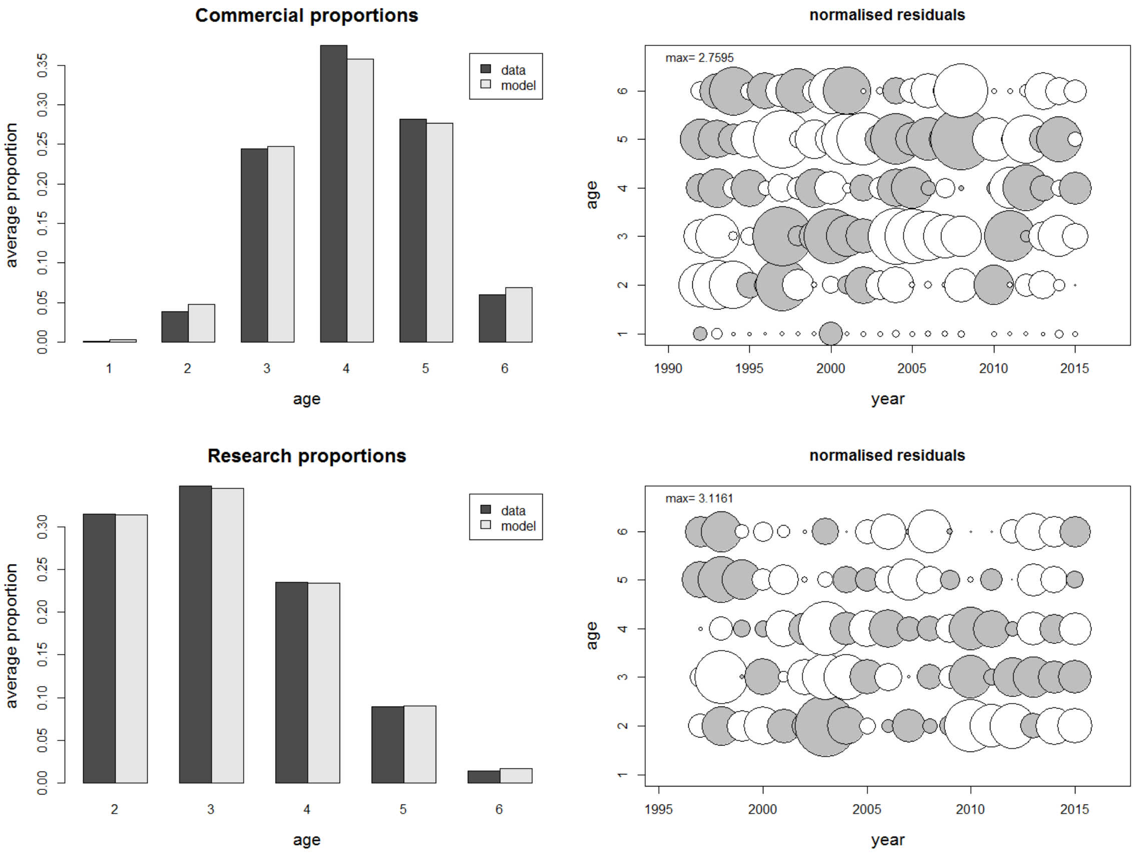

Figure 18 Updated model 19 fits to the Commercial (top) and Research (bottom) catch-at-age data, with model fits on the left (shown as average over the period for which data are available) and residual bubble plots on the right. In the bubble plots white bubbles indicate negative residuals, and grey bubbles positive; furthermore, the area of bubbles is proportional to the size of the residual, and the "max" value indicated in the top left of the plot relates to the maximum absolute value of residuals shown in the plot (i.e. the size of the largest bubble). The normalized residuals are $L^j_{p,nres}(y,a)$ (Appendix 2, A2.29).

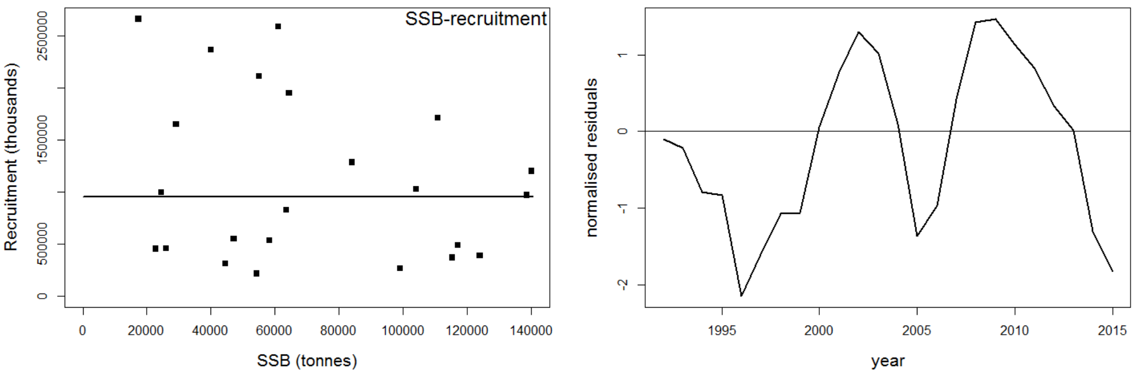

Figure 19 Updated model 19 fits: SSB-recruitment pairs with stock-recruit relationship estimated by the simple stock-recruit form (Appendix 2, A2.8) and corresponding residuals (right). The normalized residuals are $L_{R,nres}(y)$ (Appendix 2, A2.31), but note ρ is set to zero for the estimation (so $L_{R,nres}(y)=\varepsilon_y/\sigma_R$), and only calculated after the model fit (via Appendix 2, A2.32a).

Model estimates:

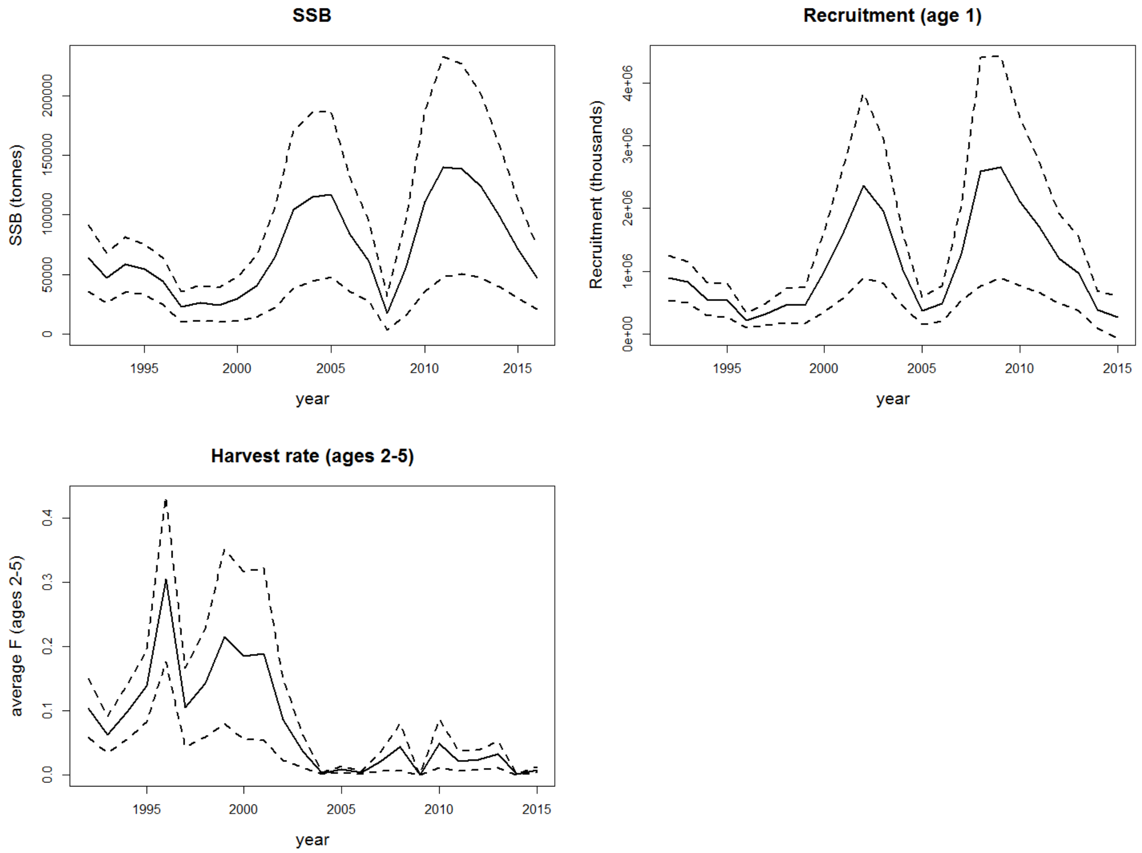

Figure 20 Updated model 19 population estimates with ± 2 standard deviations: SSB (top left) in tonnes, Recruitment at age 1 in thousands (top right) and harvest rate F averaged over ages 2–5 (bottom). [Note, the SSB plot includes one more year than the others.]

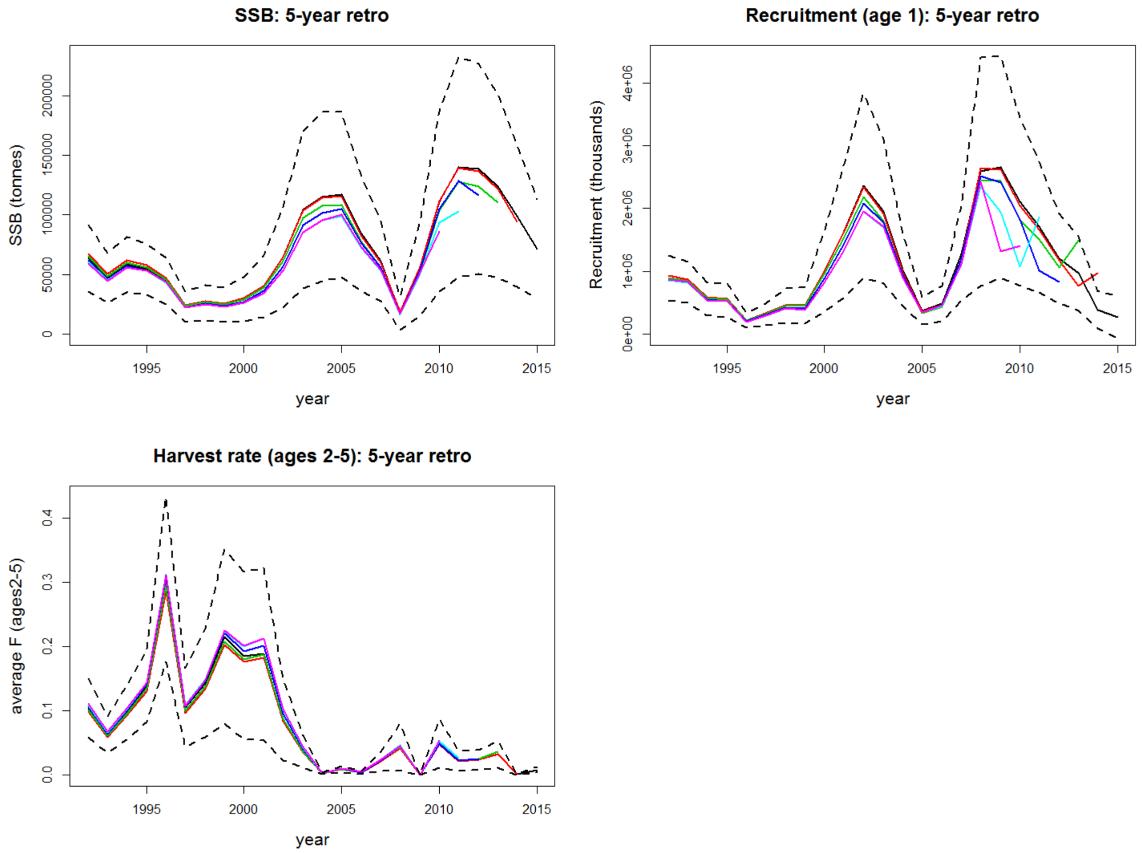

Figure 21 Updated model 19 five-year retrospective plots corresponding to Figure 20. [Note, the SSB plot has one less year than the the corresponding curve in Figure 20, so only the years for which data exist are shown.]

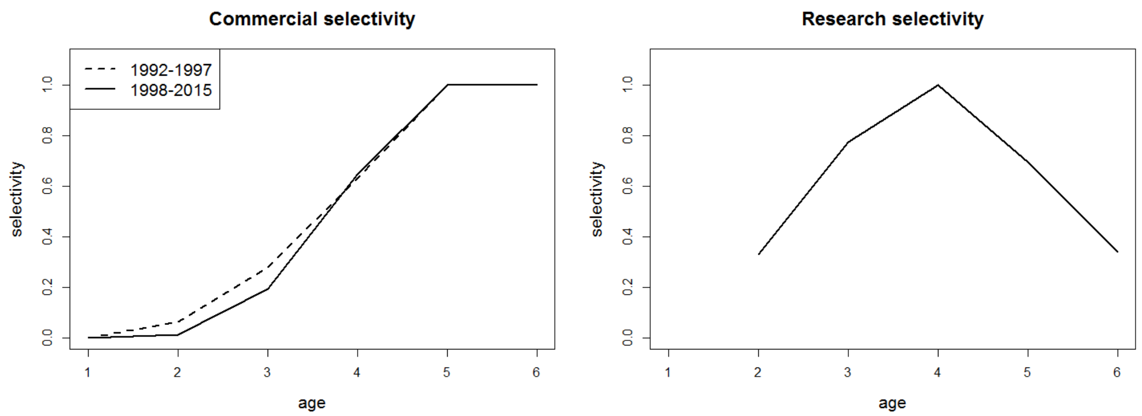

Figure 22 Updated model 19 estimates of selectivity-at-age for commercial (left) and research catches (right). Two separable periods were fitted to the commercial data, where the dashed line corresponds to the period 1992–1997 and the solid line corresponds to fishery selectivity for 1998–2015.

Table 9 Key model outputs for the baseline model 6, and an update of this model (model 19) to account for 2014/15 data, and a correction to the 2012/13 SSB indices). Note, models 6 and 19 are not strictly comparable because the underlying data have changed. Values in parenthesis are CVs.

Settings/Parameters/Diagnostics	**Baseline Model 6**	**Updated Model 19**
Settings		
Data changes	Data up to 2013	Data up to 2015 Update of SSB index 2012-2013 values
M obtained by likelihood profile	✓	✓
Input parameters		
M	0.53	0.61
σ_R	0.7	0.7
p_{virgin}	0.75	0.75
Estimated general parameters		
K^{sp}	74370 (0.23)	84799 (0.22)
R_{virgin}	861149 (0.23)	1217850 (0.22)
μ^{oil}	2.614 (0.23)	2.621 (0.20)
μ^{pgp}	3.676 (0.14)	3.231 (0.12)
Recruitment serial correlation ρ	0.739 (0.059)	0.751 (0.035)
Estimated constant of proportionality parameters		
SSB index $q^{s=ssb}$	0.449 (0.28)	0.341 (0.27)
Recruitment index $q^{s=rec}$	0.336 (0.26)	0.216 (0.25)
Estimated variability parameters		
SSB index $v_{adv}^{s=ssb}$	0.617 (0.16)	0.608 (0.15)
Recruitment index $v_{adv}^{s=rec}$	0.672 (0.17)	0.780 (0.17)
Commercial proportions σ_p^f	0.135 (0.042)	0.132 (0.038)
Research proportions σ_p^s	0.097 (0.060)	0.095 (0.055)
Likelihood contributions		
Total (-ln$L$)	**357.76**	**386.81**
SSB index	20.67	22.18
Recruitment index	21.52	26.96
Commercial proportions	236.62	255.86
Research proportions	55.24	54.15
Stock-recruit	23.71	27.67
Other diagnostics		
Estimable parameters	39	41
Maximum gradient component	5.961e-5	3.884e-5

Reference points

Stochastic projections were carried out using the baseline assessment (model 6) in order to facilitate the estimation of MSY reference points. These projections were set up in the same way as the operating model (see description below). Precautionary reference points were also needed for the development of the harvest control rules (HCRs) themselves and in order to facilitate the evaluation of these harvest control rules. The most important reference point is the limit reference point Blim, defined as the stock size below which there may be reduced reproduction leading to reduced recruitment (ICES 2016a). ICES guidelines on developing reference points (ICES 2016b) were used to define Blim, taken as the lowest SSB in the time series for the baseline assessment (Blim = Bloss = 14 830 tonnes), because there is no evidence from the stock–recruit plot of impaired recruitment for higher SSB values (Figure 11). Blim is used in the definition of risk (average probability that SSB falls below Blim, where the average of the annual probabilities is taken across the projected years; as in risk1, ICES 2013a, risk definitions).

Consideration of a precautionary safety margin, incorporating assessment uncertainty, leads to another reference point, the precautionary approach reference point Bpa; this is a biomass reference point designed to avoid reaching Blim, such that when SSB is above Bpa, the probability of impaired recruitment is expected to be low (ICES 2016a). In most cases, the safety margin used to define Bpa is a standard value such that Bpa =1.4 Blim; this approach has been used for San Francisco Bay herring, given Bpa = 20 762 tonnes. Bpa is used in the construction of HCRs (see below).

Long-term stochastic projections were conducted to estimate MSY reference points. The historic populations were projected forward 50 years under constant harvest rates (F) to estimate equilibrium yield and SSB and corresponding confidence intervals for a range of F values (0 to 1 in steps of 0.05). Median catch and SSB were derived from the results for the last 20 years of the projections. Equilibrium yields and SSB for a range of F values between 0 and 1 are shown in Figure 23. The two upper panels correspond to the fishery selectivity estimated in the assessment. The yield curve on the upper left plot increases continuously as F increases while SSB declines only slightly. This is the result of fishing mortality only having an impact on the older year classes while mature younger fish are only partially affected by the fishery (Figure 24). The lower two plots in Figure 23 illustrate the results of implementing full selectivity (all age classes are fully selected by the commercial gear) indicating that in that case, yields would be maximised at F = 0.3 with a 46% associated risk.

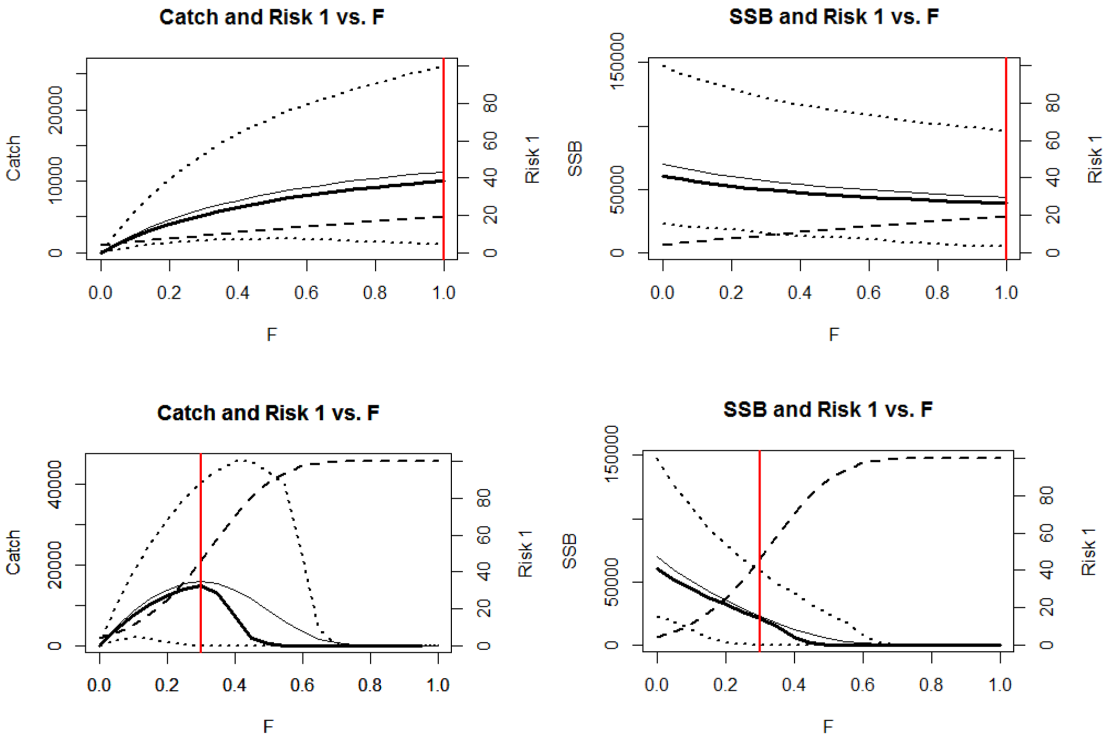

Figure 23 Average catch (left) and SSB (right) distributions, and associated average risk of SSB dropping below Blim = 14 830 t, indicated by the black bold hashed curve (same for left and right plots) for the final 20 years of 50-year long-term stochastic projection. For the upper plots, fishery selectivity as estimated by the baseline model 6, whereas for the lower plots knife-edge selectivity is assumed. The solid, bold black curve is the median, the solid light black curve the mean, and the dotted black curves the 5th and 95th percentiles. The red vertical lines are the same on the left and right-hand plots, with the solid red bold line representing the peak of the median catch curve on both plots.

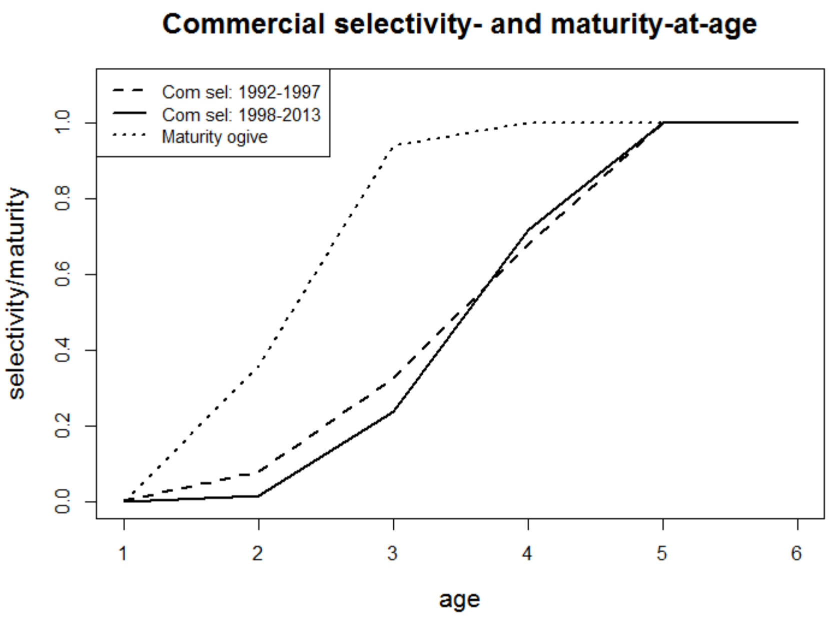

Figure 24 A repeat of Figure 14 for baseline model 6, but superimposing the maturity ogive in the plot.

Initial evaluation of the harvest control rule

The results of one thousand 50-year-forward simulations conducted to evaluate the HCRs proposed in terms of recruitment, SSB and catch for a range of F values (0, 0.25. 0.5. 0.75, 1) are shown in Figure 25a. A set of individual trajectories are included in the plots for comparison with the median. Performance statistics for the set of HCRs evaluated are shown in Table 10.

Examination of the results presented in the first column of Figure 25a (impact on recruitment) suggests that the increase in exploitation has little impact. This is partly because of the implementation of the HCR, which protects the stock by reducing catch when the biomass is low, but also because of the fishery selectivity, which allows a large fraction of mature age classes to survive the fishery (Figure 24).

The initial reduction in SSB (Figure 25a, 2nd column), even under zero F, is due to the stock coming off high SSB levels around 2010; average recruitment thereafter could no longer sustain a high SSB. As F increases, SSB stabilises at a lower level and this is primarily the result of fishing, not of reduced recruitment. Although the median SSB is well above Blim in all cases, the uncertainty in SSB is large, as reflected by the confidence intervals. The 5th percentile of the SSB distribution is below Blim when the stock is fished at or above a harvest rate of F = 0.25 (Figure 25a, 2nd column).

In order to place the simulation results in a historic context, Figure 25b compares the projections for F = 0.25 (for illustrative purposes) with the baseline assessment estimates/observations. These plots indicate reasonable consistency between assessment estimates of SSB and recruitment, and the corresponding values produced in the simulation projections. Recent catches have been lower than F = 0.25, so it is not surprising that an HCR with a harvest rate target of F = 0.25 leads to higher catches than observed.

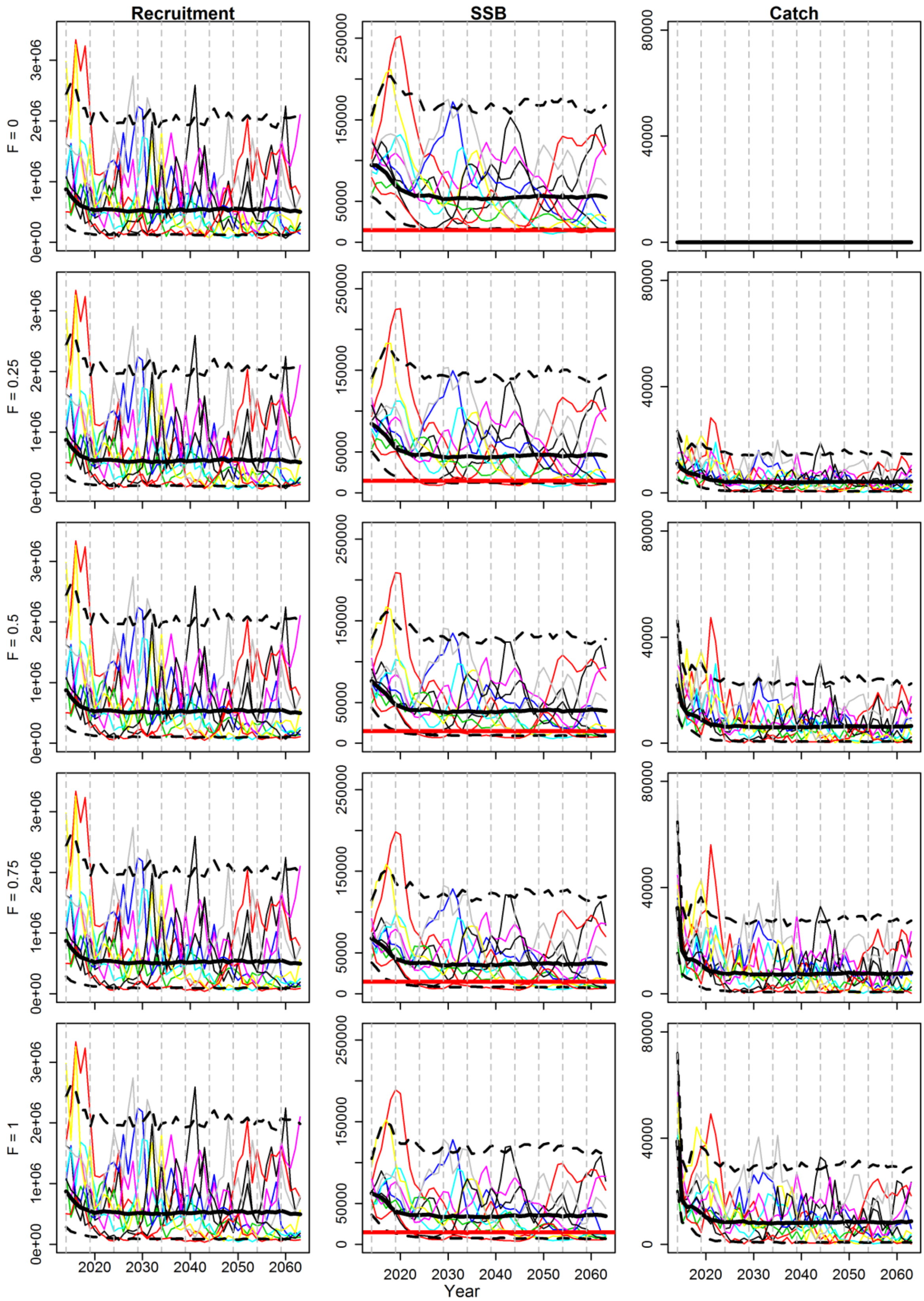

Figure 25a Results from 50-year-forward projections for F values ranging from 0 to 1 in steps of 0.25 (top to bottom row). Median recruitment, SSB and catch of simulated trajectories (solid black line). A few trajectories are shown (coloured lines) as well as 90% confidence intervals (hashed black lines). The solid horizontal red line in the SSB plots represents Blim (=14 830t), which can be compared with the 5th percentile (used in the risk calculation).

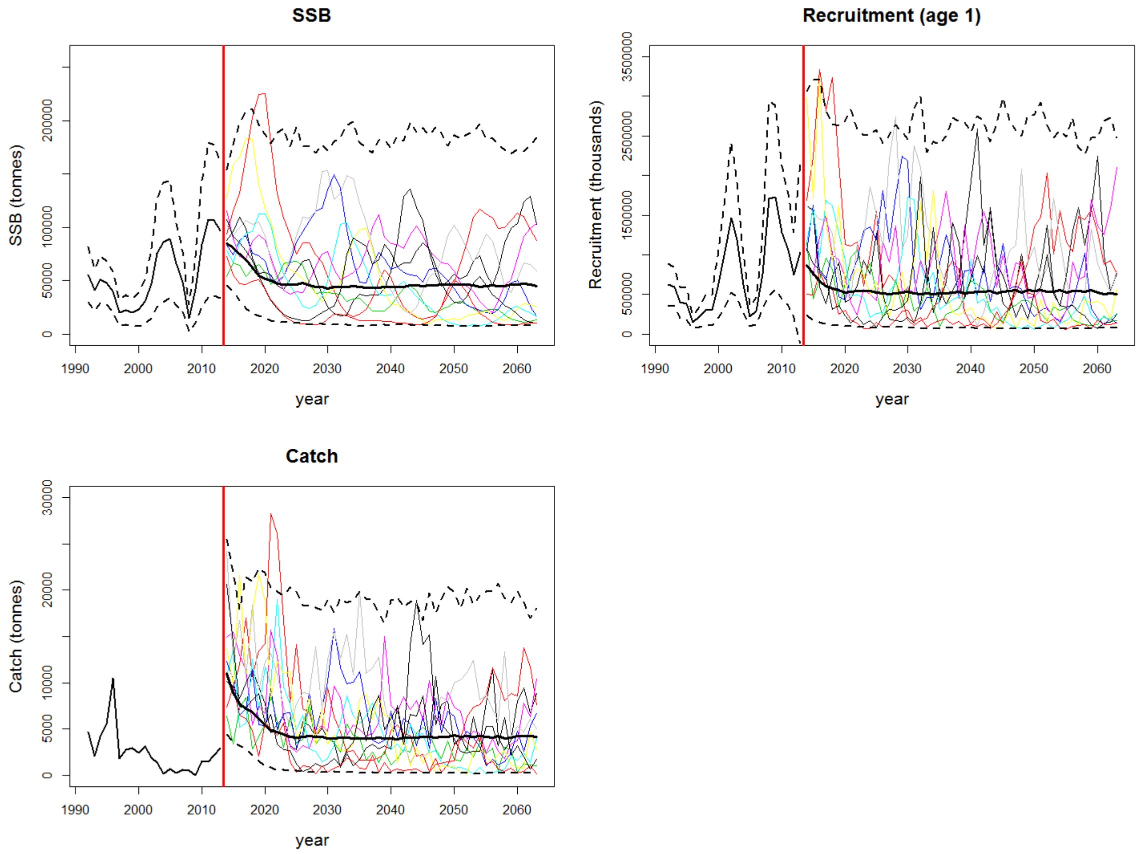

Figure 25b F=0.25 is taken from Figure 25a (but showing 95% confidence bounds instead of 90%) and the historic estimates (SSB, recruitment) with uncertainty (±2 standard deviations) or historic observations (catch) plotted for context. The vertical red line separates the baseline assessment estimates from the projections.

Table 10 Results from implementing F-based HCRs in terms of mean SSB, Yield and associated Risk; 90% confidence intervals (lower and upper CIs) are also shown.

F	SSB	lower CL	upper CL	Yield	lower CL	upper CL	Risk
0.00	60567	22407	147673	0	0	0	4.1
0.05	58065	21229	141779	1253	422	3251	4.8
0.10	55994	20232	137204	2332	772	6013	5.6
0.15	54118	19315	133205	3272	1054	8423	6.4
0.20	52349	18402	129023	4086	1296	10521	7.0
0.25	50964	17518	125190	4811	1492	12439	7.6
0.30	49564	16763	121700	5479	1638	14120	8.2
0.35	48340	16077	118502	6048	1755	15611	9.0
0.40	47162	15559	115579	6574	1830	16917	9.7
0.45	45989	14907	112975	7014	1909	18092	10.5
0.50	45024	14267	110725	7428	1988	19155	11.0
0.55	44200	13696	108561	7786	2055	20056	11.6
0.60	43297	13136	106373	8124	2111	20991	12.2
0.65	42580	12626	104659	8416	2150	21934	12.7
0.70	42019	12168	103412	8662	2184	22609	13.2
0.75	41581	11875	102168	8900	2215	23103	13.6
0.80	41194	11610	100905	9077	2205	23476	14.0
0.85	40852	11362	100100	9217	2200	23868	14.4
0.90	40547	11129	99521	9341	2197	24334	14.7
0.95	40282	10818	99068	9488	2203	24725	14.9
1.00	40003	10643	98657	9598	2211	24976	15.2

The results from implementing HCRs are illustrated in Figure 26. The increase in harvest rate results in a gradual reduction in SSB and increased associated risk of falling below Blim (=14 830 tonnes). As F increases, yields increase monotonically towards an asymptote just under 10 000 tonnes. However, annual yields would be less than 1 532 tonnes on average if keeping risk < 5% was a management objective.

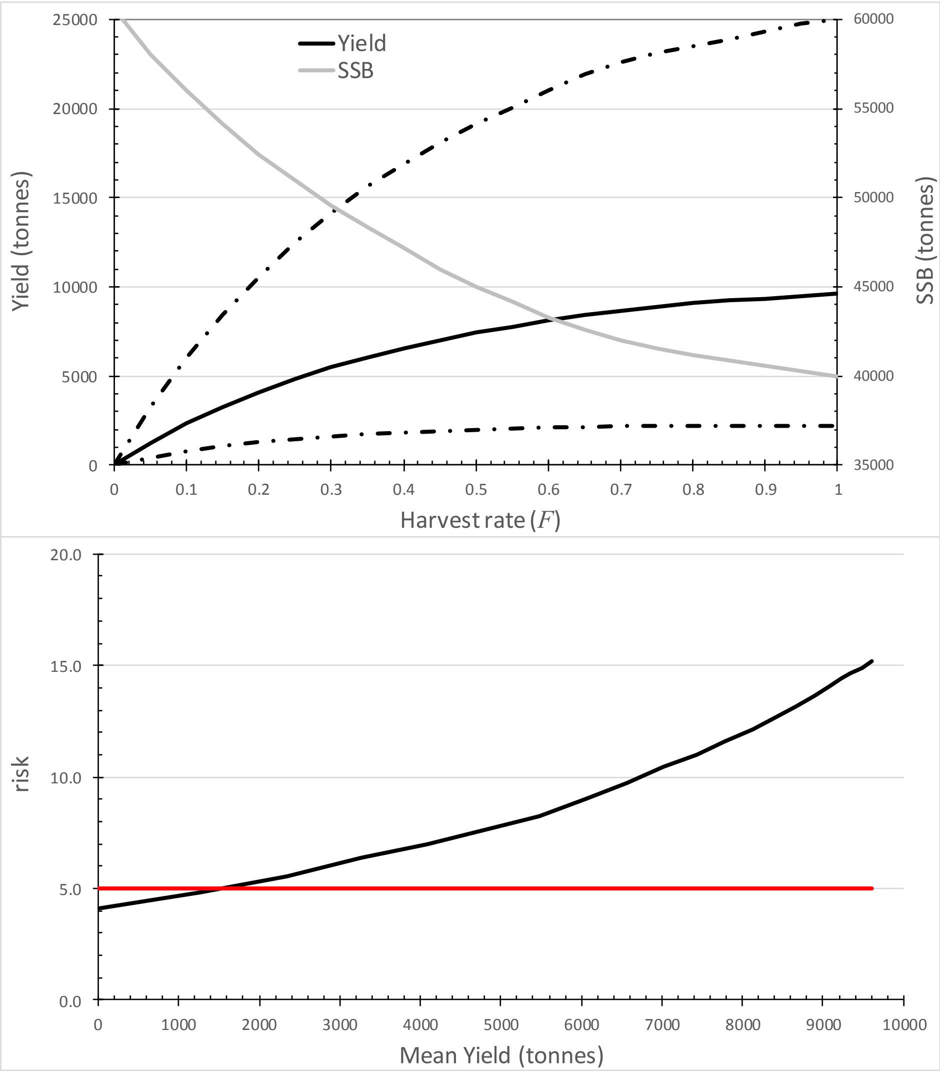

Figure 26 Results for the F-based HCR for a range of F values. Mean yield and SSB for increasing F values (upper plot); the dashed black lines represent 90% confidence intervals. Risk associated with the mean yield (lower plot); the red line indicates the 5% risk.

Discussion

Assessment model

An age-structure production model (ASPM, a particular formulation of a statistical catch-at-age model) is used to assess the San Francisco Bay herring stock. The model incorporates two indices of abundance (SSB and recruitment) and age-structured information from commercial and research catches, and includes a simple formulation of a stock–recruit curve as part of its estimation. The model provides a framework for integrating the spawning and catch at age information as suggested by a previous review of the San Francisco Bay herring assessment (Schweigert 2003).

Several considerations were taken into account when deriving the baseline model. The initial model did not impose any constraints on selectivity, which led to strong dome selection for both the fishery and research catches (stronger for the latter) because of the age-structure implied by these data, and therefore to a cryptic biomass, which was difficult to justify and potentially contributed to resilience to fishing that may not be realistic. This was addressed by introducing flat-topped selection for the commercial fishery, coupled with a plus-group mortality factor to deal with the model mis-specification for the plus-group when fitting to the commercial proportions-at-age data. A further feature that appeared to be important was the introduction of an oil-spill factor for 2007; this factor led to substantial improvements in model fit, despite there being no direct evidence for any detrimental effect of the oil spill on the herring population.

The baseline model fits the commercial and research catch at age averages well. Some patterns are noted in the residuals from the fit to data by year, but that is not a major concern. The fit to the SSB index and the recruitment are reasonable but the data are highly variable and the model cannot always fit large interannual variations. The very large 2005 SSB index data was followed by low SSB indices, although landings from 2004/05 on were relatively low. As the model cannot explain these data, it interprets the large 2005 SSB data point as noise. Retrospective analyses indicate reasonable behaviour, with retrospective fits lying well within the confidence bounds for the full model. All in all, we believe that the model is doing its best at reconciling the commercial and the scientific data available.

Natural mortality (M) has been estimated by the baseline model at 0.53. Comparison with estimates of natural mortality for British Columbia herring stocks (Schweigert and Tanasichuk 1999) indicate that this is likely to be a realistic value, although confidence intervals are relatively wide (0.24–0.98).

Several sensitivity tests were carried out, related to fishery selection, natural mortality, maturity, recruitment variability, the form of the stock–recruit relationship and the nature of the SSB index (absolute or relative). Alternative fishery selection (to deal with a mesh change in the early- to mid-2000s, and an even stronger flat-topped commercial selectivity) and natural mortality (increasing with age, after Tanusichuk 1999) did not lead to model improvements (and often to a deterioration in model diagnostics), and the increase in age 2 maturity served only to exacerbate the discrepancy between maturity and fishery selection (implying that even more mature fish escape the fishery prior to first spawning). The model was not able to estimate the steepness parameter of the more complex Beverton–Holt formulation; increasing the recruitment variability increased flexibility but also resulted in a slight deterioration in model fit. Finally, forcing the constant of proportionality parameter to be 1 (implying the SSB index is absolute) leads to a significant deterioration in model fit and a re-scaling of the population.

Despite no substantial improvements over the baseline model, the sensitivity tests did highlight other model settings that could be treated as alternative plausible model fits, which could form the basis of a set of alternative operating models for further MSE development. Settings resulting in diagnostics that indicated model mis-specification (e.g. misfits to commercial proportions-at-age in models 3 and 13) should be omitted from this set.

There are some challenges with the models presented. They are subject to high levels of uncertainty (e.g. confidence bounds around SSB, harvest rate and recruitment estimates are high throughout). There is also confounding between dome-shaped commercial selection on the one hand, and flat-topped selection coupled with a high plus-group mortality factor on the other; the model is not able to distinguish between these two extremes on the basis of the data, and the only argument used in favour of the latter (for the baseline model) was the spectre of a cryptic biomass, but the former cannot be discounted. A further issue for the models presented is the maturity ogive relative to the commercial selectivity (Figure 24), the latter estimated on the basis of the age-structure information in the commercial catches; this comparison implies that a large proportion of fish escape the fishery prior to their first spawning, and this has implications for population dynamics evident in the stochastic projections presented, where the stock appears to be quite resilient to fishing (Figures 25a and 26).

Another consideration that may need further attention is the relative weighting that the different sources of information receive in the model fit. For the baseline model, the abundance indices (SSB and recruitment) have variability parameters that are at least 4.5 × larger than the proportions-at-age data (commercial and research; Table 4a), implying a much higher weight for the proportions-at-age data relative to the abundance indices. This implies that the indices of abundance have a much lower influence on the model fit compared to the proportions-at-age data. Francis (2011) advocates applying data weighting such that the model is able to fit abundance data well, and there may be a case for following this approach here. Nevertheless, when this issue arose during the Training Workshop (held as part of the development of this work), participants were comfortable with the age composition data receiving more weight relative to the abundance indices in the model fit.

Finally, the performance of the models and reliability of output presented rely on the quality and quantity of data and information provided. Model performance and outputs, and estimation of reference points, may be improved by extending it back in time to include earlier periods of (validated) data.

Stochastic projections and initial harvest control rules

Stochastic projections were used to explore the impact of different harvest rates on the population, and to estimate MSY reference points. A comparison of SSB and recruitment trajectories in future projections with model estimates of these quantities in the past show that they are reasonably consistent with one another (Figure 25b), indicating that the stochastic projections (and operating models used in MSE simulations) appropriately recreate past behaviour.

Stochastic projections showed resilience to fishing, demonstrated by the narrow range of risk relative to the wide range of harvest rates (top plots in Figure 23). This is primarily caused by the commercial selectivity estimated on the basis of the commercial proportions-at-age data, and the difference between this selection pattern and the maturity ogive, implying a large proportion of fish are able to reproduce prior to being vulnerable to fishing. This is also evident in the inability to estimate MSY reference points (upper plots in Figure 23, where the vertical red line indicating is at harvest rate F=1). This behaviour is not attributable to the use of the fixed hockey stick (with the breakpoint at the lowest SSB estimated) because a change in commercial selectivity to reflect full selection for all ages leads to a harvest rate F_{MSY} estimate of 0.3 (albeit with a high associated risk of 46%, indicating that 0.3 may be too high for this stock under full selection; lower plots of Figure 23). The current fishery is primarily conducted with gillnets, which target larger and older fish than round-haul nets, which are less selective (Dahlstrom 1977), so the estimated commercial selection pattern of the baseline model appears reasonable.

The resilience to fishing (narrow range of risk for a wide range of harvest rates), demonstrated by the baseline model with its commercial selection pattern, cannot be interpreted in isolation. Despite this resilience, the high model uncertainty implies that, even under zero fishing, the risk of falling below Blim is non-zero (risk=4.1%). It is up to managers to decide an appropriate level of risk for the stock; under the ICES system (ICES 2016a), 5% is used, so an appropriate harvest rate would be just above 0.05 under that system (results not shown in tabular form, but are associated with the upper plots in Figure 23).

These findings appear to contradict those from a previous study which used the Coleraine catch-at-age model to assess the stock (MacCall *et al*. 2003, Schweigert 2003). At the time the stock was estimated to be at around 20% of the unfished level and was near the lowest abundance observed since the early 1970s, and a harvest range between 10 and 15% was recommended for sustainable utilisation (MacCall *et al*. 2003). It is difficult to compare results from the models presented here with those from the Coleraine model applied earlier because details are lacking for the latter (e.g. model structure and assumptions and what data was actually used), but there are important differences to note. The models are based on different time periods of data with an overlap of around ten years between them, and the Coleraine model covered a period of long-term decline in stock abundance (Schweigert 2003), whereas the underlying data in the models developed here show more contrast (the stock recovers after a steady decline). Furthermore, there was an acknowledgment in the

2003 peer-review report that the general-purpose Coleraine model was not specifically designed for assessing San Francisco Bay herring and that a future specialised model "may produce results that differ in unanticipated respects" (MacCall *et al*. 2003). Nevertheless, there appear to be some consistencies in the approaches, such as harvest rates above 20% in the 1990s (Figure 12) and that fishery exploitation allows "a proportion of the age 3 and most of the age 2 fish an opportunity to spawn" (MacCall *et al*. 2003; Figure 24).

Reference points used in conjunction with estimates of current biomass and harvest rate would allow determination of the status of the stock in relation to these reference points. Based on data up to the 2013/14 season, the stock was being fished sustainably because the spawning stock biomass was well above precautionary limits (SSB in 2014 = 85 477 tonnes, substantially above Bpa = 20 762 tonnes) and was fished at a harvest rate below 0.05 (harvest rate in 2013 = 0.037), the level that falls within the ICES 5% risk criterion.

An operating model to test harvest control rules for management was developed within an MSE framework, conditioned on the baseline assessment. Harvest rules considered were based on a constant harvest rate, which would be reduced if the stock was below a biomass precautionary reference point (Bpa = 20 762 tonnes was used). The reduction in harvest rate, F, provides the opportunity for recovery when the stock is low. There is, however, a high associated risk, even at low-F HCRs, because the uncertainty in the basic population parameters is large. Fishing mortality just above 0.05 results in 5% risk (Table 10). Estimates of risk rise slowly thereafter, so F may be increased substantially with little increase in associated risk (F = 0.2 results in 7% risk; Table 10).

The MSE framework and HCRs presented are preliminary and have not been fully developed here. Ideally, a suite of operating models covering the main sources of uncertainty (e.g. those considered in the sensitivity tests) would form the basis of the MSEs, and the robustness of HCRs tested against these operating models. Such operating models could also comprise "catastrophic events" or changes in productivity (due to environmental changes, for example) that have not been observed, but are nevertheless possible (Punt *et al.* 2014, De Oliveira *et al*. 2008, Kell *et al*. 2006). Furthermore, a much wider range of performance statistics than developed here could be considered, and fully developed MSEs should incorporate stakeholder input and interactions, as well as an in-depth consideration of the objectives for management of the fishery (Punt *et al*. 2016). Such work is beyond the scope of this study. The intention was to develop stochastic projections in such a manner that they could be readily converted into an MSE framework for testing alternative HCRs. The work presented here is a step towards a fully developed MSE framework.

As an example of the possible use of HCRs tested within an MSE framework, the results presented in this report could be used as follows for management:

1. Stakeholders decide on an appropriate harvest control rule (HCR), following consideration of the results from the simulations presented, and appraisal of acceptable levels of risk.
2. Once commercial catch and survey data are available following fishing season *y* (1^{st} November in year *y* to 31^{st} October in year *y*+1), add these data to current time-series of data and update the assessment.

3. Use the assessment estimates of $\hat{B}_y^{exp}$ and $\hat{B}_y^{sp}$ in the HCR (see equation 1 above) to calculate the TAC for the next season, *y*+1.

[Note that in this scheme, the simulations assume that the data from one season will be immediately available following that season to be used to run the assessment and to advise a TAC for the very next season.]

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Appendix 1
Data used in the assessment

This Appendix lists the data that were actually used in the assessment. Note that throughout, data in year *y* refer to the season covering the 1st November in year *y* to the 31st October in year *y*+1.

Table A1.1: Commercial catch (metric tons). The cell shaded grey indicates a zero value (but is replaced by a small number, 0.001, for computational reasons).

	Landings (tonnes)
1992	4670
1993	2085
1994	4149
1995	5501
1996	10465
1997	1783
1998	2734
1999	2955
2000	2401
2001	3071
2002	1902
2003	1396
2004	131
2005	674
2006	265
2007	623
2008	460
2009	0.001
2010	1566
2011	1482
2012	2115
2013	2901

Table A1.2: Maturity (based on Hay and McCarter 1999) and natural mortality (M) taken from North Sea herring estimates for 2012 (ICES 2013). Note that the M values shown below were used in the initial stages of the modelling but were finally replaced by values estimated in this assessment.

	Maturity	Natural mortality
1	0	0.66
2	0.36	0.38
3	0.94	0.35
4	1	0.34
5	1	0.33
6	1	0.32

Table A1.3: Commercial catch-at-age (thousands). Cells shaded grey are either zero (and replaced by a small number, 0.001, for computational reasons) or missing (indicated by "-1").

	1	2	3	4	5	6+
1992	141	1864	8751	15791	15701	3347
1993	38	445	4072	9423	7594	2546
1994	0.001	843	9783	11058	11233	4958
1995	0.001	4859	13143	21837	10168	3176
1996	0.001	9621	18866	32986	25037	10067
1997	0.001	2797	12137	6751	2414	625
1998	0.001	112	2990	10351	7092	3479
1999	0.001	1018	7307	9216	8874	2015
2000	240	785	11655	7327	2737	269
2001	0.001	2282	10287	12794	2131	1803
2002	0.001	2298	9397	6849	1283	0.001
2003	0.001	578	5591	5117	2262	340
2004	0.001	6	196	679	410	44
2005	0.001	0.001	464	4055	2262	211
2006	0.001	0.001	73	1200	1509	135
2007	0.001	0.001	76	2015	3912	503
2008	0.001	86	373	939	3347	401
2009	-1	-1	-1	-1	-1	-1
2010	0.001	2168	11898	4022	152	0.001
2011	0.001	476	7625	7091	1190	0.001
2012	0.001	258	4539	13249	4733	348
2013	0.001	106	3909	12239	12680	1633

Table A1.4: Commercial catch mean weight-at-age (kg). Cells shaded grey are assumed values (the 1998 value for age 1, and the average for a given age for ages 2-6). Mean weight-at-age in the stock is assumed equal to the mean weight-at-age in the catch.

	1	2	3	4	5	6+
1992	0.029	0.06	0.091	0.102	0.111	0.12
1993	0.029	0.049	0.065	0.081	0.098	0.113
1994	0.057	0.057	0.082	0.109	0.124	0.142
1995	0.052	0.062	0.093	0.107	0.119	0.134
1996	0.052	0.064	0.085	0.111	0.126	0.143
1997	0.052	0.055	0.066	0.077	0.099	0.112
1998	0.052	0.089	0.1	0.108	0.119	0.131
1999	0.052	0.085	0.096	0.104	0.11	0.115
2000	0.094	0.101	0.101	0.104	0.12	0.133
2001	0.052	0.09	0.102	0.107	0.117	0.106
2002	0.052	0.088	0.094	0.1	0.109	0.115
2003	0.052	0.086	0.096	0.104	0.106	0.105
2004	0.052	0.047	0.095	0.098	0.1	0.102
2005	0.052	0.073	0.089	0.094	0.101	0.104
2006	0.052	0.073	0.087	0.087	0.093	0.101
2007	0.052	0.073	0.099	0.087	0.099	0.109
2008	0.052	0.061	0.08	0.083	0.093	0.087
2009	0.052	0.073	0.089	0.097	0.106	0.115
2010	0.052	0.079	0.084	0.094	0.083	0.115
2011	0.052	0.082	0.086	0.094	0.1	0.115
2012	0.052	0.081	0.086	0.092	0.095	0.103
2013	0.052	0.080	0.086	0.091	0.100	0.105

Table A1.5: Research catch-at-age (thousands). Cells shaded grey are zero (and replaced by a small number, 0.001, for computational reasons). Note: age 1 was removed from the assessment input data because it is poorly correlated with both the corresponding YOY and the research data numbers at age in the subsequent year. [Note, these numbers have been raised to the spawning wave estimate, so do not reflect the absolute research catch sample numbers; they are, however, suitable to reflect the relative proportions amongst ages for any given year, as used in the assessment.]

	2	3	4	5	6+
1997	5734.8	18658.3	11837.5	5999	975.9
1998	37671	13561.1	37344.7	18203.6	4576.1
1999	38010.9	37426.3	16913.1	15783.9	1554.7
2000	38650.7	69479.5	26646.8	3515.9	1052.1
2001	89158.8	44123.1	20615.2	3030.5	0.6
2002	71821	41953	18431	3923.6	0.001
2003	304968.5	135147.5	29609.4	9347.9	3218.1
2004	285462.5	271791	206810.2	46558	0.001
2005	297677.1	879473.2	529758.4	191926.8	10355.9
2006	13185.9	39549.2	69769.9	23081.7	1364.4
2007	27831.9	22119	46434.3	22187.4	5186.2
2008	32809.6	16981.8	9227.5	6678.5	885.6
2009	498850.9	100920.7	20379.8	10221.7	5461.3
2010	187366	422290.2	70954.3	6017.2	0.001
2011	149060.8	347250.2	270119.9	18982.5	0.001
2012	174834.7	509636.3	380745.2	129589.6	787.4
2013	146198.9	287967.4	168350.2	70884.3	4430.3

Table A1.6: SSB and recruitment indices, the former (short tons) from egg deposition surveys, and the latter (number) from Young-of-the-Year surveys averaged over the months April-July. The cell shaded grey represents missing data (indicated by "-1"). Note, the recruitment index is for age 0 in April-July of year y, but the model assumes it represents an age 1 recruitment index for the $y/y+1$ season (modelled as year y in the assessment).

	SSB index	Recruitment index
1992	8169	74634
1993	21389	251464
1994	15481	-1
1995	50482	244298
1996	29361	65242
1997	3526	247072
1998	10550	64980
1999	9236	28683
2000	11331	442997
2001	11682	442921
2002	10996	884909
2003	32845	395108
2004	58789	68639
2005	144309	51757
2006	10601	48044
2007	10435	176938
2008	4322	923655
2009	38409	422271
2010	55356	536706
2011	59353	996900
2012	79509	175719
2013	60626	515471

Appendix 2
Description of the ASPM model

The ASPM model used follows the approach of Butterworth and Rademeyer (2008; Section B in their Supplementary Material). The following set of equations describe the basic population dynamics and contributions from the different sources of data to the (penalised) negative log-likelihood function. Quasi-Newton minimisation (using AD Model Builder; Fournier *et al.* 2012) is applied to estimate model parameters by minimising the total negative log-likelihood function.

Note that, throughout, y refers to the y /y+1 season (i.e. commencing 1st November in year y and ending 31st October in year y+1). Note also that in the description below, there are some components that are not used for San Francisco Bay herring, but because these options are available in the code (and may be useful in future), they are kept.

Basic Dynamics

Numbers-at-age

Numbers-at-age in the population are modelled by the following equations (which reflect Pope's form of the catch equation (Pope 1972), where catches are assumed to occur in a pulse in the middle of the fishing season):

$$N_{y+1,a} = \begin{cases} R_{y+1} & , a = a_{\min} \\ N_{y,a-1}(1-F_{y,a-1})\, e^{-M_{y,a-1}} & , a_{\min} < a < a_{pg} \\ N_{y,a_{pg}-1}(1-F_{y,a_{pg}-1})\, e^{-M_{y,a_{pg}-1}} + N_{y,a_{pg}}(1-F_{y,a_{pg}})\, e^{-M_{y,a_{pg}}} & , a = a_{pg} \end{cases} \qquad \text{A2.1}$$

for $y = y_{beg}, y_{beg}+1,\ldots, y_{end}$, where

$$F_{y,a} = \sum_f S^f_{y,a} F^f_y \qquad \text{A2.2}$$

and

$$F^f_y = \frac{C^f_y}{\sum_{a=0}^{a_{pg}} w_{a+\frac{1}{2}} S^f_{y,a} N_{y,a} e^{-M_{y,a}/2}} \qquad \text{A2.3}$$

where $N_{y,a}$ is the number of fish (thousands) aged a at the start of the $y/y+1$ season, R_y is the number of recruits (thousands) at the start of the $y/y+1$ season, $M_{y,a}$ is the natural mortality (per year) of fish age a during fishing season $y/y+1$, $F_{y,a}$ is the harvest rate of fish aged a during the $y/y+1$ season, $S^f_{y,a}$ is the selectivity of fish age a in fleet f during the $y/y+1$ season, F^f_y is the proportion of a fully selected age class that is fished by fleet f during the $y/y+1$ season, C^f_y is the catch (metric tonnes) by fleet f during the $y/y+1$ season, and $w_{a+\frac{1}{2}}$ is the mean weight (kg) of fish aged a caught mid-season. For San Francisco Bay herring, only a single commercial fleet is modelled, although at least two selectivity periods are considered (hence the y subscript in $S^f_{y,a}$); furthermore, $a_{\min} = 1$

(age at recruitment), $a_{pg}=6$ (plus-group of age 6 and older), y_{beg}=1992 and y_{end}=2013. [Note, although in a different form and generalised for fleets, equations A2.1-3 are essentially the same as those given in Section B of the Supplementary Material of Butterworth and Rademeyer 2008).

Natural mortality

For the baseline model for San Francisco Bay herring, natural mortality is assumed to be year- and age-invariant (i.e. $M_{y,a}=M$), apart from two cases. The first is related to the much lower numbers of plusgroup age 6 fish in both the commercial and survey observed proportions-at-age than would be expected under the assumption of age-invariant natural mortality (see main text). Therefore, a plusgroup mortality factor, μ^{pgp}, is introduced (so that $M_{y,6}=\mu^{pgp}M$ for all years except y=2007). The second is related to an oil spill in late 2007 which may have had a detrimental effect on herring mortality (see main text). To capture this effect, an oil spill factor, μ^{oil}, is introduced (so that $M_{2007,a}=\mu^{oil}M$ for ages 1-5, and $M_{2007,6}=\mu^{pgp}\mu^{oil}M$).

Spawning biomass

Spawning biomass is based on mature fish, as follows:

$$B_y^{sp}=\sum_{a=a_{\min}}^{a_{pg}} m_a w_a N_{y,a} \qquad \text{A2.4}$$

for $y=y_{beg}+1, y_{beg}+2,\ldots, y_{end}+1$, where B_y^{sp} is the spawning biomass (metric tonnes) at the start of the $y/y+1$ season, m_a is the proportion of fish mature at age a, and w_a is the mean weight (kg) of fish aged a at the start of the fishing season (other parameters and variables as before).

Recruitment

Shepherd stock–recruit function:
The number of recruits is related to the spawning stock, with a lag of a_{min} years (=1 year for San Francisco Bay herring) through a stock-recruit relationship. The Shepherd stock–recruit relationship (Shepherd 1982) is used for this purpose:

$$R_y=\frac{\alpha B_{y-a_{\min}}^{sp}}{(\beta+(B_{y-a_{\min}}^{sp})^{\gamma})}e^{\varepsilon_y-\sigma_R^2/2} \qquad \text{A2.5}$$

for $y=y_{beg}+1, y_{beg}+2,\ldots, y_{end}+1$ where the Shepherd stock–recruit parameters are re-parameterised in terms of K^{sp} (unfished or virgin spawning biomass, also referred to as carrying capacity) and h (steepness; defined as the proportion of R_{virgin} that would be produced by 20% of unfished spawning biomass) as follows:

$$\alpha=\frac{R_{virgin}(K^{sp})^{\gamma-1}h\,(5-0.2^{\gamma-1})}{5h-1} \qquad \text{A2.6}$$

and

$$\beta=\frac{(K^{sp})^{\gamma}(1-0.2^{\gamma-1}h)}{5\,h-1} \qquad \text{A2.7}$$

where R_{virgin} is the recruitment level produced when the stock is at the unfished spawning biomass, K^{sp}, and α, β and γ are the parameters of the Shepherd stock–recruit function. Setting γ to 1 gives the Beverton–Holt function. The variables ε_y reflect annual fluctuations (estimated by the model) about the deterministic stock–recruit relationship, assumed to be normally distributed with mean zero and standard deviation σ_R.

Simple stock–recruit function based on virgin recruitment:
It is often difficult to estimate even two parameters of a stock–recruit relationship, let alone three. An alternative is to not impose a particular relationship between spawning biomass and recruitment, and instead simply estimate annual fluctuations about virgin recruitment, which reduces the number of parameters estimated by the model, as follows:

$$R_y = R_{virgin} e^{\varepsilon_y - \sigma_R^2/2} \quad \text{A2.8}$$

It should be noted that when conducting stochastic projections or evaluating harvest control rules in a Management Strategy Evaluation framework, it is not sensible to use A2.8 "as is", particularly for levels of spawning biomass below the lowest level estimated, as it implies a resilient stock that continues to produce recruitment down to near-zero levels of spawning biomass – this approach would not be precautionary. For the stochastic projections and initial work on Management Strategy Evaluation presented, a hockey stock model is used instead, based on A2.8, but fixing the SSB breakpoint (i.e. where the curve starts to decline linearly to zero) at a suitable value (the lowest estimated SSB was used because of the lack of evidence for reduced recruitment at low stock sizes for this stock – see main text and Figure 3).

Calculation of virgin recruitment:
In all cases, virgin recruitment, R_{virgin}, is calculated as follows:

$$R_{virgin} = \frac{K^{sp}}{B_{virgin}^{spR}} \quad \text{A2.9}$$

$$B_{virgin}^{spR} = m_{a_{\min}} w_{a_{\min}} + \sum_{a=a_{\min}+1}^{a_{pg}-1} m_a w_a e^{-\sum_{i=a_{\min}}^{a-1} M_{y,i}} + m_{a_{pg}} w_{a_{pg}} \frac{e^{-\sum_{a=a_{\min}}^{a_{pg}-1} M_{y,a}}}{1 - e^{-M_{y,a_{pg}}}} \quad \text{A2.10}$$

Equation A2.9 could be generalised as $R = B^{sp} \big/ B_{virgin}^{spR}$, and this, in deterministic terms, represents the replacement line (i.e. it is the amount of recruitment needed at any level of spawning biomass to replace this spawning biomass).

Initial conditions

Given K^{sp}, the virgin (unfished) spawning biomass (i.e. the equilibrium B^{sp}, given constant recruitment and an absence of exploitation), and p_{virgin}, the proportion of the virgin population assumed as the starting conditions for the stock in year y_{beg}, the numbers-at-age and spawner biomass in year y_{beg} are:

$$B_{y_{beg}}^{sp} = p_{virgin} K^{sp} \quad \text{A2.11}$$

$$N_{y_{beg},a} = \begin{cases} R_{y_{beg}} & , a = a_{\min} \\ p_{virgin} R_{virgin} e^{-\sum_{i=a_{\min}}^{a-1} M_{y,i}} & , a_{\min} < a < a_{pg} \\ \dfrac{p_{virgin} R_{virgin} e^{-\sum_{i=a_{\min}}^{a_{pg}-1} M_{y,i}}}{1 - e^{-M_{y,a_{pg}}}} & , a = a_{pg} \end{cases} \quad \text{A2.12}$$

where R_{ybeg} is calculated using equation A2.8, setting $y = y_{beg}$ (because a_{min}=1, A2.5 is not used; furthermore, the first residual, $\varepsilon_{y_{beg}}$ in A2.5 and A2.8, is an estimable parameter).

Selectivity-at-age

Selectivity-at-age could be modelled either as a parametric function, or non-parametrically where selectivity at each age is estimated, apart from a pre-selected age (since selectivity is constrained to be no more than 1). The approach used for San Francisco Bay herring was to follow the non-parametric option, but the parametric formulation is kept for completeness.

Parametric [not used for San Francisco Bay herring]

The following is a logistic curve (defined by parameters δ^j and γ^j) that has been modified up to age a^j_{bef} (by g^j_a) and from age a^j_{aft} onwards (by the exponential term $\upsilon^j(a - a^j_{aft})$) to reflect, e.g. dome selection:

$$\Phi^j_{y,a} = \begin{cases} 0 & , a = 0 \\ \dfrac{g^j_a}{1 + e^{-\delta^j (a-1) + \gamma^j}} & , 1 \le a \le a^j_{aft} \\ \dfrac{g^j_a \, e^{\upsilon^j (a - a^j_{aft})}}{1 + e^{-\delta^j (a-1) + \gamma^j}} & , a > a^j_{aft} \end{cases} \quad \text{A2.13}$$

where *j* refers to fleet *f* or survey *s*, and

$$g^j_a = \begin{cases} \lambda^j & , a \le a^j_{bef} \\ 1 & , a > a^j_{bef} \end{cases} \quad \text{A2.14}$$

Then, for any *a*

$$S^j_{y,a} = \Phi^j_{y,a} / \max_a (\Phi^j_{y,a}) \quad \text{A2.15}$$

The y subscript in A2.15 reflects the possibility that a selectivity curve can be defined for one or more periods of the fishery (each with their own set of selectivity parameters). For simplicity, the y subscript is left off the other selectivity parameters.

Non-parametric [used for San Francisco Bay herring]

Given *j* (fleet *f* or survey *s*), then for *a* = *a** (age at which selectivity should reach a maximum) set $\Phi^j_{y,a*} = 1$ and treat the remaining $\Phi^j_{y,a}$ as estimable (bounded to be ≥ 0), and calculate selectivity-at-age using equation A2.15. Note, for surveys (j=s), the selectivity is usually assumed constant over time, so the y subscript is dropped.

Exploitable biomass

Exploitable biomass models the component of biomass that is available to commercial fleet or survey, adjusted for the time during the fishing season the activity is assumed to occur.

Commercial fleets

The assumption for commercial fleets is for pulse fishing in the middle of the season, as follows:

$$B_y^f = \sum_{a=a_{\min}}^{a_{pg}} w_{a+\frac{1}{2}} S_{y,a}^f N_{y,a} e^{-M_{y,a}/2}(1 - F_{y,a}/2) \qquad \text{A2.16}$$

Thus far, no commercial abundance indices are available for San Francisco Bay herring, so A2.16 is not used.

Surveys

A similar calculation is used for surveys, as follows:

$$B_y^s = \sum_{a=a_{\min}}^{a_{pg}} w_{a+t^s} S_a^s N_{y,a} e^{-t^s M_{y,a}} (1 - t^s F_{y,a}) \qquad \text{A2.17}$$

where t^s is a pre-set parameter reflecting the timing (e.g. midpoint) of the survey relative to the start of the fishing season ($0 \le t^s \le 1$). However, the only indices available for San Francisco Bay herring is an SSB index and a recruitment index, and A2.17 is not quite appropriate for these. Instead, the following are used:

SSB index

$$B_y^s = B_y^{sp} \qquad \text{A2.17a}$$

where B_y^{sp} (metric tons) is from A2.4, and assumes the egg deposition survey measures spawning biomass at the start of the fishing season.

Recruitment index

$$B_y^s = N_{y,a_{\min}} \qquad \text{A2.17b}$$

where $N_{y,a_{\min}}$ (thousands of fish) is from A2.1 and assumes the Young-of-the-year surveys measure recruitment at the start of the fishing season that follows these surveys (i.e. the surveys held in the fishing season $y/y+1$ provide an age 1 recruitment index for the fishing season $y+1/y+2$). [Note: B_y^s in A2.17b is in numbers, while B_y^s in A2.17a is in biomass]

Proportions-at-age

Observed proportions-at-age, either in commercial catches or surveys, contain information about relative recruitment strength between cohorts, and can also be used to estimate the selectivity-at-age for corresponding fleets or surveys.

Note, for commercial fleets (*j*=*f*) and surveys (*j*=*s*) , $a^j_{\min}$ and $a^j_{\max}$ reflect the minimum and maximum ages for which data are available, while a^j_{mngp} and a^j_{mxgp} reflect a contraction of the age-range to avoid zero values in the data (problematic when taking logs).

Commercial fleets

The model-predicted proportions-at-age for the commercial fleets use the estimated numbers of fish caught at age (assumed to be taken as a pulse in the middle of the fishing season), as follows:

$$\hat{p}^f_{y,a} = \begin{cases} \sum_{i=a^f_{\min}}^{a^f_{mngp}} S^f_{y,i} F^f_y N_{y,i} e^{-M_{y,i}/2} \Big/ \sum_{i=a^f_{\min}}^{a^f_{\max}} S^f_{y,i} F^f_y N_{y,i} e^{-M_{y,i}/2} & , a = a^f_{mngp} \\ S^f_{y,a} F^f_y N_{y,a} e^{-M_{y,a}/2} \Big/ \sum_{i=a^f_{\min}}^{a^f_{\max}} S^f_{y,i} F^f_y N_{y,i} e^{-M_{y,i}/2} & , a^f_{mngp} < a < a^f_{mxgp} \\ \sum_{i=a^f_{mxgp}}^{a^f_{\max}} S^f_{y,i} F^f_y N_{y,i} e^{-M_{y,i}/2} \Big/ \sum_{i=a^f_{\min}}^{a^f_{\max}} S^f_{y,i} F^f_y N_{y,i} e^{-M_{y,i}/2} & , a = a^f_{mxgp} \end{cases} \qquad \text{A2.18}$$

The observed proportions-at-age for the commercial fleets are calculated in the same way, but the estimated numbers of fish caught are replaced by observed numbers of fish caught [in A2.18, $\hat{p}^f_{y,a}$ is replaced by $p^f_{y,a}$, and the term $S^f_{y,x} F^f_x N_{y,x} e^{-M_{y,x}/2}$ is replaced by $C^f_{y,x}$ (where x is either i or a, as appropriate). $C^f_{y,a}$ is the observed numbers of fish aged a caught during fishing season y/y+1]. For San Francisco Bay herring, $a^f_{mngp} = a^f_{\min} = 1$ and $a^f_{mxgp} = a^f_{\max} = 6$.

Surveys

The model-predicted proportions-at-age for the surveys use the estimated numbers of fish available to the survey at the time the survey is conducted (midpoint t^s, as defined above), as follows:

$$\hat{p}^s_{y,a} = \begin{cases} \sum_{i=a^s_{\min}}^{a^s_{mngp}} S^s_i N_{y,i} e^{-t^s M_{y,i}} (1 - t^s F_{y,i}) \Big/ \sum_{i=a^s_{\min}}^{a^s_{\max}} S^s_i N_{y,i} e^{-t^s M_{y,i}} (1 - t^s F_{y,i}) & , a = a^s_{mngp} \\ S^s_a N_{y,a} e^{-t^s M_{y,a}} (1 - t^s F_{y,a}) \Big/ \sum_{i=a^s_{\min}}^{a^s_{\max}} S^s_i N_{y,i} e^{-t^s M_{y,i}} (1 - t^s F_{y,i}) & , a^s_{mngp} < a < a^s_{mxgp} \\ \sum_{i=a^s_{mxgp}}^{a^s_{\max}} S^s_i N_{y,i} e^{-t^s M_{y,i}} (1 - t^s F_{y,i}) \Big/ \sum_{i=a^s_{\min}}^{a^s_{\max}} S^s_i N_{y,i} e^{-t^s M_{y,i}} (1 - t^s F_{y,i}) & , a = a^s_{mxgp} \end{cases} \qquad \text{A2.19}$$

The observed proportions-at-age for the surveys are calculated in the same way, but the estimated numbers of fish available to the surveys are replaced by observed numbers of fish caught in the survey [in A2.19, $\hat{p}^s_{y,a}$ is replaced by $p^s_{y,a}$, and the term $S^s_x N_{y,x} e^{-t^s M_{y,x}} (1 - t^s F_{y,x})$ is replaced by $C^s_{y,x}$ (where x is either i or a, as appropriate). $C^s_{y,a}$ is the observed numbers of fish aged a caught during the survey in fishing season y/y+1]. For San Francisco Bay herring, $a^s_{mngp} = a^s_{\min} = 2$ and $a^s_{mxgp} = a^s_{\max} = 6$.

Constants of proportionality

Constants of proportionality relate observed indices to their model equivalents, and deal with any scaling issues (e.g. for the recruitment index, the model estimate, $B_y^s = N_{y,a_{\min}}$, is in thousands of fish, while the corresponding observation, U_y^s, is in numbers of fish). Closed-form solutions for these parameters are obtained by differentiating the total negative log-likelihood function with respect to the given parameter, setting the result equal to zero, and solving the equation for this parameter.

Commercial fleet CPUEs

$$q^f = \exp\left[\frac{\sum_{y\in Y_U^f}(\ln U_y^f - \ln B_y^f)}{\sum_{y\in Y_U^f} 1}\right] \qquad \text{A2.20}$$

where Y_U^f reflects the set of years for which commercial CPUE estimates, U_y^f, are available for feet f. Since commercial abundance indices are not currently available for San Francisco Bay herring, A2.20 is not used.

Survey CPUEs

$$q^s = \exp\left[\frac{\sum_{y\in Y_U^s}(\ln U_y^s - \ln B_y^s)/[(\sigma_{U,y}^s)^2 + (v_{adv}^s)^2]}{\sum_{y\in Y_U^s} 1/[(\sigma_{U,y}^s)^2 + (v_{adv}^s)^2]}\right] \qquad \text{A2.21}$$

where Y_U^s reflects the set of years for which the survey indices, U_y^s, are available for survey s. See below for further descriptions of the variability parameters $\sigma_{U,y}^s$ and v_{adv}^s.

Variability parameters

Variability parameters are associated with each data source, and provide relative weighting amongst the various data sources. These can be estimated either through a closed-form solution (as above for the constant of proportionality parameters), or where this is not possible, directly estimated.

Commercial fleet CPUEs

$$\sigma_U^f = \sqrt{\max\left[\frac{\sum_{y\in Y_U^f}[\ln U_y^f - \ln(q^f B_y^f)]^2}{\sum_{y\in Y_U^f} 1} - (v_{fix}^f)^2 \;\; ; 0\right]} \qquad \text{A2.22}$$

where v_{fix}^f is a pre-specified constant allowing for a lower bound to be set on the total variance $(\sigma_U^f)^2 + (v_{fix}^f)^2$. Since commercial abundance indices are not currently available for San Francisco Bay herring, A2.22 is not used.

Survey CPUEs

The total variance is given by $(\sigma^s_{U,y})^2 + (v^s_{adv})^2$, which comprises a component $\sigma^s_{U,y}$ associated with "sampling" variability of individual survey estimates U^s_y which can be input (e.g. as sampling CVs from the survey), if available, while the "additional" variability parameters v^s_{adv} (variability not associated with sampling) are treated as estimable. Because sampling CVs are not available for San Francisco Bay herring, an arbitrary value, $\sigma^s_{U,y} = 0.05$, is used (for convenience only), and the v^s_{adv} estimated, so that $(\sigma^s_{U,y})^2 + (v^s_{adv})^2$ reflects the total variance for that data source.

Proportions-at-age

$$\sigma^j_p = \sqrt{\frac{\sum_{y \in \mathrm{Y}^j_p} \sum_{a=a^j_{mngp}}^{a^j_{mxgp}} p^j_{y,a} (\ln p^j_{y,a} - \ln \hat{p}^j_{y,a})^2}{\sum_{y \in \mathrm{Y}^j_p} \sum_{a=a^j_{mngp}}^{a^j_{mxgp}} 1}} \qquad \text{A2.23}$$

where *j* refers to fleet *f* or survey *s*, and Y^j_p reflects the set of years for which $p^j_{y,a}$ estimates are available. Further details about the statistical distribution implied by this formulation is given below.

Likelihood function

The total negative log-likelihood function comprises several components related to the data sources that the model fits to, and a penalised likelihood term associated with recruitment deviations. These are all listed below. Estimation is by maximum likelihood (in practical terms, the total negative log-likelihood is minimised), where observations are assumed to have particular statistical distributions, reflected by the likelihood formulation of each component.

Commercial fleet CPUEs

Observations are assumed to be lognormally distributed, with total variance reflected by $(\sigma^f_U)^2 + (v^f_{fix})^2$ as follows:

$$L^f_U = \tfrac{1}{2} \sum_{y \in \mathrm{Y}^f_U} \left\{ \left(L^f_{U,nres}(y) \right)^2 + \ln\left[2\pi \left((\sigma^f_U)^2 + (v^f_{fix})^2 \right) \right] \right\} \qquad \text{A2.24}$$

where

$$L^f_{U,nres}(y) = \frac{\ln U^f_y - \ln(q^f B^f_y)}{\sqrt{(\sigma^f_U)^2 + (v^f_{fix})^2}} \qquad \text{A2.25}$$

Because commercial abundance indices are not currently available for San Francisco Bay herring, A2.24 and A2.25 are not used.

Survey Indices

Observations are assumed to be lognormally distributed, with total variance reflected by $(\sigma^s_{y,U})^2 + (v^s_{adv})^2$, with the first term representing sampling variance (input to the model, if available), and the second additional variance (not related to sampling), as follows:

$$L^s_U = \tfrac{1}{2} \sum_{y \in \mathrm{Y}^s_U} \left\{ \left(L^s_{U,nres}(y) \right)^2 + \ln\left[2\pi \left((\sigma^s_{y,U})^2 + (v^s_{adv})^2 \right) \right] \right\} \qquad \text{A2.26}$$

where

$$L^s_{U,nres}(y) = \frac{\ln U^s_y - \ln(q^s B^s_y)}{\sqrt{(\sigma^s_{y,U})^2 + (v^s_{adv})^2}} \qquad \text{A2.27}$$

For San Francisco Bay herring, sampling variance $(\sigma^s_{y,U})^2$ is not available, so an arbitrary value, $\sigma^s_{y,U} = 0.05$, is used for convenience, and the additional variability parameter, v^s_{adv}, is estimated.

Proportions-at-age

Ernst (2002) identified three different approaches for treating age composition data in a likelihood function. All three approaches result in multinomial-type likelihoods. The first (the option usually used) assumes the age composition data have a multinomial distribution about their expected values (Methot 1989, Punt and Hilborn 1997). The second uses a "robustified" normal likelihood formulation (Fournier *et al*. 1990, Hilborn *et al.* 2003). These first two approaches require the specification of an effective sample size (i.e. number of independent sample units). This can prove difficult if age composition data are not based on simple random samples from the total catch, which is often the case (Punt and Kennedy 1997, McAllister and Ianelli 1997).

The third approach, adopted here and termed the adjusted lognormal distribution, avoids arbitrariness in the specification of the effective sample size by assuming a lognormal distribution for the age composition data, where the CV is taken to be inversely proportional to the square-root of the expected value (Punt and Kennedy 1997, Smith and Punt 1997, Ernst 2002). This form has its basis in the mean-variance relationship for multinomial sampling, and allows larger proportions to be given greater weight, so that undue importance is not given to observations based on only a few samples (Punt 1997, Punt and Kennedy 1997, De Oliveira 2003). Punt (pers. commn) has more recently suggested that a CV inversely proportional to the square-root of the observed rather than expected value should instead be considered for the lognormal formulation. This suggestion is based on the simulation work by Ernst (2002) that showed better performance (in terms of estimation bias) of the robustified normal likelihood when variance was based on observed rather than expected values. The adjusted lognormal formulation is as follows:

$$L^j_p = \tfrac{1}{2} \sum_{y \in \mathrm{Y}^j_p} \sum_{a=a^j_{mngp}}^{a^j_{mxgp}} \left\{ \left(L^j_{p,nres}(y,a) \right)^2 + \ln\left[2\pi (\sigma^j_p)^2 / p^j_{y,a} \right] \right\} \qquad \text{A2.28}$$

where j refers to fleet f or survey s, and

$$L^j_{p,nres}(y,a) = \frac{\ln p^j_{y,a} - \ln \hat{p}^j_{y,a}}{\sqrt{(\sigma^j_p)^2 / p^j_{y,a}}} \qquad \text{A2.29}$$

Stock-recruit curve

Stock-recruitment residuals, ε_y, are assumed to be serially correlated and normally distributed with mean zero and variance σ^2_R, as follows:

$$L_R = \tfrac{1}{2} \sum_{y=y_{beg}}^{y_{end}} \left\{ \left(L_{R,nres}(y)\right)^2 + \ln\left[2\pi\, \sigma^2_R (1-\rho^2) \right] \right\} \qquad \text{A2.30}$$

where (assuming $\varepsilon_{y_{beg}-1} = 0$)

$$L_{R,nres}(y) = \frac{\varepsilon_y - \rho\varepsilon_{y-1}}{\sqrt{\sigma^2_R\,(1-\rho^2)}} \qquad \text{A2.31}$$

For San Francisco Bay herring, ε_y are estimable parameters and the serial correlation, ρ, is set to zero during the model fit (simplifying A2.30 and A2.31), and only calculated after the model fit (often done for computational tractability), as follows:

$$\rho = \frac{\sum_{y=y_{beg}}^{y_{end}-1} \varepsilon_y \varepsilon_{y+1}}{\sqrt{\left(\sum_{y=y_{beg}}^{y_{end}-1} \varepsilon^2_y\right)\left(\sum_{y=y_{beg}}^{y_{end}-1} \varepsilon^2_{y+1}\right)}} \qquad \text{A2.32a}$$

For the purposes of stochastic projections and MSE (management strategy evaluation) simulations (performed after the model fit) recruitment serial correlation is accounted for as follows:

$$\lambda_y = \rho\, \lambda_{y-1} + \sqrt{1-\rho^2}\;\, \varepsilon^*_y \qquad , y = y_{end}+1, y_{end}+2, \ldots \qquad \text{A2.32b}$$

where y_{end} is the final year of the assessment (so $y_{end} + 1$ is the first year of the projection period) $\lambda_{y_{end}} = \varepsilon_{y_{end}}$ ($\varepsilon_{y_{end}}$ being the final recruitment residual from the assessment), and ε^*_y being historic recruitment residuals sampled with replacement. λ_y then replaces ε_y in A2.5 or A2.8 for future years.

Total negative log-likelihood

Total negative log-likelihood, –lnL, is calculated as follows:

$$-\ln L = \sum_f L^f_U + \sum_s L^s_U + \sum_f L^f_p + \sum_s L^s_p + L_R \qquad \text{A2.33}$$

Note for San Francisco Bay herring L_U^f is not used (i.e. $L_U^f = 0$)

Input parameters

Input parameters, values which were derived by profiling over the negative log-likelihood surface (see main text), were

- Natural mortality, M
- Proportion of unfished spawning biomass, p_{virgin}
- Recruitment variability, σ_R

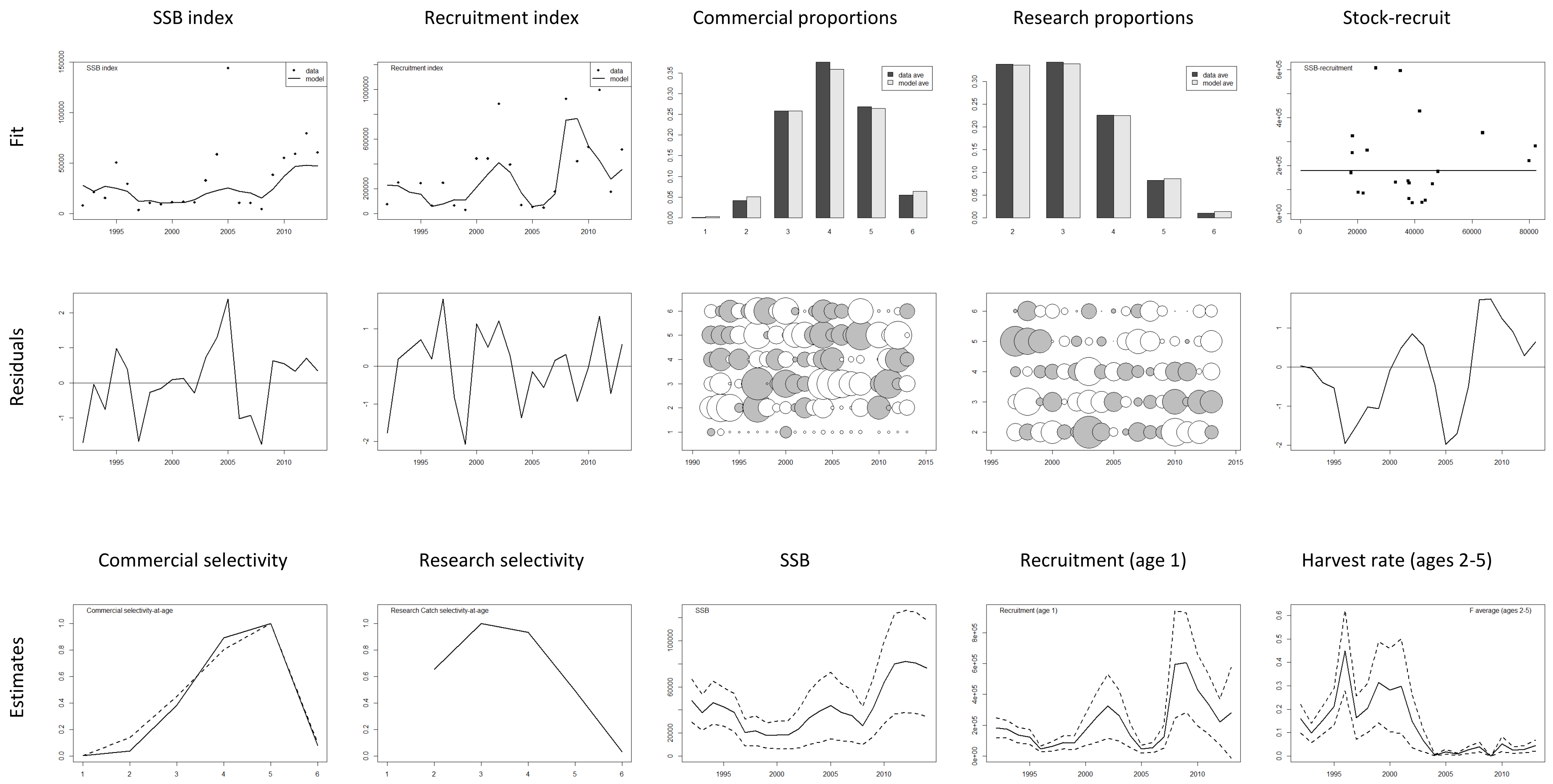
Estimable parameters

The estimable parameters (39 in total) of the baseline model are:

- Unfished spawning biomass, K^{sp} (although ln(K^{sp}) is actually estimated)
- Commercial selectivity, $\Phi^f_{y,a}$, for two selectivity periods: y=1992-1997 and y=1998-2013; for a=1-4 (for the other ages, a*=5, and age 6 set equal to age 5, so $\Phi^f_{y,6} = \Phi^f_{y,5} = 1$)
- Survey selectivity, Φ^s_a, for a=2-5 (a*=6, so $\Phi^s_6 = 1$)
- Recruitment residuals, ε_y, for y=1992-2013
- Survey variability parameters, v^s_{adv}, one for the SSB index, $v^{s=ssb}_{adv}$, and one for the recruitment index, $v^{s=rec}_{adv}$
- The plus-group mortality factor, μ^{pgp}
- The 2007 oil spill mortality factor, μ^{oil}

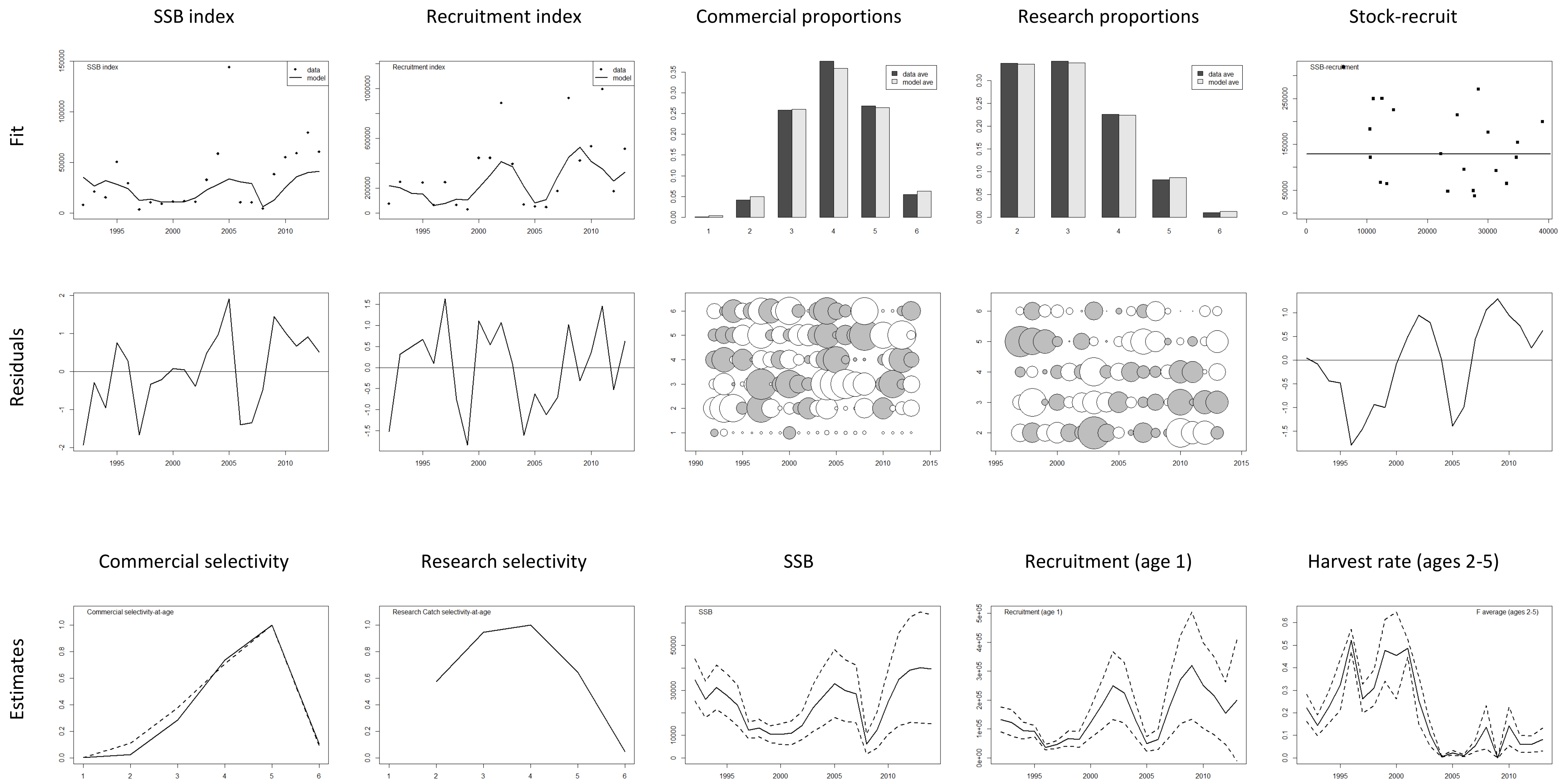
Appendix 3
Initial model to baseline model

Model 1: Initial Model



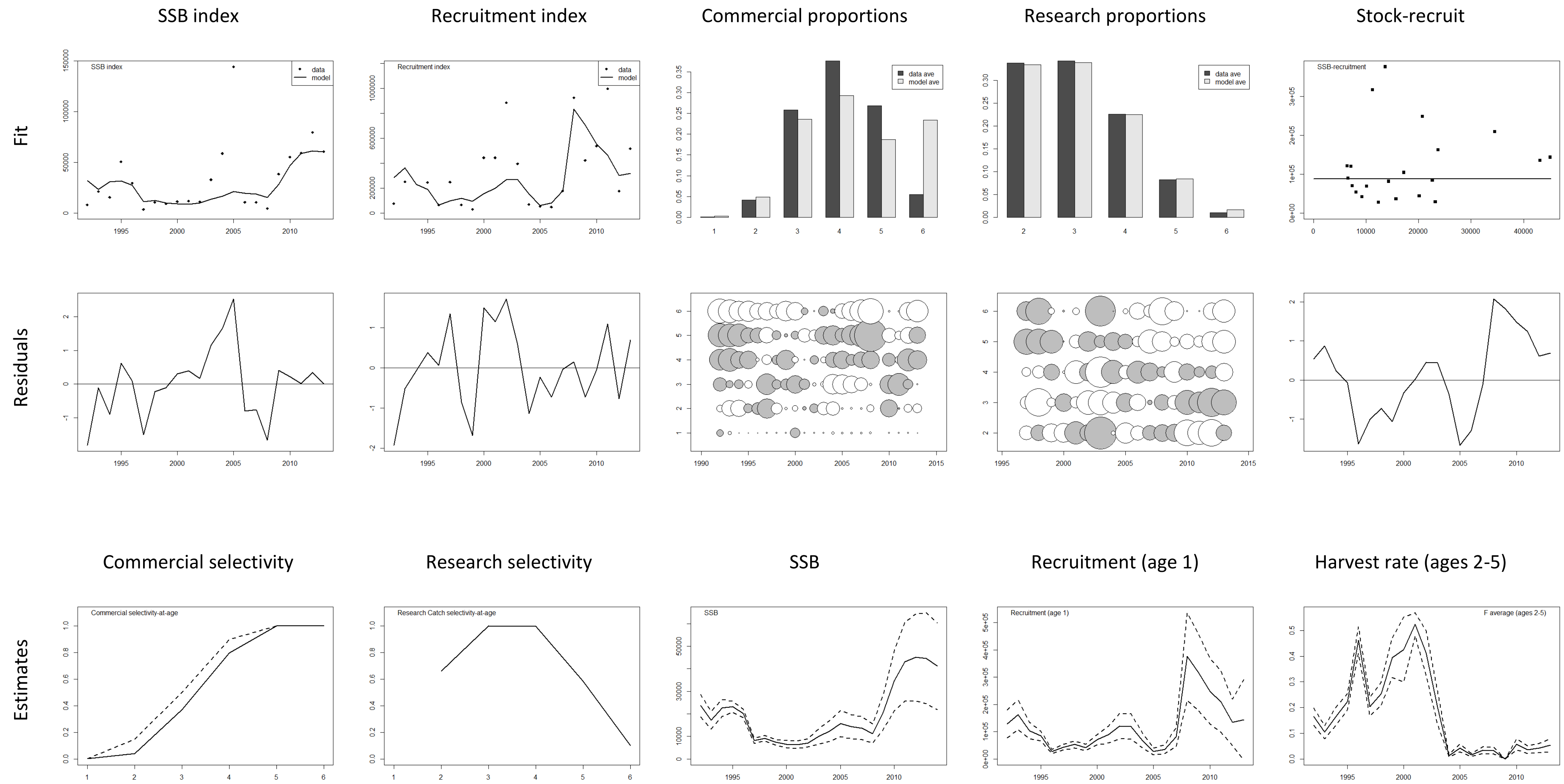
For more detailed explanation of the individual plots, please refer to the main text.

Model 2: Introduce, μ^{oil}, the 2007 M factor



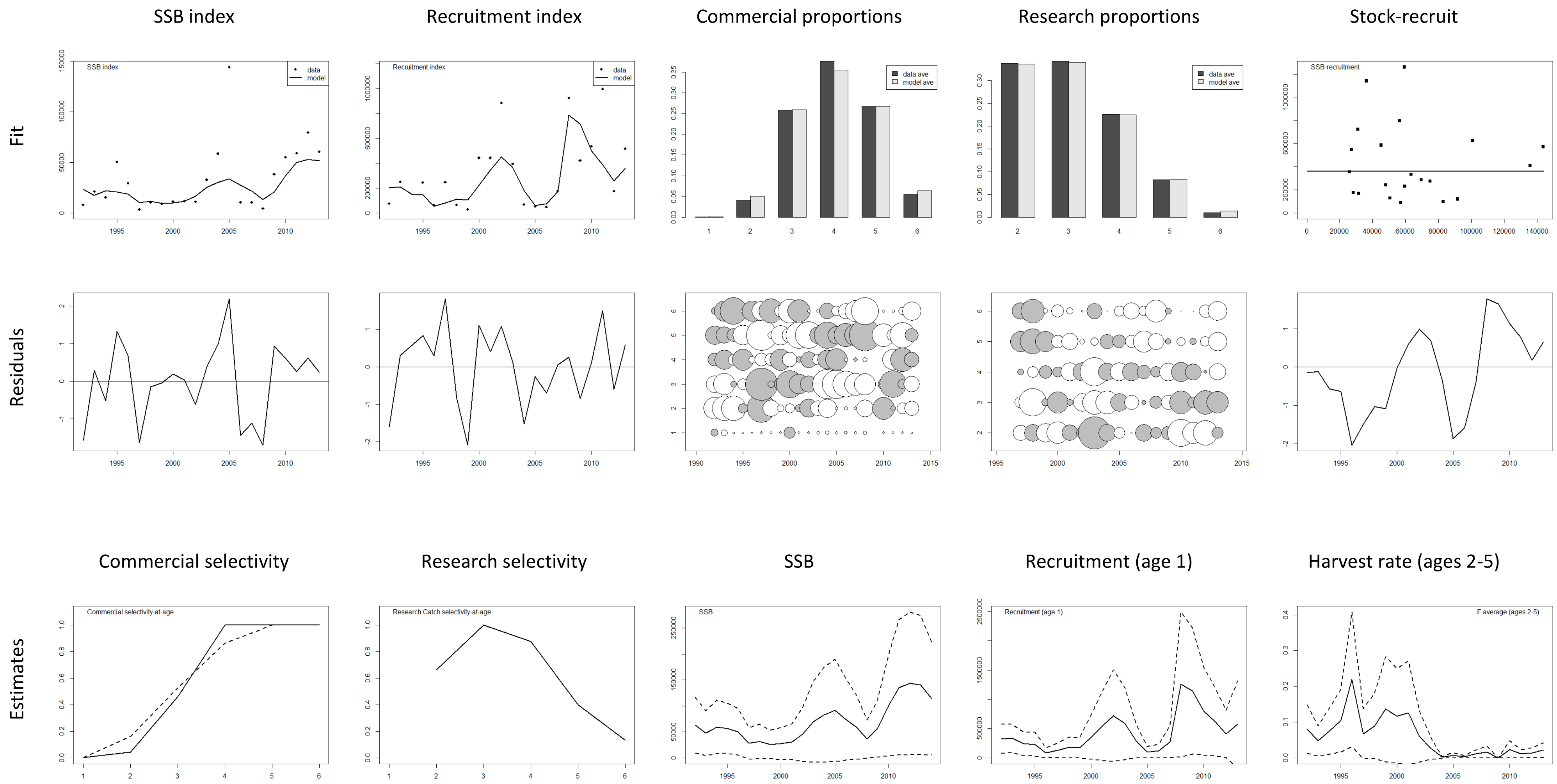
For more detailed explanation of the individual plots, please refer to the main text.

Model 3: Set $\Phi^{f}_{y,6} = \Phi^{f}_{y,5}$ for commercial selectivity (to mimic flat-topped selection)



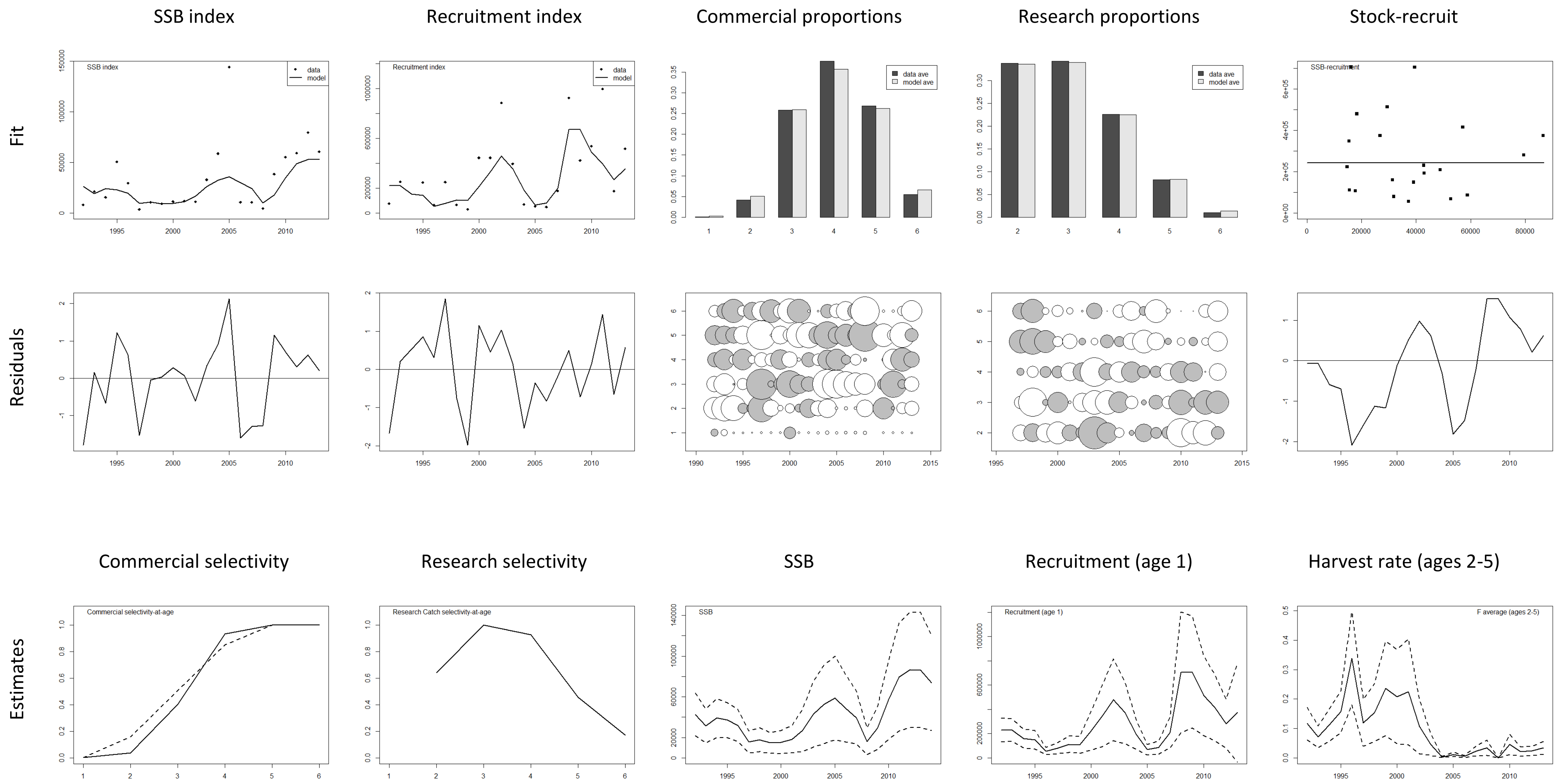
For more detailed explanation of the individual plots, please refer to the main text.

Model 4: As for model 3, but also introduced μ^{pgp}, the age 6 M factor



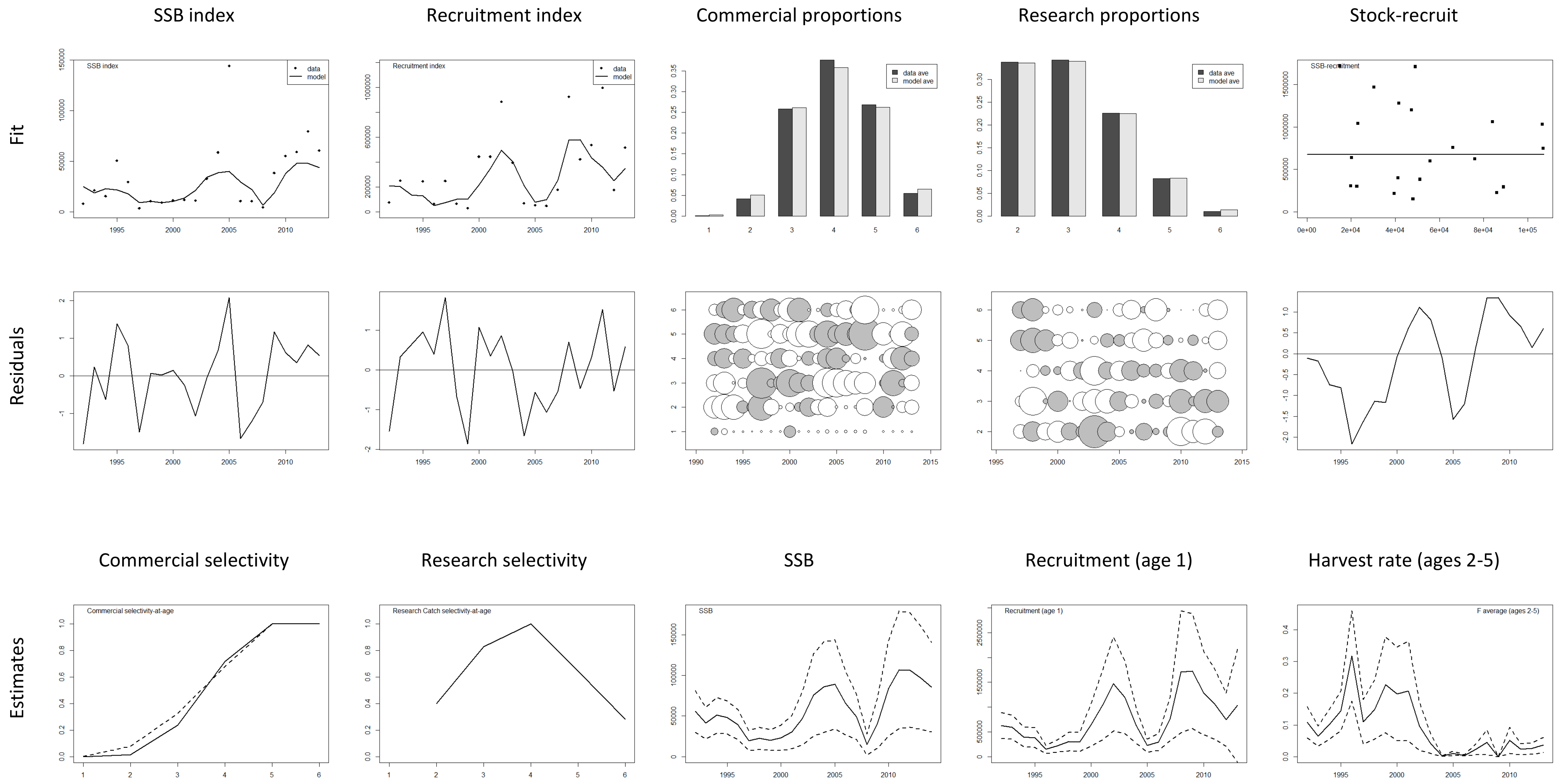
For more detailed explanation of the individual plots, please refer to the main text.

Model 5: As for model 4, but additionally introduce μ^{oil} (so both μ^{oil} and μ^{pgp} are used)



For more detailed explanation of the individual plots, please refer to the main text.

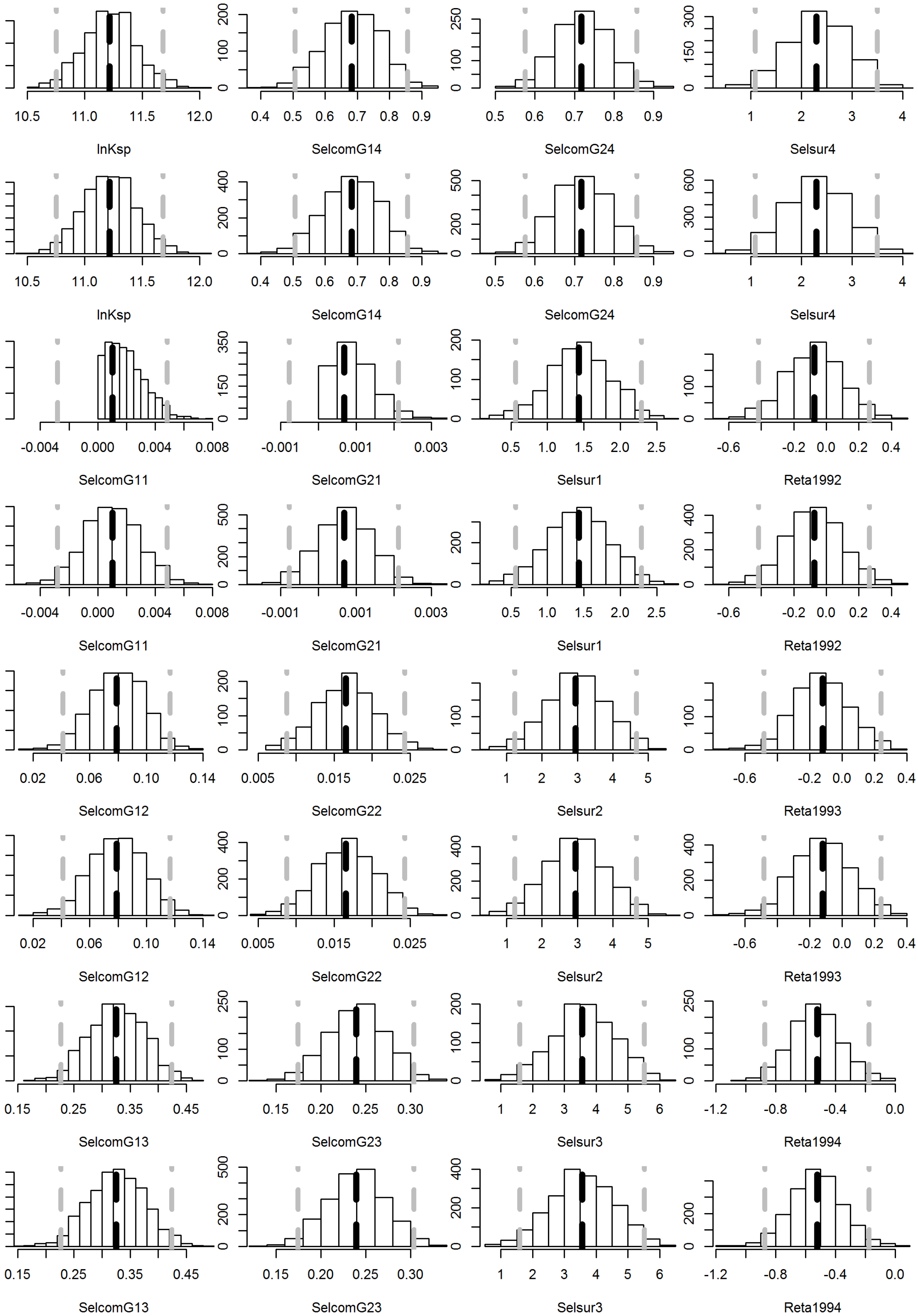
Model 6: As for model 5, but set M=0.53 (instead of 0.27), based on a likelihood profile

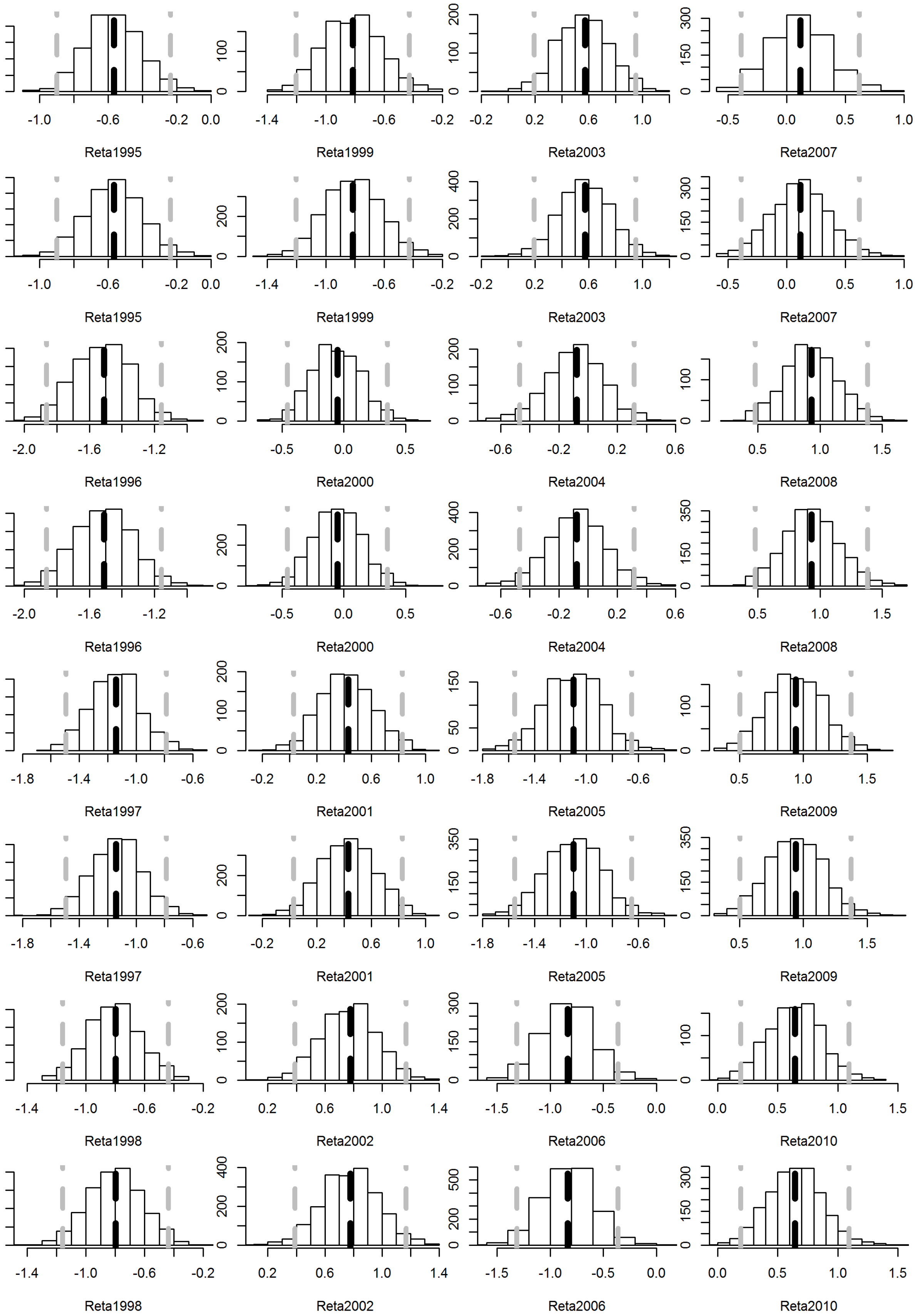


For more detailed explanation of the individual plots, please refer to the main text.

Appendix 4

Conditioning the operating model




Reta1995
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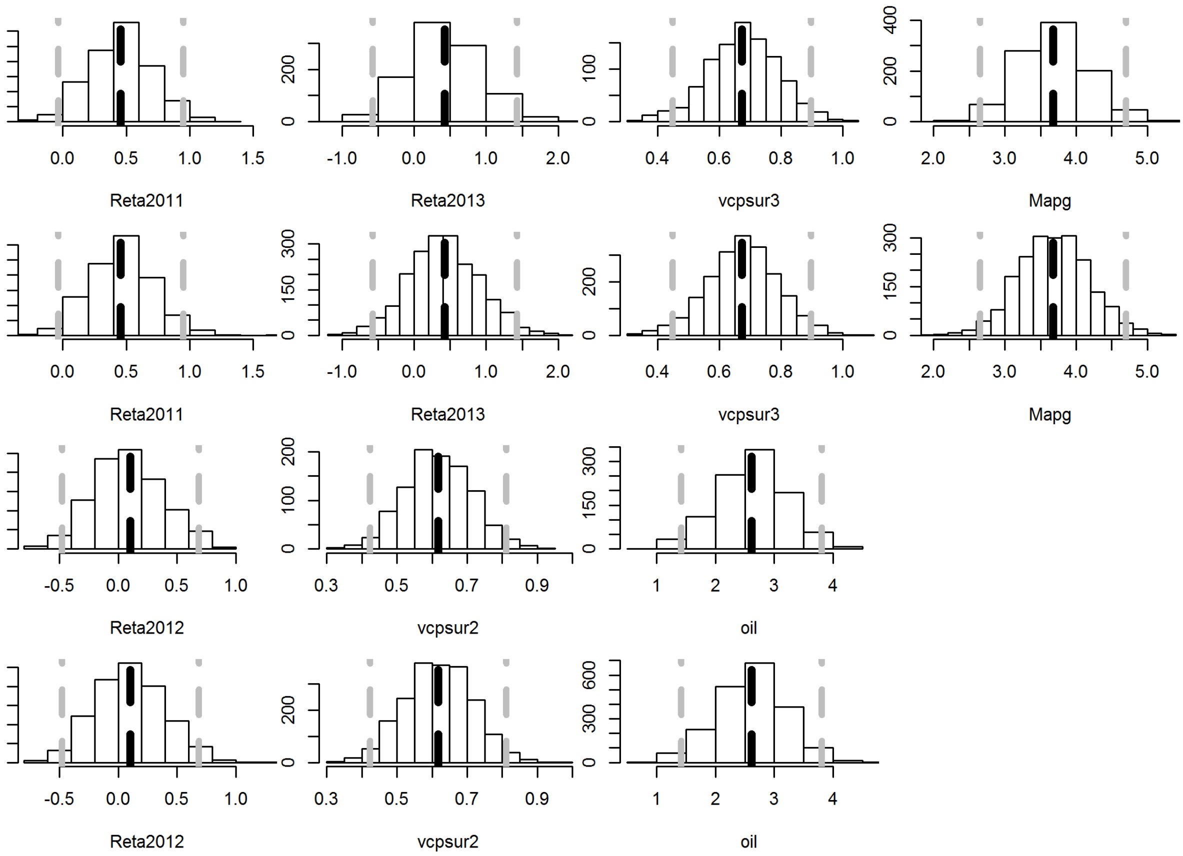

Figure A4.1 Parameter distributions after sampling from a multivariate normal distribution. For each parameter the upper plot shows the truncated distribution and the lower plot shows the full distribution. The black lines show estimates from the fit model and the grey lines show ±2 standard deviations. Where "lnKsp" is logarithm of virgin SSB, "Mapg" is the plus group mortality factor, "oil" is the 2007 oil spill factor, "Reta1992" to "Reta2013" are the residuals of the fit to the recruitment estimates, "Selcom" are the selectivity parameters at age for the commercial fishery, "Selsur" refer to selection at age for the research catch, and "vcpsur1" and "vcpsur2" correspond to the variability parameters for the SSB and recruitment indices.

Figure A4.2 Historic stock–recruit pairs for population i (red dots), with stock–recruit relationships fitted to these (solid black curves) and future recruitment (black dots) for 100 simulations. Serial correlation is included.

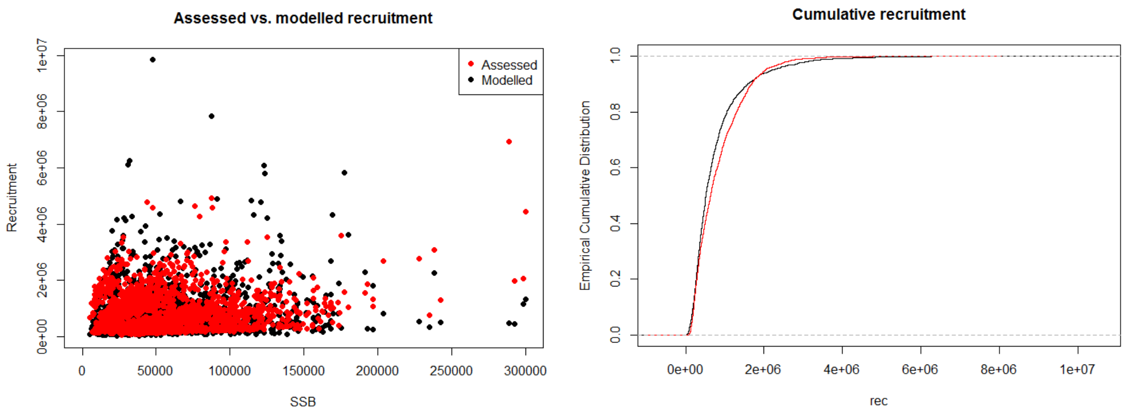

Figure A4.3 A comparison of historic (red) and future recruitments (black) for the stock–recruit pairs shown in Figure A4.2. On the left hand side plot historic recruitment points and generated recruitment for the same SSB values are represented. An empirical cumulative distribution function (ecdf in R) is shown on the right.

San Francisco Bay Pacific Herring Spawning Stock and Commercial Fishery Management Overview

March 2017
Final Report

California Department of Fish and Wildlife
Aquaculture and Bay Management Project
Herring Management and Research
Marine Region, 5355 Skylane Blvd. Suite B
Santa Rosa, CA 95403

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Introduction

The California Department of Fish and Wildlife (Department) has conducted herring research in San Francisco Bay as part of its ongoing monitoring and management of the commercial fishery since 1972. The Department uses annual vegetation dive surveys and individual spawn deposition surveys to calculate a spawning stock biomass estimate each year. It also uses commercial fishery and research mid-water trawl and gill net survey data to estimate the age class structure, sex composition, and general condition of the spawning population each season.

In July, 2011, the San Francisco Bay Herring Research Association contracted with Cefas to develop a stock assessment model for the herring population in San Francisco Bay that would build upon existing scientific and commercial fishery data. The goal of the assessment is to provide an objective basis for managing the stock. In October 2016, the Department hosted a two-day peer review workshop where a panel of experts was assembled to evaluate the stock assessment and operating models for the San Francisco Bay Pacific herring fishery. The peer review committee (Committee) made a number of recommendations for changes to the report structure, requested a description of input data, asked for revisions to the model structure, and additional analyses or justifications for modeling decisions. The Department and Cefas have made every effort to address those areas in the below description and attached stock assessment report.

Management Strategy Evaluation

The Committee was asked to determine whether the stock assessment model "is appropriate and sufficient for use in managing the Pacific herring fishery in San Francisco Bay via incorporation into the Fishery Management Plan for this fishery." Based on this request, the Committee made a number of recommendations for how to improve the Management Strategy Evaluation (MSE) to ensure stock assessment robustness prior to its use in management decisions. A comprehensive MSE analysis that incorporates the review committee's suggestions for herring in San Francisco Bay is currently under way. The goal of this analysis is to establish a management strategy (comprising current data collection protocol and a harvest control rule to set quotas) that adheres to the precautionary management approach of the last 10 years. The MSE will include robust assumptions and address likely uncertainties.

The team conducting the MSE analysis has conditioned a simulation model on the revised version of the Cefas model, and is currently testing a management strategy that uses spawning biomass estimates from the Cefas stock assessment against other, less complex spawning biomass estimation methods. For these tests, the Cefas assessment has been embedded within the simulation model to assess the effects of model uncertainty and misspecification. The MSE team is currently working with various stakeholders to craft a broad range of performance metrics that reflect management objectives and risk tolerances, over short and long time periods. While the current analysis considers the revised Cefas model to be the base case operating model, the MSE team is also testing the performance of each management strategy under a range of uncertainty scenarios, including alternate stock recruitment relationships, cyclical behavior in productivity, as well as including future climate change scenarios that could impact herring.

While we understand that having the results of the analyses described above would vastly improve the ability of the review committee to determine whether the Cefas stock assessment model is sufficient for use in management, the additional work required to complete that analysis was beyond the scope of the Cefas contract and is currently being conducted under separate contract as a key element of the FMP process. The Department requests that the review committee confine the majority of their review to the Cefas stock assessment itself and whether it represents a defensible operating model given the available data.

Data Integrity

The Committee recommended the Department establish a process to ensure a single quality-assured, complete data set is adopted for modeling that is maintained for subsequent analyses and updates or revisions should be tracked. The Committee further recommended the Department adopt a stronger policy of documentation detailing each year's surveys and monitoring in timely internal reports. Each dataset used in the model is appended to the Cefas report (Appendix 1) and is maintained and archived on Department workstations at the Santa Rosa field office.

Data Used for the Analysis

The following sections describe field survey methods, the data that were provided to Cefas by the Department, and the subset of data that were used for the stock assessment model. Three types of fishery-independent surveys were employed to produce these datasets: spawning deposition surveys, which are used to determine spawning-stock biomass; young-of-the-year surveys, used to determine annual recruitment; and population mid-water-trawl surveys, which were used to estimate age composition of the spawning-stock biomass. Fishery-dependent surveys of commercial landings yielded tonnage data, and biological samples from the commercial catch provided commercial age composition data. Each data source is described in detail below.

Fishery-Independent Surveys

Spawning Deposition Survey

The Department began conducting spawning deposition surveys during the 1973-74 season to estimate the number of eggs deposited around the bay as herring move into spawn (Spratt 1981; Watters and Oda 2002). The spawn survey was designed to estimate the total number of eggs spawned and to convert that estimate to the total tons of adult spawners, using a conversion factor based on fecundity. The area of the spawn is measured and samples are collected from which the density (number of eggs/m^2) of eggs is calculated. This is expanded to the total area of the spawn to estimate the total number of eggs spawned. The total eggs spawned is then converted to tons of adult spawners. These estimates were used, along with commercial landings data, to estimate the total spawning-stock biomass (SSB) in each year. During the early years of the fishery the sampling protocol evolved with increased understanding of San Francisco Bay herring spawning biology. During the 1982-83 season, the methods used to convert the number of eggs

spawned to tons of herring was also altered to include information on sex ratio and fecundity data for individual spawning runs, improving the accuracy of the estimate (Spratt 1983).The sections below describe the evolution towards the current sampling protocol, which has been employed consistently since the 1982-83 season with only minor modifications to the area searched and length of season in response to the expansion of herring spawning times and locations over time (Watters and Oda 2002).
Beginning with the 1973-74 season searches for intertidal Pacific herring spawn activity were conducted from a small boat approximately 2-4 days per week during low tide periods, from December to mid-March (Spratt 1981; Watters and Oda 2002). Starting with the 1996-97 season, the search period was expanded slightly to include November and all of March. Spawns were also surveyed outside of these periods, when anecdotal reports were received. When intertidal spawns were located, the area of the spawn was estimated, and a two-stage random sampling plan was then used to collect eggs and estimate the average density for the spawning area. Sites were also sampled opportunistically depending on a variety of factors, including safety, access, tidal height and available daylight. Spratt (1981) and Watters and others (2004) contain a detailed description of the intertidal sampling protocol, but in summary, the length of shoreline was marked and measured on Coast and Geodetic Charts or using a Global Positioning System (GPS) and the width of the spawning area was estimated. Area expansion factors based on habitat type were applied to account for slope and irregularity of surfaces. The shoreline was divided into sections, and $10cm^2$ subsamples were selected, and all eggs and algae were removed from each subsample. The number of eggs in each subsample was estimated by weighing the eggs in that portion, and calculating the number of eggs in the subsample. Then the density of egg deposits for each section was calculated by averaging value from the subsamples. The total number of eggs for each area was then calculated by multiplying the area by the average spawning area.

Beginning with the 1979-80 season, Department staff found large areas of subtidal spawning in San Francisco Bay that was not being accounted for in spawn estimates. Prior to this time it is likely that large subtidal spawns went undetected, and the spawning estimates from earlier years are likely an underestimate of the entire spawning biomass. For subtidal spawns, estimates of vegetation density are needed to calculate spawning biomass from subtidal spawns. Subtidal vegetation samples are collected prior to the season from spatially-random sampling locations within beds composed primarily of the red alga, *Gracilaria* spp., and eelgrass, *Zostera marina*, at known spawning areas around the bay. At each sample site, scuba divers collect one sample from each of four ¼ square-meter quadrats. Samples are processed in the lab, weighed, and averaged to estimate vegetation density (kg/m^2).

When subtidal spawning occurs, samples of vegetation with eggs are systematically collected within the spawn boundaries, during the process of locating the edges of the spawn area. A weighted rake is dragged along the bottom from a research vessel to collect vegetation and eggs throughout the bed to determine the extent of the spawning area and to obtain an egg deposition sample. Each 'rake toss' is documented as a 'waypoint' with a GPS unit. Additionally, the absence or presence of vegetation and type, as well as quality of spawn deposition on the vegetation, are recorded on field data sheets for each rake drag. The GPS waypoints are input into a geographic information system, where they are analyzed along with vegetation and deposition attributes to calculate the areal extents of each spawn event. As with the intertidal spawn samples, the subtidal sample is processed in the lab to calculate the number of eggs per kg of vegetation. This data along with estimated vegetation density and estimated extent of the spawning area yields the total number of eggs deposited during the spawn event.

Beginning in 1981-82, herring were also observed to spawn on pier pilings. Pier pilings are sampled using a protocol similar to that for intertidal spawns (Spratt 1984). Pier pilings are sampled randomly due to accessibility and $10cm^2$ samples of eggs are collected where possible. The area of spawn is calculated by multiplying the number of pilings by their circumference, then multiplying by the depth of the spawn. Spawn depth is estimated subjectively based on bottom depth shown on the research vessel depth sounder; the density of eggs, and the deepest depth that eggs could be scraped from the piling.

Hydroacoustic Survey

Between 1981 and 2003, the Department also conducted hydroacoustic surveys using a Department research vessel. Surveys were conducted during slack tides (usually high) to reduce error due to tide-related school movement. Herring schools were initially located and qualitatively surveyed with a fish finder and confirmed by sampling with a mid-water trawl. Once the school was verified as herring, quantitative hydroacoustic surveys were conducted with a paper recording fathometer. During this time period when both methods were used, the total spawning biomass estimate was calculated by meshing the results of the hydroacoustic and spawn deposition surveys. If there were constraints for one of the surveys (i.e. equipment failure, missed school or spawn), then the biomass estimate from the other survey was used for that spawn.

In 2003, the Department commissioned an independent review of the hydroacoustic and spawning deposition surveys (Geibel 2003). This review examined how well the spawning biomass estimate from each method correlated with the following year's spawning biomass estimate with the assumption that an estimate of one season's spawning biomass is a good estimator of the spawning biomass in the next year. The review found that while the spawning deposition surveys could explain 50 percent of the variation seen from year to year, the hydroacoustic surveys could only explain 4 percent, and the two surveys were not significantly correlated with each other. Based on the results of the review, the Department discontinued the hydroacoustic surveys and has since relied only on the spawning deposition surveys to estimate biomass and set quotas.

SSB Data used by Cefas

Yearly estimates (in short tons) of SSB from the spawning deposition surveys beginning in 1973-74 through 2013-14 were provided to Cefas for use in the assessment model. These are referred to in the Cefas report as SSB estimates (see Table A1.5 on page 54), but note that they reflect only estimates derived from the Department's spawning deposition surveys, as described above, and do not include the addition of commercial landings or the hydroacoustic survey estimates. Note also that estimates from 1973-74 through 1991-92 were not included in the assessment model, a decision made by Cefas to ensure temporal consistency among the various data sources that served as inputs. Specifics regarding the estimation of numbers-at-age for the SSB are addressed below in the section 'Age Composition Data Calculations'.

Young of the Year (YOY) Survey

Data on the abundance of young of the year (YOY) herring (age 0) throughout the year in San Francisco Bay are available as part of the Department's San Francisco Bay Study. This program began in 1980 with the goal of determining the trends in abundance and distribution of fish and macroinvertebrates in relation to environmental variables in San Francisco Bay. A Department research vessel fishes a mid-water trawl and an otter trawl year-round at each of 52 open-water sampling locations. These locations are sampled monthly and range from southern San Francisco Bay through San Pablo and Suisun bays and into the Delta. Juvenile herring and other species are caught in a mid-water trawl, which has a 3.7 m^2 mouth and meshes that graduate from 20.3 cm at the mouth to 1.3 cm at the cod end. The mid-water trawl is towed with the current for 12 minutes and retrieved obliquely, sampling the water column from bottom to surface. All fish are identified to species and enumerated, and up to 50 fish and 30 crab of each species are measured before being returned to the water (Orsi 1999). These data, along with the volume of water swept, are used to calculate a monthly abundance index of juvenile herring observed in the San Francisco estuary. Monthly YOY indices from 1992-93 through 2013-14 were used to calculate annual recruitment indices for the assessment model (see Table A1.5 on page 54 of the San Francisco Bay Herring Stock Assessment and Initial Evaluation of Harvest Control Rules). The 1992-93 start date of this dataset chosen by Cefas for inclusion into the stock assessment model coincides with the start date of the commercial catch-at-age data used in the assessment.

Population Surveys

The Department has employed surveys to sample the herring population in San Francisco Bay since the 1982-83 season. Surveys typically begin in November when herring schools start moving into the bay, and usually end in March. Trawl or research gill net samples are taken at least once a week, though historically sampling was conducted more frequently when staff levels were higher than today. Department biologists perform on-the-water surveys with the aid of a SONAR fish finder, looking for evidence of herring schools, and opportunistically sampling the schools as they are observed throughout the bay.

Herring population sampling is conducted using two different gear types. A mid-water trawl is the primary method for sampling the adult population. The trawl net has the same design as described in the YOY survey, using a 3.7 m^2 mouth and meshes that graduate from 20.3 cm at the mouth to 1.3 cm at the cod end. However, multi-paneled gill nets are also used when the mid-water trawl survey vessel is unavailable or when fish are in areas too shallow for the mid-water trawl gear to operate. The multi-paneled gill nets are constructed of variable mesh sizes, and include 1¼, 1½, 1¾, 2, 2¼, and 2½ inches to sample the entire range of herring sizes present in the San Francisco Bay spawning population. In many years both types of sampling are used, though in some years only a single method was employed. While the two gear types are likely to have a different selectivity, following a discussion with Cefas, it was decided that all research catch data should be combined in order to create a more complete time series. The removals from the research catch biomass are not included in the stock assessment because these removals only number in the hundreds to a few thousands of fish collected per season.

Fishery-Dependent Surveys

Herring Eggs-On-Kelp Fishery

The San Francisco Bay herring eggs-on-kelp (HEOK) fishery began in 1966-67 with a 5 ton product weight quota which was harvested by divers from wild kelp. The current HEOK fishery uses the open pond method and has been in place since the 1989-90 season. Giant kelp, *Macrocystis pyrifera*, is harvested outside San Francisco Bay and suspended from rafts inside the bay for herring to spawn on in shallow water areas. The product of this fishery is the egg-coated kelp blades that are processed and exported to Japan. The HEOK fishery is allocated a separate quota from the gill net fishery. The harvested product is converted to the equivalent of short tons of whole fish. Landings have historically ranged from 0 to 12.6 percent of the total commercial catch, with an average of 2.8 percent of the total catch each year. These data were not used in the stock assessment because the tonnage associated with these landings represent removed herring eggs, not adult fish. Adult herring are not captured in the HEOK fishery and thus, are able to return to spawn in subsequent years.

Gill Net Fishery

The herring gill net fisheries catch herring as they move into shallow areas to spawn. The traditional product from this fishery, *kazunoko*, is the sac roe (eggs) removed from the females, which is processed and exported for sale in Japan. California's roe fishery began in the 1972-3 season and a formal limited-entry permit system was implemented in 1977. In San Francisco Bay, the fishery is separated into Even and Odd fishing groups (platoons) based on permit numbers. Platoons rotate fishing weeks throughout the season.

In the 1980-81 season, the Commission opened a December gill net fishery (with separate permits and quotas) in San Francisco Bay. Due to a variety of factors, the fishery has not landed herring since December 2006 and beginning with the 2010-11 season permits from that fishery were incorporated into the Odd and Even platoon fisheries which fish from January through March.

Commercial landings data (in short tons) have been collected via landing receipts each season since the roe fishery began in the winter of 1972-73. Through the history of this fishery round-haul (purse seine and lampara) and gill nets have been used in San Francisco Bay to catch herring. Each gear type had separate quotas. Lampara gear was phased out after the 1987-88 season, and purse seine gear was prohibited after the 1997-98 season, which followed a 5-year conversion period.

Over time the minimum gill net mesh size used in San Francisco Bay has varied due to proposals by both the Department and commercial fishery representatives (Table 1). In the

1976-77 season, a minimum mesh size of 2 inches and a maximum of 2½ inches was established for the roe fishery. In 1982-83, the minimum mesh size was increased to 2¼ inches for any fishing prior to January 14, with the option to authorize mesh sizes of 2⅛ or 2 inches for fishing after that date by the Department. The following year this was changed so that the December fishery had a minimum mesh size of 2¼ inches, while the Odd and Even gill net fleets both had a minimum mesh size of 2⅛. In the 1984-85 season, a minimum mesh size of 2⅛ in was established across all fleets in San Francisco Bay, and this remained unchanged until the 2005-06 season, when regulations were changed to decrease the minimum mesh size for gill net fleets in San Francisco Bay from 2⅛ to 2 inches.

Time Period	Gill Net Mesh Size (inches)	
	Minimum	Maximum
1976 to January 14, 1983 (No restrictions prior to 1976)	2	2 1/2
November 28, 1982 – December 16, 1983	2 1/4	2 1/2
January 2, 1984 – March 11, 2005	2 1/8	2 1/2
December 19, 2005 -- Present	2	2 1/2

Table 1. San Francisco Bay Commercial Herring Fishery Gill Net Mesh Size Summary

The commercial herring fishery on the San Francisco Bay spawning stock is regulated through a catch quota system. The annual SSB estimate, age class structure, condition indices, commercial catch analysis, along with various environmental indicators all serve as the basis for establishing fishing quotas for the next season. Annual fishing quotas are necessary to provide for a sustainable fishery and have historically been limited to a total commercial take not to exceed 20 percent (harvest percentage) of the previous season's estimated SSB. This harvest percentage is based upon the results of a previous peer reviewed model (Coleraine) that assumes stable environmental and biological conditions (Hilborn and others 2003; MacCall and others 2003). Each year, the Department recommends a harvest percentage that is not determined by a fixed mathematical formula; rather, the recommendation is informed by the modeling results and takes into account additional data collected each season, including: ocean productivity and estuarine conditions, growth rates of herring, strength of individual year-classes, and predicted size of incoming year-classes (i.e., recruitment). In response to poor recruitment or indication of population stress and/or unfavorable oceanographic conditions, harvest percentages for the past ten years have been set at or below ten percent. The Department calculates the exploitation rate, defined as total commercial catch divided by the SSB estimate plus commercial catch, which has ranged from zero to 38.7% of the SSB estimate for the time period between 1992-93 and 2013-14 (Figure 1).

Landings data from 1972-73 through the then-most-recent season (2013-14) were provided to Cefas for development of the stock assessment. However, for consistency and to match the commercial age composition model inputs, the decision was made to only include landings data back to 1992-93 in the assessment model. Landings are available by individual gear type, but were combined for use in the assessment model. In addition to tracking total landings, the Department samples individual fish caught in the fishery. These data are used to estimate annual age composition for the commercial fishery, and were used by Cefas as inputs to the assessment model. The section below provides specifics on calculating age composition of the commercial catch.

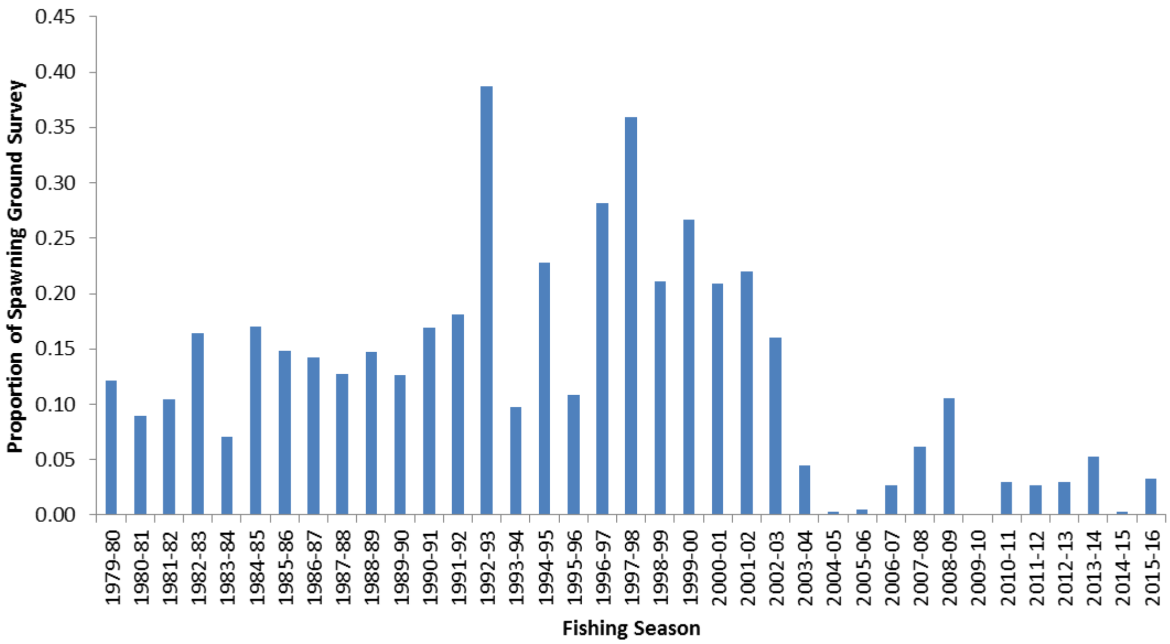

Figure 1. San Francisco Bay Pacific herring commercial roe fishery exploitation rates, landings tonnage as a proportion of spawning ground survey

Recreational Fishery

The recreational fishery is comparatively small and widely dispersed due to the spawning behavior of herring in San Francisco Bay. As a result, few recreational herring fisherman have been sampled in the Department's recreational fish surveys and no data are available on removals that could be included in the assessment model.

Age Composition Data Calculations

Age composition data used by Cefas to condition the assessment model are produced by Department staff from both fishery-independent and dependent biological samples, termed 'research' and 'commercial', respectively. As described above, the research data are obtained by Department staff using mid-water trawl gear and multi-panel gill nets. Commercial catch is sampled by Department staff as the fish are landed as well as directly from fishing vessels during fishing operations. Fish with ripe gonads from research samples are used to determine age composition of the SSB, and all fish sampled from the commercial landings are used to determine age composition of the commercial catch.

Length and maturity data are recorded for all sampled fish. For research samples weight data and otoliths are only collected from the mature fish, however these data are collected for all commercial herring sampled. All removed otoliths are surface aged at the end of the season by Department biologists. Proportions-at-age estimated from these samples are used to calculate annual numbers-at-age for both commercial catch and the SSB estimate.

Number-at-age and average weight-at-age data are used to estimate age composition of the SSB and commercial landings. The first step in the process is to associate biological samples with spawning waves or landings events based on temporal and spatial proximity. Once this is completed, number-at-age, mean weight-at-age, and total weights are determined for each sample. The number-at-age is multiplied by mean weight-at-age, and then divided by the total sample weight for the spawning wave or landings to get the percent weight for each age. Percent weight is then multiplied by the spawning wave biomass or commercial landing to calculate short tons at age. Tons-at-age are multiplied by a conversion factor (907,185 grams/short ton) and divided by the mean weight-at-age to calculate numbers-at-age in the commercial landing or spawning wave The tons-at-age and number-at-age for each spawning wave are summed to get the season totals. Total tons at each age are divided by the total weight for all ages to get the proportion of numbers-at-age, which was used in the model. The mean commercial weight-at-age is calculated from the total weight-at-age divided by the total number-at-age, and these data for each season are used in the model.

SSB Numbers-at-Age

The Department has sampled the spawning biomass for age composition and weight data since the 1982-83 season. Prior to the 2003-04 season, age-length keys were used to assign ages to the entire sample. These keys were constructed annually, after ageing a subset of the catch (17 fish per each 10 mm increment for each spawning wave) to assign ages to the unaged portion of the samples. In 2003, the Coleraine stock assessment review committee recommended using direct aging and after the 2003-04 season direct aging of the otoliths was used to determine age composition. The only exception was the 2011-12 and 2012-13 seasons when the length-age key method was used because Department staff did not have sufficient time to age the large number of fish collected.

Note that only a small fraction of age 1 fish are mature, and the model only used data from fish ages 2–6+ for the SSB numbers-at-age data. Also note the age 6+ group includes all fish age 6 and older. Weighted numbers-at-age data from 1997-98 to 2013-14 were used in the assessment. Numbers-at-age data from the period 1982-83 through 1996-97 were not used in the assessment due to time constraints associated with producing the data in the format required by Cefas to develop the assessment model.

Commercial Catch Numbers- and Mean Weight-at-Age

The Department has sampled the commercial catch for age composition and weight data from the roundhaul catch since the 1973-74 season and gillnet catch since the 1976-77 season. Commercial samples of herring are collected opportunistically from waves of herring as they are caught in the fishery. Generally, each sample consists of 10 – 40 fish and is collected from individual vessels or from fish buyers by landing date. Each sample records length (mm body length), weight (to the nearest 0.1g), sex, maturity, and otoliths for individual fish are removed. Spent or immature fish are typically not caught in the commercial gill net fishery, but because they are a portion of the removals, no herring are discarded from sampling based on their maturity.

Data from the period 1973-74 to 1991-92 were not used in the assessment because the information required to recreate age composition data in the format required by Cefas were not available due to time constraints. Commercial catch age composition and average weight-at-age data from 1992-93 to 2013-14 were recalculated using the method required by Cefas (see Age Composition Data Calculations, above) and used in the assessment.

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Review of the Revised Stock Assessment for the Pacific Herring Population in San Francisco Bay

May 16, 2017

Both the Cefas analysts and CDFW staff have done a good job of addressing a number of concerns raised by the Review Panel regarding the preliminary assessment of the San Francisco Bay herring population. In particular, the Panel notes big improvements in the documentation of the methods used in data collection and compilation, the description and presentation of equations used in the model formulation, and the explanation of the simulations. We wish to especially note the very important March 2017 management overview, produced by California Department of Fish and Wildlife, and specifically acknowledge the importance of this history. In addition, Cefas analysts conducted a number of additional assessment runs to test alternative model formulations and provided figures and tables with likelihood estimates and plots of the results. Although the Cefas report is very much improved, and many of our criticisms have been addressed, we did find some of the same deficiencies that were pointed out in our previous review. Moreover, after reviewing the latest draft, the Review Panel found itself somewhat unsure of our mission and somewhat confused by the goal of the review.

Cefas has clearly stated in the new discussion, "the MSE framework and HCRs presented are preliminary and have not been fully developed here." We agree with that conclusion and take note of it. We also acknowledge the request from CDFW to limit our review to "the Cefas stock assessment itself and *whether it represents a defensible operating model given available data* (emphasis added)." The conclusion that this model is not "fully developed" seems to answer the question as to whether or not the assessment represents a "defensible operational model." The analysis under review, as the Panel understands it, appears to be a single model based on a combination of assumptions and model fits to data. This exercise has been very useful in identifying several scientific questions that remain about San Francisco Bay herring dynamics. But, because so many questions remain, we cannot agree that a single model—that in some sense might be the best—can be used to reliably predict the actual dynamics of the herring stock.

The available data have not been sufficient to resolve a number of issues. These data are not sufficient to develop a clear picture of the relationship between stock size and subsequent recruitment—especially at small stock sizes. After considerable work, the relationship between fish age and gear selectivity has not been clearly defined. The question of whether or not the 2007 *Cosco Busan* oil spill affected the stock productivity to a substantial extent remains, as do questions about the best way to model variation in recruitment in the years potentially affected by the oil spill. The Cefas analysts found reasons to adopt Model 6 as their base model. The Review Panel, on the other hand, can see many reasons to delete either the oil spill factor or the somewhat ad hoc mortality multiplier for the age-6+ group, which we will discuss below. Either way, the application of data to the modeling process has resulted in controversy and uncertainty. Moreover, that uncertainty should be reflected in the larger MSE process by considering Model 6 along with a range of other operating models that consider alternative hypotheses. That uncertainty cannot be adequately captured and communicated by simply focusing on any single model that might, in some sense, be the best.

Modeling Issues

The stock-recruit relationship remains an issue with respect to the defense and validation of the proposed operating model. A large amount of the revised report is devoted to estimating the stock-recruit relationships. In the end, the available data simply do not support any particular, biologically reasonable stock-recruit relationship. It may be that there is simply too much measurement error in either the stock size estimates, the recruitment estimates, or both for the stock-recruitment relationship to be statistically determined. In any event, after considerable manipulation of stock-recruit data, the stock-recruitment relationships used in all of the proposed models are principally a matter of just assumption. If there is decreased recruitment at low or moderate stock sizes, measurement error may be obscuring the actual stock-recruitment relationship[1]. It needs to be emphasized that the assumption around the form of the stock-recruit relationship is critical to the dynamics of the population in any simulation scenario of future productivity and resilience and will affect any decision about an optimal harvest control rule.

The Cefas authors dismiss the dome-shaped selectivity function that was observed in Model 1 because it led to apparently excessive numbers of fish in the age-6+ group. However, given that the fishery has used only gillnets since 1999 (Figure 4 in the revised report), and this being a very selective gear targeting particular size groups of herring, one might expect the domed selectivity function that is evident here in the plots. To address the apparent surplus of fish in the age-6+ group, a flat-topped selectivity function was inserted for the age-5 and -6+ groups. Importantly, this flat-topped model does not appear to select any fish of age 2 (see Figure 14). However, in Table A1.3 we note that there are substantial catches of age-2 fish in many years. Therefore, the selectivity function in the base model appears to be incorrect or at least unrepresentative of the available data. Additionally, the likelihoods for Model 1 in both Tables 4a and 4b (355.81 and 357.54) are equivalent to that for Model 6 (357.76). In our view there is no justification for adopting the more complex Model 6, or at least that justification cannot be based on improved fit to available data.

As noted above, large numbers of age-2 fish are mature and captured in the fishery, and likely virtually all age-3 herring are mature (based on the research selectivity curves). Therefore, we suggest that a selectivity function that is fixed at 1 for all fish aged 3 and older would be a more realistic reflection of San Francisco Bay herring and the selectivity of the gillnet fishery. It is almost certain that such a function would deal with the issue of an accumulation of fish in the age-6+ group, the so-called “cryptic” biomass.

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[1] See Hilborn, R. and C.J. Walters. 1992. *Quantitative Fisheries Stock Assessment*. Chapman Hall, pages 287 to 290.

The Panel remains unconvinced that an ad hoc adjustment for the oil spill is justified, and we remain concerned about model over-fitting. We note that there has been a multitude of studies of potential oil impacts on the herring population in Prince William Sound and there has been no conclusive evidence of any negative short-term impact on the population. While the *Cosco Busan* oil spill was somewhat different in that it was a spill of refined petroleum product, it is evident from oceanographic data that both 2005 and 2007 were very unusual years in the eastern Pacific Ocean. Unusual ocean conditions may have played a role in the apparent mortality event associated with the oil spill. Not unexpectedly, the addition of more parameters into the model (oil spill effect) will result in a better fit of the model to data and the appearance of reduced variability in recruitment. However, we did not find adequate justification in the report to include this effect in the model.

Other data issues

We were also surprised to learn that much of the age composition data are derived from an age-length key prior to 2003. This led us to wonder whether this may also be a partial explanation for the apparent "cryptic" age-6-and-older biomass. In particular, Chilton and Stocker[2] report that surface aging of otoliths—rather than break-and-burn methods—typically resulted in lower age readings for herring. Therefore, an age-length key based solely on surface aging would be expected to under-represent the existence of any individuals in older age classes. It seems at least possible that there may be some individuals age 10 or older, as is observed in other Pacific herring populations, which could also account for some of the "cryptic" biomass.

On page 46 of the revised report, the analysts comment on the question of relative weighting of age composition versus abundance index data and discount reduction of the weight on the age composition data but provide no clear explanation. Given the fact that much of the age composition data derives from the application of an age-length key, and the uncertainty in ages associated with surface ageing versus break-and-burn techniques, we believe that the high confidence placed on the age composition data is unwarranted and likely results in overfitting of the model to the age composition data. Further it is difficult to believe that the spawn index data, which are the only empirical estimate of the SSB for this population, and which CDFW uses directly to set harvest quotas are given less weight in the likelihood function than all of the other data inputs. In any event, Francis[3] describes statistical methods for determining the weightings on the various data sources and should be applied to properly weight the data inputs.

Model Selection

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[2] Chilton, D. E., & Stocker, M. (1987). A comparison of otolith and scale methods for aging Pacific herring. North American Journal of Fisheries Management, *7*(2), 202-206.

[3] Francis R.I.C.C. (2011) Data weighting in statistical fisheries stock assessment models. Canadian Journal of Fisheries and Aquatic Sciences 68: 1124–1138.

The mortality multiplier for age 6+ is evaluated in Table 7. It presents the results of a number of alternative model fits using other natural mortality formulations as presented in Models 10 to 13. They all produce similar likelihood values to the baseline model. We note that Model 13, which is discounted, still has a significant function gradient. The likelihood function for Model 13 (omits 6+ group mortality multiplier) is at a local rather than global minimum, so this effect cannot be tested by this run. However, Model 12, which also omits the age 6+ mortality multiplier, results in the same likelihood function value as the base Model 6, seeming to indicate that this mortality multiplier does not really improve the model fit.

In Table 9, the results for Model 19 relative to Model 6 (models differ due to adding additional years of data) change the perspective on the population substantially. The unfished abundance increases from 74,000 to 85,000 and the estimate of the proportion of the population observed by the spawn assessment surveys decreases from almost half to about one third (q=0.449 to 0.341). We find this sensitivity to the model fitting due to the addition of small amounts of data troubling and may be a function of the disproportionate weighting of the age composition data relative to the spawn and recruit index information.

In Table 18, the results of increasing the proportion of fish mature at age 2 are presented and show a slight decrease in likelihood function value, suggesting a very slight improvement in fit to the available data. The result is discounted because it is "difficult to compare model fits because of the change in underlying data." While that may be true, there is a widely held understanding that there is a cline in maturity of Pacific herring in moving from Alaska to California, with more fish maturing at younger ages as one progresses southward. One would expect that more herring are mature at age 2 than has been assumed in the base model and this is evident from catches in the commercial fishery. Very few age-2 herring are seen in any British Columbia or Alaska fisheries but it is maturity data from BC that are the basis for the maturity function applied in the base model here. We believe that applying a more realistic selectivity function using the known or assumed maturity ogive will lead to a better fit to the available age composition data.

Assessing the Harvest Control Rule and Risk

In the MSE context, any model that can be defensibly conditioned on historical data is appropriate to *consider* as an alternative hypothesis about the historical and future population dynamics. The data fitting procedures used in conditioning such models should provide some measure of the relative degrees of credibility for each of the operating models. In the MSE context, this credibility should be used to rank model predictions at a later stage in the process. Accordingly it is not really appropriate to ask that the Review Panel confine their review to the single Cefas preferred model, and then ask whether it represents a (single) defensible operating model given the available data. Cefas has provided several alternative models that could be used as operating models as long as their relative plausibility can be ranked[4]. An additional measure of plausibility, that should be part of a complete analysis, has to do with how well the simulations reflect the experience managing other herring populations in the Pacific.

The Panel strongly agreed that the Cefas preferred model (Model 6) by itself should not be assumed to realistically simulate all aspects of the dynamics of the actual San Francisco Bay herring population for the purpose of managing the fishery in this or subsequent years. While the Panel noted the comments about testing “each management strategy under a range of uncertainty scenarios” on page 3 of the management overview provided by CDFW, the Panel was left to wonder which management strategies were being entertained and to wonder how uncertainty was introduced into the simulations. If it is safe to assume that such uncertainty scenarios included an alternative operating model, then the alternative operating models will need to be ranked by their plausibility.

Regardless of the range of operating models being proposed, we view that it is essential that the current management strategy be tested along with the range of other strategies. Certainly a facsimile of the current management strategy, together with the Cefas assessment model, should be tested alongside other alternatives. While the management strategy has varied somewhat from year to year, it is important to consider the historical experience of applying the current management strategy: its use, in this case, defined by a range of exploitation rates from 0-38%, with exploitation rates since 2000 of less than 20%. The experience so far demonstrates that, when used with the harvest control rule, this has not resulted in depletion of SF Bay herring stocks. Given that history, CDFW should be aware that adopting an operating model that doubles the perceived biomass (given the estimates of q in Table 8), and then uses this assumed higher biomass as the basis for evaluating future management procedures, may seem to justify management procedures that produce higher catch given the same apparent exploitation rates that were applied historically. Unlike the management strategy that has been in place for which there has been some historical experience, there will only be a relatively novel set of simulations to justify adopting this approach.

In conclusion

Perhaps the most troubling aspect of the updated report is the risk assessment presented in Table 10. The forward projection model assumes little or no impairment of recruitment across the range of observed spawning biomass. An assumed fishing mortality rate of 1.0 when combined with the natural mortality rate of 0.63 implies an overall survival rate of about 20 percent of the population but a depletion of only about 53 percent (SSB/K_{SSB}). This does not seem realistic, nor is it consistent with what is known about herring management in other areas. Evidence from other herring populations in British Columbia and Alaska have shown much higher depletion levels at much lower harvest rates. In particular, past experience in British Columbia during the reduction fishery of the 1960s demonstrated that removal rates of 60 percent virtually extirpated the fishable population.

[4] Punt, André E., et al. 2014. Management strategy evaluation: best practices. Fish and Fisheries, 17(2): 303-334.

Further, recent experience in both British Columbia and Alaska with harvest rates of less than 20 percent have shown risk levels (i.e. spawning biomass less than 25% of virgin comparable to B_{lim} used here) much higher than the 6.4 to 7.0 percent risk identified in Table 10. We believe that the operating model used to generate the risk table does not adequately reflect the experience of what has been observed in exploited Pacific herring populations elsewhere and does not reflect what is known about the productivity of the San Francisco Bay herring population.

In our view, there are significant problems with the assessment (operating) model, as one would expect with an analysis that is "preliminary" and not "fully developed." While we acknowledge that this analysis has been valuable as a preliminary investigation, we believe that using it to make projections of the risk associated with fishing the San Francisco Bay herring population at high removal rates will lead to unrealistic estimates of resilience that, if implemented, could result in serious conservation impacts to the resource.

Minor Comments

Page 9 (in the introduction) it is stated here that "annual fishing quotas are necessary to provide for a sustainable fishery and have historically been limited to a total commercial take not to exceed 20 percent (harvest percentage) of the previous season's estimated SSB." The term *estimated* often refers to a quantity derived through a statistical procedure. We are curious as to which quantity was determined through the MacCall et al 2003 peer review not to exceed 20%: the exploitation rate h referred to in Figure 1 is the quotient of total commercial catch C at time t divided by the spawning stock biomass, SSB at time t-1: $h=C_t/(SSB_{t-1}+C_t)$. However, the "harvest percentage" looks like it should be defined as C_t/SSB_{t-1}.

Figure 2 still does not have proper axis labels. Note that the word *April* is misspelled in this figure caption.

Review Panel

Hal Geiger, Chair
Jake Schweigert
Nathan Taylor

Appendix C Coleraine Stock Assessment Model Report

Peer Review of the California Department of Fish and Game's Commercial Pacific Herring Fishery Management and Use of the Coleraine Fishery Model
Completed: August 20, 2003

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Problem Statement

The California Department of Fish and Game (DFG) has traditionally used spawn surveys and hydroacoustic surveys to assess the stock size of Pacific herring in San Francisco Bay. These surveys have demonstrated a steady downward trend in the stock size over the past 25 years. Beyond the downward trend, during the past several years there was disagreement between the population estimates derived by using these two survey techniques. This year (2003) DFG decided to use currently available statistical modeling techniques to further assess the status of the population and the results that might be expected from different management strategies. The selected model, the

Coleraine model, had not previously been used by DFG, and this general purpose model was not specifically designed for assessing San Francisco Bay Pacific herring. DFG requested that California Sea Grant assemble a panel of peer reviewers to determine if it was appropriate to use the Coleraine model, to instruct them in its use, to help its staff in interpreting the results, and possibly to suggest appropriate changes in management strategy. Sea Grant assembled a team of scientists with demonstrated expertise in modeling and assessing fish populations: Alec MacCall; Mark Maunder, and Jake Schweigert. They assembled together with DFG staff for a two-day workshop (August 19 and 20, 2003) designed to accomplish the above stated goals. Following are their findings, conclusions, and recommendations.

Findings

Estimates of stock abundance and trajectory over the available time series by an equilibrium surplus production model, the Coleraine catch-age model, and the Canadian herring catch-age model all result in similar estimates of stock status. The indication is that the San Francisco Bay herring population has been reduced to a level of roughly 20% of the unfished level and is presently at or near the lowest abundance observed since the early 1970s. All data (survey, CPUE, and catch-at-age) are generally consistent with these findings. The exploitation rate defined as catch divided by spawning biomass has been over 20% for most of the period since 1990. The fishery tends to catch a very high proportion of the individuals that are vulnerable to the gear.

The age composition of the catch has changed towards younger individuals. At present there are essentially no individuals aged 6 years or older in the catch, while in earlier years these ages made up over 50% of the catch. Due to higher exploitation rates it is expected that the average age in the catch should have reduced. However, there is substantial evidence that the fishery has increasingly targeted younger individuals. The present mesh size limit in the fishery represents a lower limit for the exploitation of this population allowing a proportion of the age 3 and most of the age 2 fish an opportunity to spawn. Any further reduction in the mesh size or increase in the hanging ratio would negatively impact the population.

The spawn survey tends to underestimate spawning biomass by about 10% and the hydroacoustic survey tends to overestimate the spawning biomass by about 20%. The errors (coefficients of variation) in the annual spawning biomass indices are about 40% for the spawn survey and about 75% for the hydroacoustic survey. This indicates that the spawn survey is a better estimate of spawning biomass than the hydroacoustic survey.

The practice (or tendency) of using the higher value of the spawn survey or the acoustic survey as the basis for setting quotas has contributed to overfishing. The target exploitation rate (catch per spawning biomass) of 20% may be higher than optimal, and also has been exceeded frequently over the past decade. Maximum sustainable yields are obtained using an exploitation rate (catch divided by spawning biomass) of about 16%. Simulation analysis suggests that under the current age-specific selectivity pattern of the gear, this may involve harvesting nearly all the vulnerable individuals depending on the shape of the stock-recruitment relationship (which is not well estimated at the present time).

Recommendations

The San Francisco Bay herring population has been reduced to a level of roughly 20% of the unfished level and is presently at or near the lowest abundance observed since the early 1970s. A rebuilding policy should be implemented.

The current harvest strategy for this stock should be re-evaluated and explicitly documented. The current harvest rate policy of 20% appears to be too aggressive under current levels of stock production. A harvest rate in the range of 10-15% appears to be sustainable with the lower level providing a desirable target for stock rebuilding. The CDFG should investigate the suitability of a fishing threshold or cutoff level similar to that in place in British Columbia and Alaska to conserve spawning biomass and during periods of reduced productivity.

The Department should develop a specialized herring stock assessment model using an approach similar to that in Coleraine. This will make the best use of the variety of data that exists for herring and would better reflect unique biological properties of the San Francisco Bay stock. While this could be done by contract, the Department would benefit greatly by developing this model in-house. This would assure that DFG has staff who understand the techniques and assumptions in such a model, who would be capable of maintaining and updating the model, and who would be capable of applying the technology to other resource management problems.

Spawn surveys provide a sound empirical estimate of current stock size and should be continued on an annual basis as the primary index of abundance and as the biomass estimate for use in setting the fishery quota for the upcoming season until an integrated catch-age model can be developed and verfied. Hydroacoustic surveys should be continued on a developmental basis as resources allow to support the location and timing of spawn assessment surveys and to better understand possible changes in pre-spawning herring behaviour within the bay. Such surveys can be conducted in conjunction with the trawl surveys that are critical for the collection of information on the age structure of the spawning population. The results of this year's Coleraine model runs may provide useful guidance for decision-making, with the understanding that the future specialized model may produce results that differ in unanticipated respects and the two models are unlikely to be exactly equivalent.

The biological sampling program currently in place for estimating the age-structure of the population is not providing an unbiased estimate of the true population age composition. The present system of obtaining age compositions by means of age-length keys should be replaced by direct (random) sampling of ages from the fishery and survey catches. The allocation of age samples would be approximately equal between surveys and fishery catches, and should be based on an approximately constant rate of samples per ton. The DFG may also want to consider the use of scales rather than otoliths to maximize the use of available ageing resources.

We recommend that the Department adopt a stronger policy of documentation. Details of each year's surveys and monitoring should be recorded and archived at least in timely internal reports.

Acknowledgement
We commend the professionalism of the DFG staff in supporting this review. Their dedication to herring research over the past 25 years has made it possible to do the statistical analyses required for sound management.

Appendix D Herring Spawning Habitat Maps

Figure D1. Bays and estuaries in the central California Current Ecosystem with known and potential Herring spawning habitat.

Figure D2. Eelgrass (*Zostera marina*) habitat in the Smith River estuary.

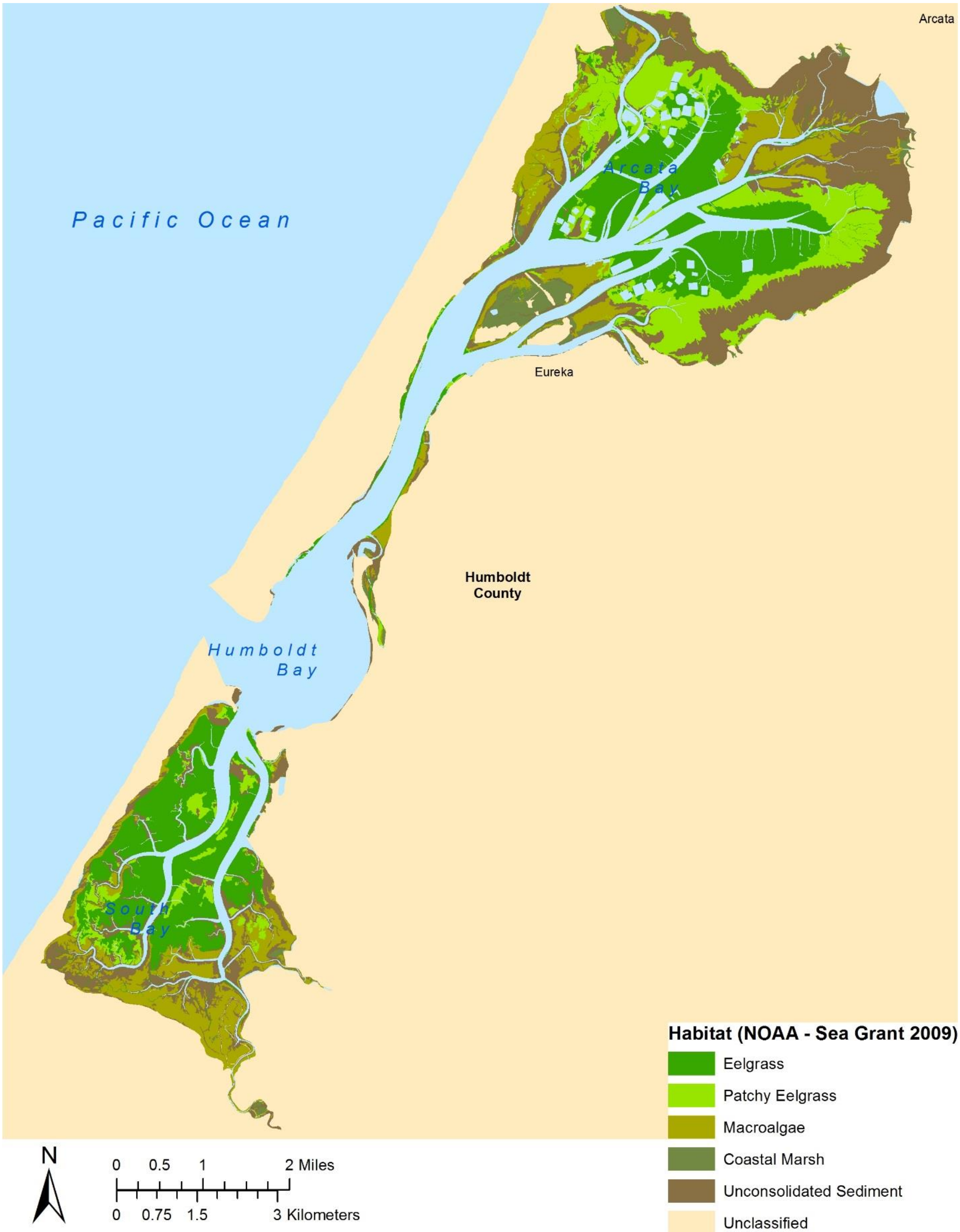


Figure D3. Eelgrass and other habitat types in Humboldt Bay (from Schlosser and Eicher, 2012).

Figure D4. Eelgrass and other habitat types in the Eel River estuary (from Schlosser and Eicher, 2012).

Figure D5. Eelgrass habitat in Ten Mile River estuary.

Figure D6. Eelgrass habitat in the Big River estuary.

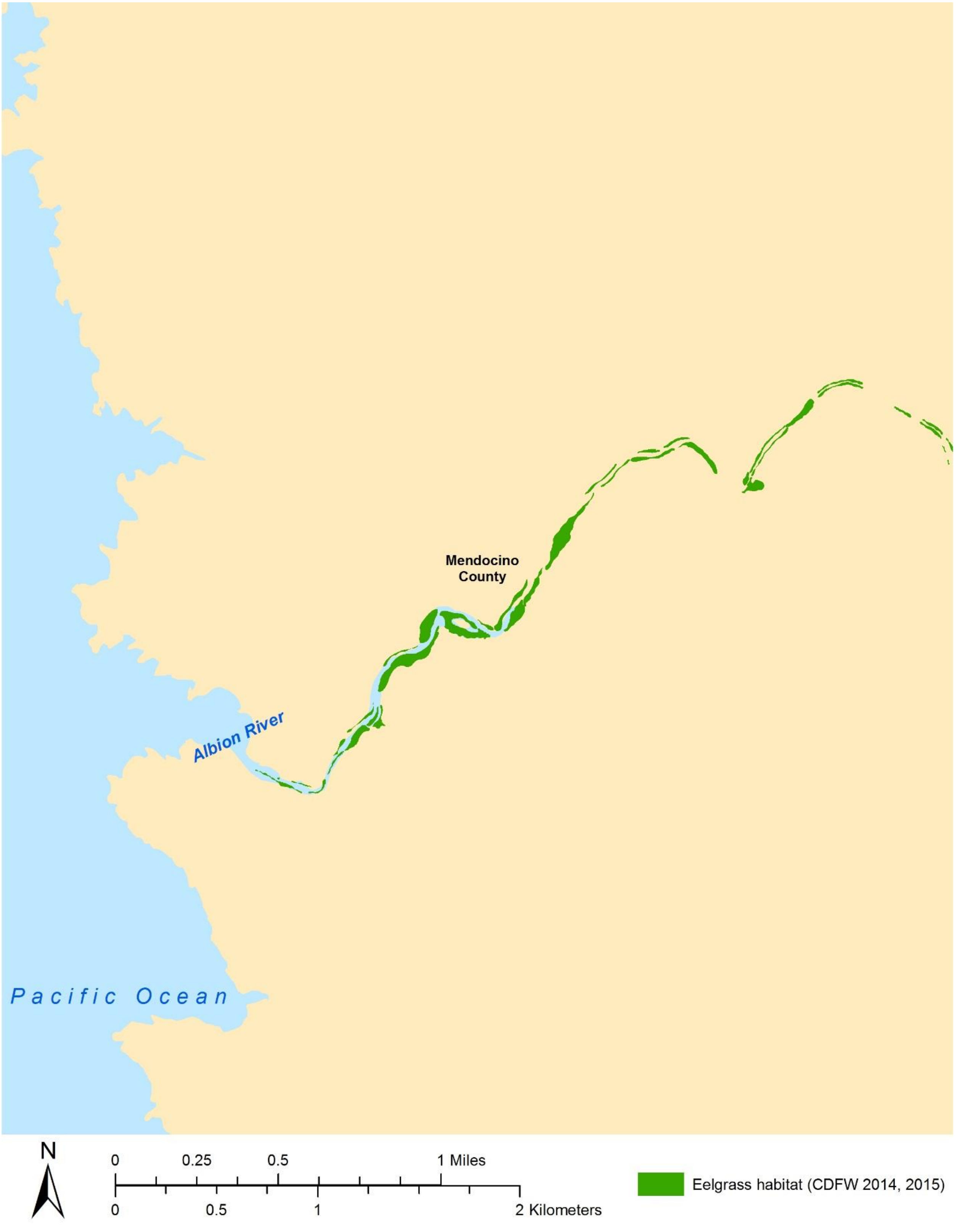


Figure D7. Eelgrass habitat in the Albion River estuary.

Figure D8. Widgeongrass (*Ruppia maritima*) habitat in the Russian River estuary.

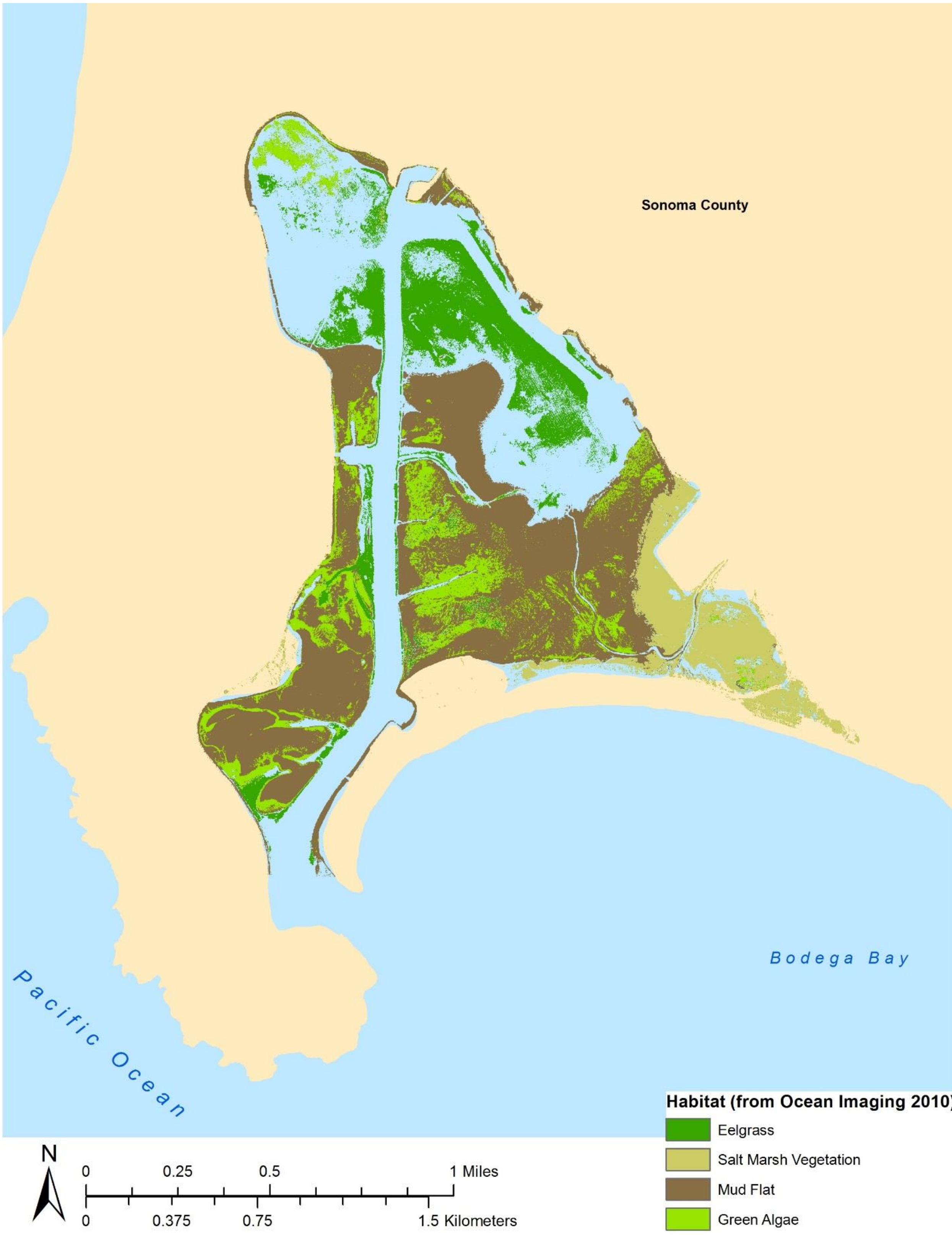


Figure D9. Eelgrass and other habitat types in Bodega Harbor.

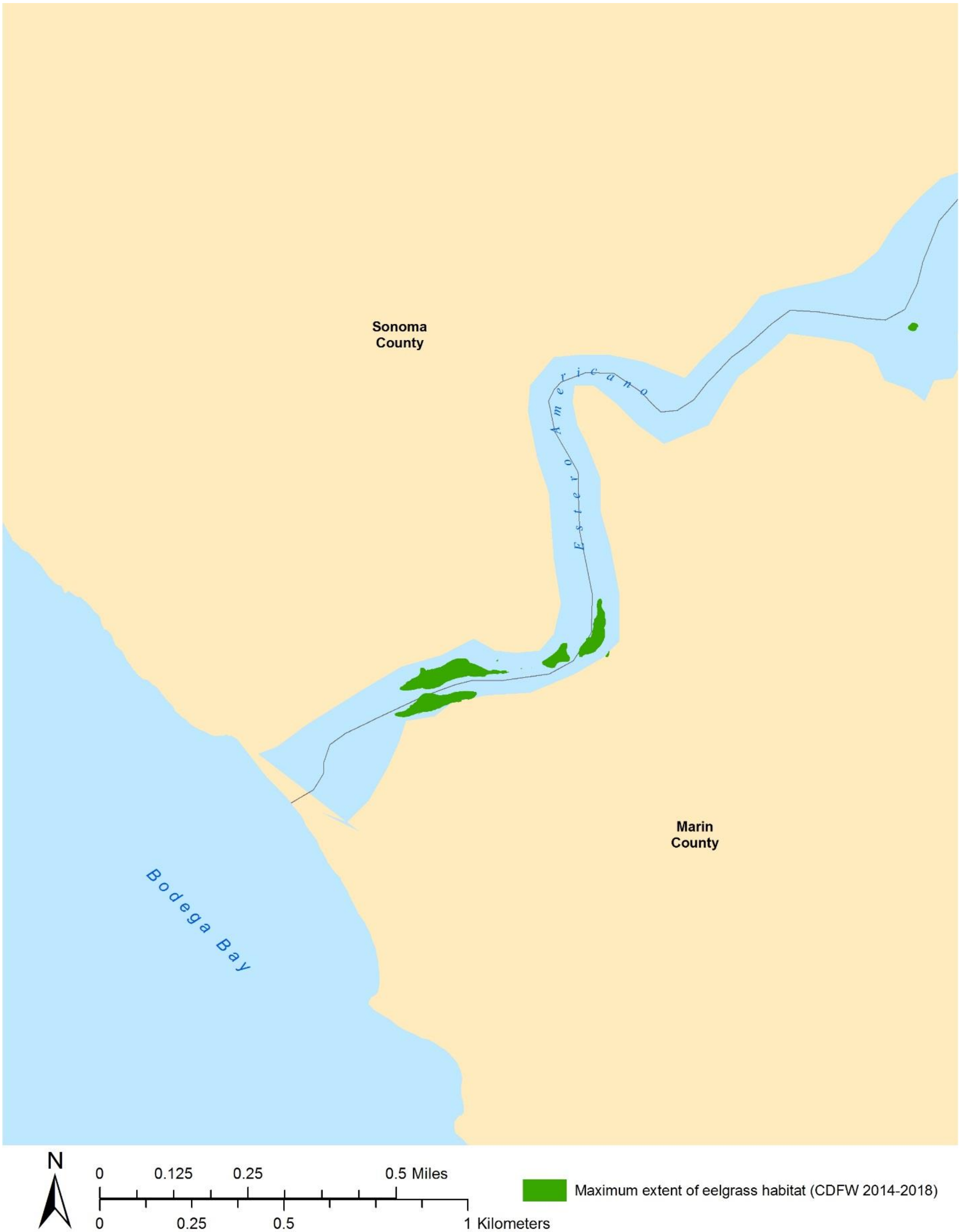


Figure D10. Eelgrass habitat in Estero Americano.

Figure D11. Eelgrass habitat in Estero de San Antonio.

Figure D12. Eelgrass habitat in Tomales Bay.

Figure D13. Eelgrass habitat in Drakes Estero and Estero de Limantour.

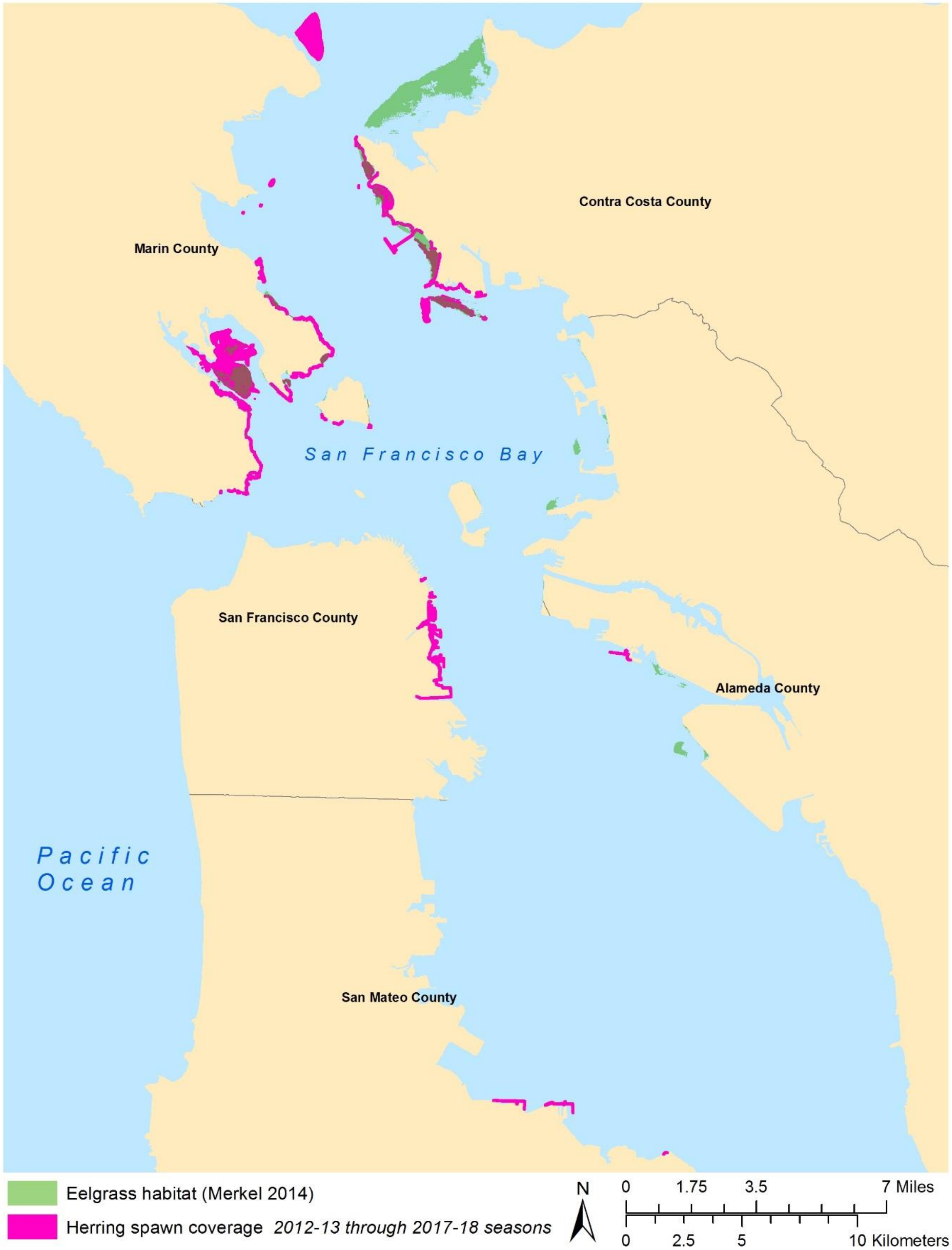


Figure D14. Eelgrass habitat and Herring spawn coverage in San Francisco Bay.

Figure D15. Eelgrass habitat in Elkhorn Slough (Wasson and others, 2019).

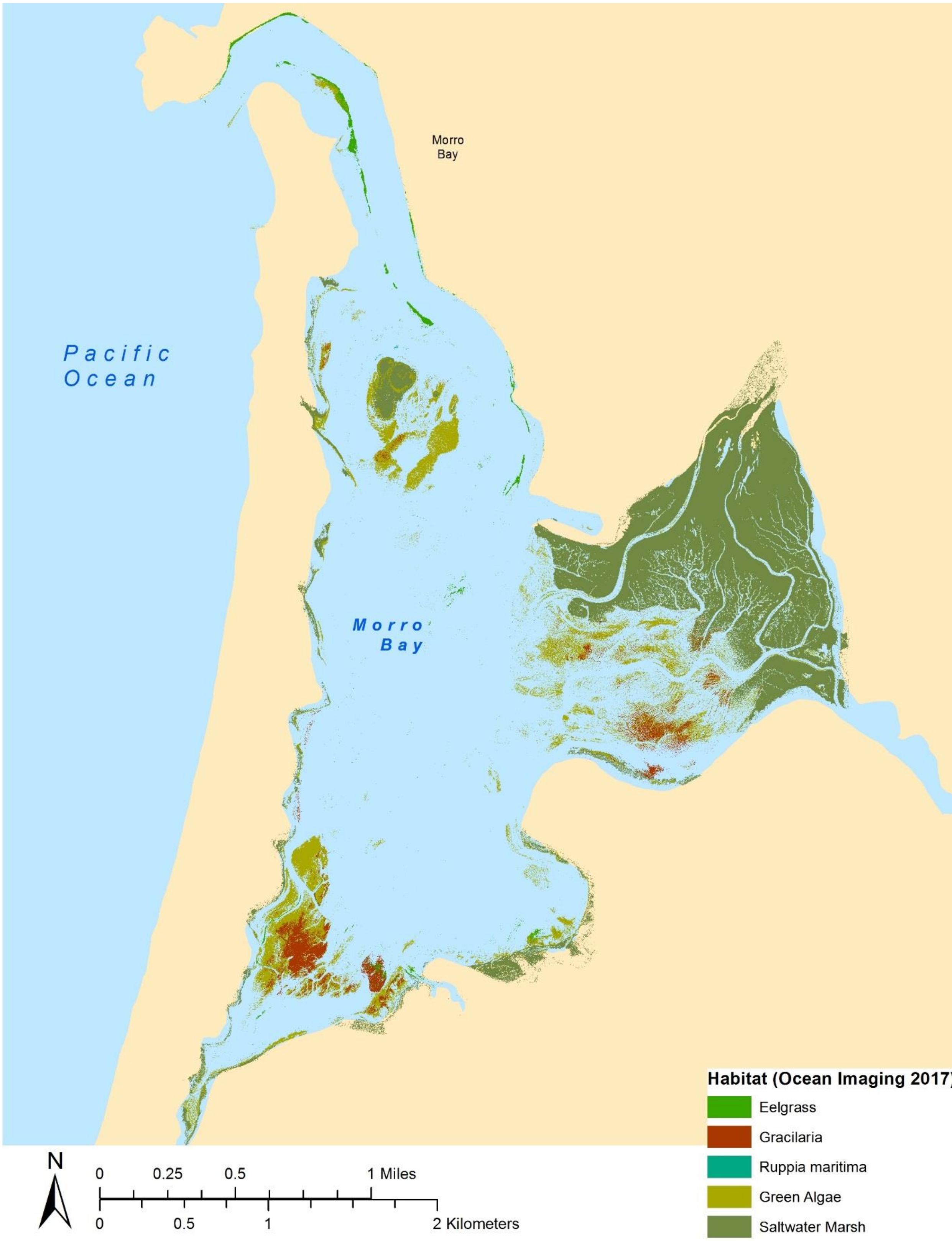


Figure D16. Eelgrass and other habitat types in Morro Bay.

Appendix E Forecasting Herring Biomass in SF Bay

The California Marine Life Management Act (MLMA) requires ecosystem considerations in fisheries management, in this case for the San Francisco Bay Pacific Herring (Herring), *Clupea pallasii,* fishery. Herring exhibit high variation in abundance from year to year, and are thought to respond very quickly to changes in environmental conditions. Previous analyses have had difficulty in developing stock-recruitment relationships due to the high variability, and it was hypothesized that including environmental variables might help managers to identify a relationship that could be used to predict future biomass.

As part of the Fishery Management Plan (FMP) development, the Farallon Institute was contracted to conduct a study on correlations between environmental indicators and metrics of Herring stock health in San Francisco Bay, and to develop a model to predict spawning stock abundance each year. The Farallon Institute is a nonprofit scientific organization that conducts research designed to provide the scientific basis for ecosystem-based management practices. The information below is taken from the report they produced in fulfillment of this contract, and is included as an Appendix in the FMP in support of the proposed management strategy.

The results of this study were also published in Sydeman and others (2018). In that paper, the Multivariate Ocean Climate Indicator (MOCI) (García-Reyes and Sydeman, 2017) was included in the best predictor model of Spawning Stock Biomass (SSB). However, this index is not available before the beginning of each commercial Herring season, when quota decisions need to be made. The Sea Surface Temperature (SST) indicator used here achieved almost as much predictive skill while being available for use in the management process.

Environmental Correlations

Biomass of the San Francisco Bay Herring population has been monitored by the Department of Fish and Wildlife (Department) during the winter spawning season from November through March since the 1970s (Watters and others, 2004) (Figure E-1). The Herring spawning season runs across the calendar year (November through April); throughout this appendix the January year is used to indicate the season (for example, 2018 indicates the 2017 to 2018 season). SSB is based on egg deposition surveys only. All references herein to Herring biomass are reported in metric tons (mt); the Department's reporting system is based on short tons (t) and comparison between the two units requires a conversion.

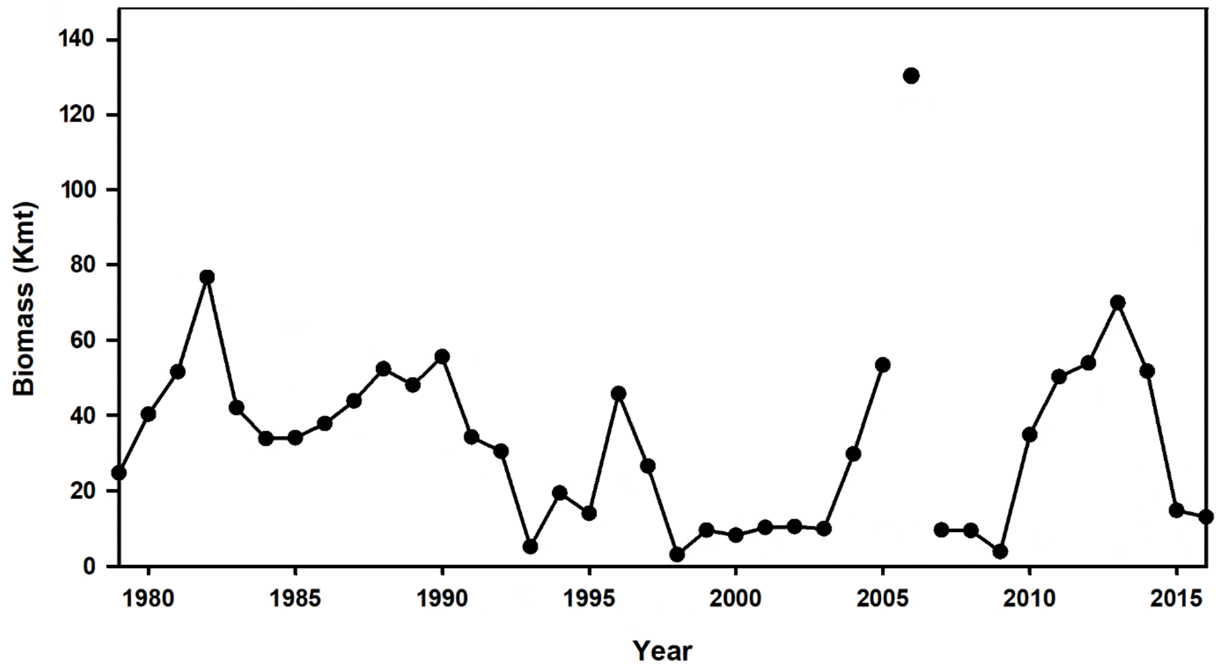


Figure E-1. Herring SSB in thousand metric tons (Kmt) for the San Francisco Bay estimated from egg deposition surveys, summed from December to March each year. Note: These values are from a truncated season so are lower than those in the published Department report because they do not include some spawning which occurs earlier or later in the season. Anomalously high SSB in 2006 is indicated by the break in the time series; the 2006 value was identified as an outlier and excluded from the regression analysis for forecasting purposes. Figure modified from Sydeman and others (2018).

Based on a recognized biological shift in the ecosystem around 1990 (Hare and Mantua, 2000), relationships between potential indicators (Table E-1) and Herring SSB were explored for both the full time series (1979 to 2016) and the more recent period (1991 to 2016). We applied Spearman rank correlations to initially examine pair-wise relationships (Table E-2). Correlation analysis computes a correlation coefficient (denoted as the Greek letter "rho" (ρ)) that describes the linear relationship between two variables. This metric describes how much one variable tends to change when the other variable changes. The value of ρ can range from -1 to +1, and magnitude of ρ quantifies how much the two variables appear to be related. For example, in cases where both variables increase or both decrease (a positive correlation), the magnitude of ρ will be higher (closer to +1). In cases where one increases while the other decreases (a negative correlation), the magnitude of ρ will be lower (closer to -1). A correlation between two variables was considered statistically significant when $p < 0.05$.

Because it takes two to three years for Herring to mature, time lags from one to three years were incorporated into these analyses (Figure E-2). All but one environmental variable produced non-significant correlations during the full time period, most likely due to changing variability through the SSB time series.

There were many more significant relationships for the later period. The highest correlations were found between SSB_{yr-1} and SSB ($r^2 = 0.41$, $p < 0.005$) and between Young of the Year $(YOY)_{yr-3}$ and SSB ($r^2 = 0.57$, $p < 0.005$).

Table E-1. Ecosystem variables, including those tested in the model but not selected and those not used because they were redundant or had insufficient data[2] (Sydeman and others, 2018) (Supplement 1, in Table SM1, SM2).

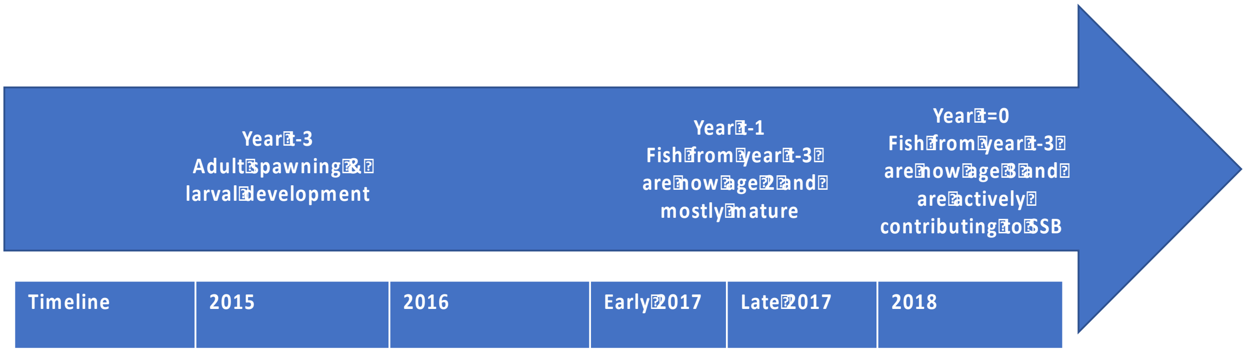
Data	Label	Period	Location	Units	Temporal resolution	Source
Ecosystem						
Herring SSB	SSB	1980–2016	San Francisco Bay	Thousand metric tons (Kmt)	Seasonal sum across months	Department Herring Management Program
Midwater trawl Catch Per Unit Effort (CPUE) of age-0 Herring	YOY	1980–2015	San Francisco Bay	Number of fish standardized by effort	Seasonal average over several months	Department San Francisco Bay Study/Interagency Ecological Program for San Francisco Estuary
Midwater trawl CPUE Age-1, and Age-2+[1]	Age-1, Age-2+	1980–2015	San Francisco Bay	Number of fish per effort	Seasonal average over several months	Department San Francisco Bay Study/Interagency Ecological Program for San Francisco Estuary
Herring condition index[1]	HCI	1984–2015	San Francisco Bay	g/cm^3	Seasonal average across months	Department Herring Management Program
Herring age structure[2]	HAS	1983-2015	San Francisco Bay	% biomass	Annual	Department Herring Management Program
Seabird productivity[1a]	SBP	1980-2014	Farallon Islands	Repro-ductive success	Annual	US Fish and Wildlife Service/Point Blue Conservation Science
Environmental						
Midwater trawls temperature and salinity[1]	Trawl T Trawl S	1980–2016	35 stations throughout San Francisco Bay	°C, PSU	3-month average	Department San Francisco Bay Study/Interagency Ecological Program for San Francisco Estuary
Sacramento River Delta Outflow[1b]	Outflow	1996–2016	San Francisco Bay	Acre-ft	3-month average	California Department of Water Resources

Buoy N26 sea surface temperature	SST	1982–2015	37.8°N, 122.8°W	°C	3-month average	NOAA National Data Buoy Center
Farallon Islands sea surface salinity[1]	Far-SSS	1979–2015	Gulf of the Farallones	PSU	3-month average	Point Blue Conservation Science, Shore Station Program
Bakun Upwelling Index[1c]	BUI	1979–2015	39°N	$m^3/s/$ 100m	3-month average	Pacific Fisheries Environmental Laboratory/ NOAA
Multivariate El Niño Southern Oscillation Index[1d]	MEI	1979–2015	Tropical Pacific	No units	3-month average	Earth System Research Laboratory/NOAA
Pacific Decadal Oscillation[1e]	PDO	1979–2015	North Pacific	No units	3-month average	Joint Institute for the Study of the Atmosphere and Ocean, University of Washington
North Pacific Gyre Oscillation[1f]	NPGO	1979–2015	North Pacific	No units	3-month average	E. Di Lorenzo
Multivariate Ocean Climate Indicator[1g]	MOCI	1979–2015	Central California (34.5-38°N)	No units	Seasonal	Farallon Institute

Note: [a]Krill-eating seabirds Common Murre, *Uria aalge*, Western Gull, *Larus occidentalis*, and Cassin's Auklet, *Ptychoramphus aleuticus,* were chosen to provide an indicator of forage conditions for Herring, which also consume krill.
[b]When considering influences on Herring, including outflow and precipitation, outflow was tested since it serves as a proxy for salinity and precipitation.
[c]The Bakun upwelling index is an indicator of the wind forcing on the coastal ocean; it can also serve as a proxy for Ekman transport.
[d]The MEI synthesizes six observed variables (sea level pressure, meridional and zonal wind, air and sea surface temperature, and total cloudiness) over the tropical Pacific to monitor ENSO.
[e]The PDO is a water surface temperature pattern in the North Pacific, defined as the leading principal component of SST variability from 20 to 90°N.
[f]The NPGO is a climate pattern in the North Pacific defined as the second dominant mode of sea surface height variability, related to water circulation around the basin.
[g]MOCI is a synthesized indicator of regional and local ocean and atmospheric conditions in central California (34.5 to 38°N). This indicator includes the variables: BUI, sea level, along shore wind stress, SST and sea level atmospheric pressure from NDBC buoys, MEI, PDO, NPGO, and the Northern Oscillation Index (García-Reyes and Sydeman, 2017).

Table E-2: Spearman rank correlation (ρ) between SSB and potential indicators of SSB. Lag, in years, and months if applicable, are shown in parentheses. Only nominally significant correlations ($p < 0.05$) are shown. Correlations were performed for the periods 1979–2016 and 1991–2016 due to increased variance in the latter period (Sydeman and others, 2018).

Biological Data	1979-2015	1991-2015
Standing Stock Biomass	ρ=0.65 (yr-1)	ρ=0.51 (yr-1)
CPUE Age-0 abundance	ρ=0.55 (yr-2, ρ=0.64 (yr-3)	ρ=0.57 (yr-2), ρ=0.70 (yr-3)
CPUE Age-1 abundance	ρ=0.35 (yr-3)	ρ=0.42 (yr-3)
CPUE Age-2+ abundance	-	ρ = 0.42 yr-3)
Herring condition index	-	-
Seabird productivity	-	-
Environmental Data	1979-2016	1991-2016
Midwater trawls temperature	-	-
Buoy N26 sea surface temperature	-	ρ=-0.41 (May-Jul, yr-3)
Midwater trawls salinity	-	ρ=0.48 (Aug-Oct, yr-3)
Farallon Islands sea surface salinity	-	-
Sacramento River Delta Outflow	-	ρ=-0.59 (Jul-Sep, yr-3)
Bakun Upwelling Index	ρ=-0.41 (Oct-Dec, yr-3)	-
Multivariate El Niño Southern Oscillation Index	-	-
Pacific Decadal Oscillation	-	ρ = -0.46 (Apr-Jun, yr-3)
North Pacific Gyre Oscillation	-	ρ = 0.45 (Jul-Sep, yr-2, yr-3)
Multivariate Ocean Climate Indicator	-	ρ = -0.46 (Jul-Sep, yr-3)



Timeline	2015	2016	Early 2017	Late 2017	2018
Measured/ Predicted value	YOY abundance		SSB	Offshore Temperature	SSB
Time Frame	April-October		December-March	July-September	December-March
Modeled Year	Year t-3		Year t-1	Year t-1	Year t=0

Figure E-2. Timeline of Herring maturation with example of time lags based on data from 2015 to 2017 for predictions for 2018.

Next, a stepwise multivariate regression model was used to understand which variables could together provide the best explanation of observed patterns in Herring SSB. Regression analysis is another technique used to help understand the relationship between two variables. However, while correlation analysis uses rankings to define the relationship between variables, regression analysis uses a line. When the relationship between the two variables is significant ($p < 0.05$), it is possible to use the equation of the line to make predictions about values that might be of interest. Variables on the x-axis are called "independent variables", while variables on the y-axis are called "dependent variables" because they change depending on x-axis values. Regression analysis computes a regression coefficient (denoted as r^2) that describes the relationship between variables: the higher the value of r^2, the more related the two variables are. In the case of multiple regression, the linear relationship is tested between multiple independent variables (for example, SST and YOY abundance) and the same dependent variable (SSB in this study). The goal of including more independent variables is to improve predictions of the dependent variable. The goal of the Farallon Institute was to develop a model with the following characteristics:

- parameters that explained the most variability (in other words, the highest and most significant r^2 values),
- low predictive error values (an indicator of reliability),
- the lowest AIC values (an estimation of the quality of the model relative to other possible models),
- and utilized monitoring data readily available to managers in an appropriate timeframe for setting fishing quotas.

Based on these criteria, the model that provided the best prediction for the current year SSB included three factors: SSB_{yr-1}, YOY_{yr-3} and $SST_{(Jul-Sep)\ yr-1}$ (Table E-3 and Figure E-3). Notably, current Department fishing quotas are based on SSB_{yr-1}. The three-factor models out-performed simpler one- and two-factor models, including the current model used by the Department, by a large margin (improved r^2 = 0.64-0.67 compared to 0.31 to 0.58; improved model fit AIC = 188 to 190 compared to 193 to 204, and reduced predictive error of 63 to 64% compared to 77 to 119%). This finding strongly supports the inclusion of YOY data in particular as well as SST data in estimation of SSB, and highlights how incorporating additional information can result in more accurate forecasts of SSB.

Table E-3. Multivariate regression models and statistics for the period 1991 to 2016. F-statistics, p-values, adjusted r^2 and AIC values are given by forward and backward stepwise regression. Predictive error is the averaged prediction errors from the cross-validation method (Sydeman and others, 2018). Lag in years for each term indicated in parentheses. SST consists of the 3-month average from July to September prior to the season in question.

Term	Coefficient	t-stat	p-value
SSB ~ SSB_{yr-1} $F_{1,22}$ = 11.3, p-value < 0.01, Adjusted R^2 = 0.31, AIC = 204, Predictive Error = 119%			
SSB_{yr-1}	0.57	3.36	< 0.005
SSB ~ YOY_{yr-3} $F_{1,23}$ = 31.1, p-value < 0.0001, Adjusted R^2 = 0.56, AIC = 201, Predictive Error = 77%			
YOY_{yr-3}	0.025	6.42	< 0.0001
SSB ~ SSB_{yr-1} + YOY_{yr-3} $F_{2,21}$ = 16.6, p-value < 0.0001, Adjusted R^2 = 0.58, AIC = 193, Predictive Error = 81%			
SSB_{yr-1}	0.25	1.58	0.13
YOY_{yr-3}	0.02	3.85	< 0.001
SSB ~ SSB_{yr-1} + YOY_{yr-3} + $SST_{(Jul-Sep)\ yr-1}$ $F_{3,20}$ = 15.9, p-value < 0.0001, Adjusted R^2 = 0.66, AIC = 189, Predictive Error = 69%			
SSB_{yr-1}	0.28	1.97	0.06
YOY_{yr-3}	0.019	4.06	< 0.005
$SST_{(Jul-Sep)\ yr-1}$	-7.26	-2.49	< 0.05

The use of a validation procedure is recommended to establish guidelines for model estimates to remain within certain bounds. For model validation, each year the Department should compare forecast SSB from the model with observed/measured SSB from egg deposition surveys. If the model prediction skill deviates from the mean value (in other words, the estimate is within about 69% of the predicted value) in one year, no management response is necessary. If skill deviates by more than 69% for two sequential years, it is recommended that the Department consider this a warning. If it deviates for more than two sequential years this may indicate a potential problem, and the model should be checked for continuing veracity. The model prediction skill should also not stay consistently above or below the mean. Regardless of annual model prediction skill, it is also recommended that every five years the Department test for continuing significance of predictor variables (in other words, the independent variables) in the forecasting model. If terms lose significance or model prediction skill decreases significantly, the Department should consider revision of the forecasting model.

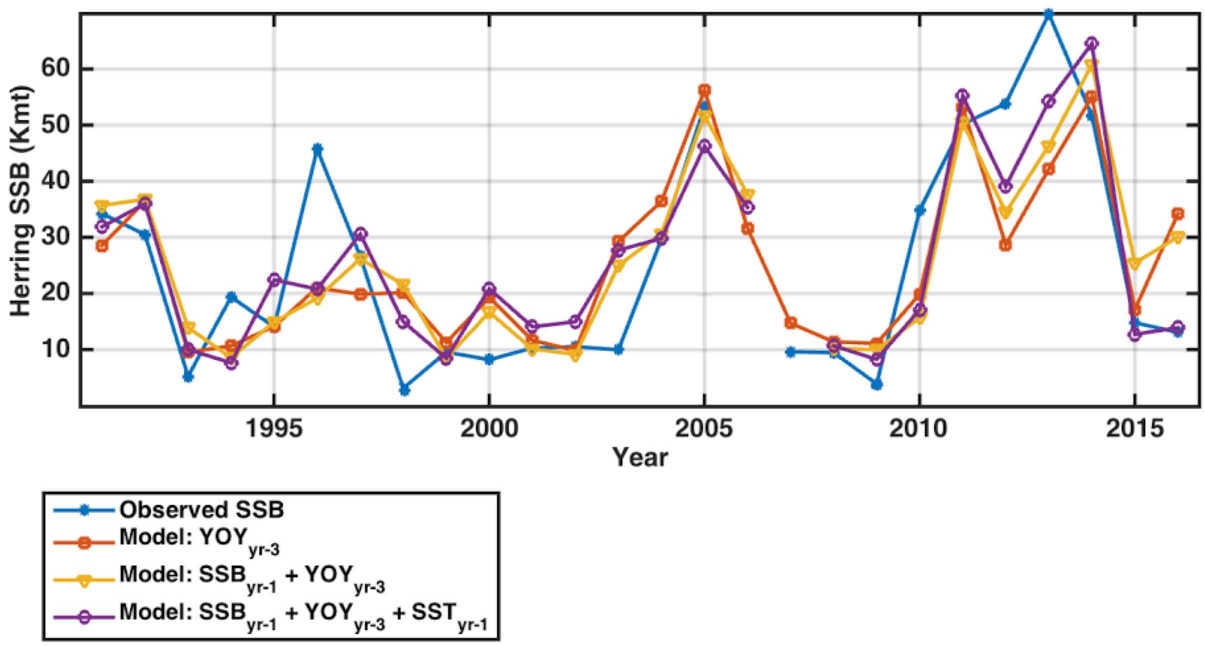


Figure E-3. Observed and modeled San Francisco Bay Herring SSB time series for 1991 to 2016. Note: There is no observation for 2006 since it was identified as an outlier during analysis. Observed biomass is shown in blue and other colors indicate the different models for biomass that include the terms YOYyr-3, SSByr-1, and SST(Jul-Sep) yr-1. Figure modified from Sydeman and others (2018).

Calculating future estimates of SSB

This section describes an approach that can be followed each year using readily available information to provide improved estimates for SSB. The data used for analysis are available by the end of September each year, which allows one month to calculate estimates prior to the start of the commercial Herring fishing season in November.

The equation for prediction of current year SSB is as follows:

Equation 1: SSB (in Kmt) = SSB_{yr-1} (sum: December through March) + YOY_{yr-3} (mean: April through October) + SST_{yr-1} (mean: July through September)

Therefore, estimation of SSB (2018) requires: SSB (2017, summed December through March), YOY (2015, average of individually-summed months for April through October), and SST (2017, average of July through September).

SSB_{yr-1} is based on spawning egg deposition only and can be acquired from the Department. This value is typically reported during the summer. The model uses the sum of biomass across San Francisco Bay for December to March, which can be derived from the annual Department report table. If additional spawning occurs outside this date range, e.g., in November or April, it would need to be excluded. Department reports Herring SSB in short tons, which needs to be converted to thousand metric tons for use in Equation 1:

Equation 2: 1 short ton = 0.907184 metric tons

Therefore, SSB_{2017} was 18,313 short tons, or 16.613 thousand metric tons. YOY abundance data are available from a spreadsheet maintained by the Department (Kathy Hieb, pers. comm.). The Department collects abundance data on pelagic fish using mid-water trawls throughout the San Francisco Bay at monthly intervals at 52 stations; this analysis is based on the original 35 stations that have been standardly sampled since 1980 including those focused on the central San Francisco Bay region where Herring are common. To summarize YOY_{yr-3} abundance, calculate the mean CPUE for three years prior. First select the appropriate stations using only Series = 1 (representing the original 35 stations), and calculate CPUE for each station:

Equation 3: CPUE = (PACHERAge0/ tow volume) * 10,000

Where PACHERAge0 represents the number of age-0 Herring caught in each net tow, and is used in combination with tow volume data presented in the Department spreadsheet. Next sum the CPUE data for each month based on survey numbers four to ten, representing months April through October. Finally, average the summed monthly data. For calculations of SSB_{2018}, mean CPUE from 2015 is used, which based on survey months April to October was 36.1.

SST data comes from offshore buoy N26 at station 46026 provided by the National Data Buoy Center (NDBC) and the National Oceanic Atmospheric Administration (NOAA). Data for each month from the current year (July through September) can be downloaded (http://www.ndbc.noaa.gov/station_history.php?station=46026) and located in the column labeled WTMP. Data should be averaged for each month, then subtract the mean temperature from each month (based on years 1985-2015: July = 13.16 C˚, August = 13.97 C˚, September = 14.24 C˚) to calculate the temperature anomaly for each month. Finally, average the anomaly across the three months (July through September). For 2017, the average $SST_{(Jul-Sep)yr-1}$ was 14.1 C˚, and the anomaly was 0.2923.

Lastly, apply the forecasting model:

Equation 4: SSB_{2018} (Kmt) = (SSB_{2017} (Kmt) * 0.2803) + (YOY_{2015} * 0.019026) + ($SST_{(Jul\text{-}Sep)\ 2017}$ * -7.2582) + 4.092
SSB_{2018} = (16.613 * 0.2803) + (36.1 * 0.019026) + (0.2923 * -7.2582) + 4.092 = 7.98 Kmt

Full model results from Equation 4 for 2018 SSB are presented in Table E-4.

Table E-4. Full model results for the forecasting model selected

$SSB \sim SSB_{yr-1} + YOY_{yr-3} + SST_{(Jul\text{-}Sep)\ yr-1}$
$F_{3,20} = 15.9$, p-value < 0.0001, Adjusted $R^2 = 0.66$, AIC = 189, Predictive Error = 69%

Term	Coefficient	t-statistic	p-value
SSB_{yr-1}	0.28	1.97	0.06
YOY_{yr-3}	0.019	4.06	< 0.005
SST_{yr-1}	-7.26	-2.49	< 0.05

Model validation should be conducted every year to verify model prediction skill, and every five years to verify that the relationships between SSB, YOY abundance, and SST are maintained. To validate that the modeled SSB is still performing within the range of deviation described by the regression equation (69%), comparison of predicted and observed SSB estimates is required. For the 2018 example, calculate the percent error based on 2017 predicted and observed SSB values:

Equation 5: Percent Deviation = ((Observed SSB – Predicted SSB)/Observed SSB)*100

Based on 2017 values for observed (16,613 mt) and predicted (15,113 mt): Percent $Deviation_{2017}$ = ((16,613-15,113) / 16,613) * 100 = 9%. Therefore, the model is performing within the expected range of error (in other words, <69%). If the percent deviation exceeds the mean, pay attention: deviation in one year is acceptable; if high deviation in two sequential years is observed this should be interpreted as a warning, and if for three sequential years, the model prediction skill has likely broken down. The next step would be to re-test the relationships between SSB, YOY abundance, and SST (see main text for more detail on testing the significance of the predictor variables every five years).

Appendix F Summary of Data on Trophic Interactions and Potential Forage Indicators for Pacific Herring (*Clupea pallasii)* in San Francisco Bay

During development of the Pacific Herring (Herring), *Clupea pallasi,* Fishery Management Plan (FMP), the Farallon Institute was contracted by the Steering Committee, a group of stakeholders representing industry and conservation groups and Department of Fish and Wildlife (Department) staff, to conduct a study on the trophic interactions affecting the Herring stock in San Francisco Bay, as well as recommend a suite of environmental indictors that could be used to assess regional forage conditions each year when setting quotas. This information on predator-prey dynamics in the San Francisco Bay region was used to develop a decision tree to incorporate ecosystem considerations into yearly quota decision making. This document summarizes the information produced by the Farallon Institute in fulfillment of their contract, describes a decision tree developed from this information to assist Department staff in considering forage conditions when setting quotas each year. Additionally, a retrospective analysis of the decision tree's potential performance is presented and discussed.

Predators of Pacific Herring

Data from a total of 83 predators known to eat Herring (58 species) or Herring roe (33 species, including eight that also eat fish), were summarized to assess the occurrence of Herring in predator diets within the California Current Ecosystem (CCE) (Table F-1), which is an eastern boundary current upwelling system off the West Coast of the United States.

Adult Herring can compose up to 30% of Pacific Cod, *Gadus macrocephalus*, diet, and 51% of Chinook Salmon, *Oncorhynchus tshawytscha*, diet in the CCE, with feeding occurring mostly during winter months. Northern Fur Seal diet samples in California studies contained no Herring presumably because the offshore distribution of Northern Fur Seal range in California does not overlap with nearshore Herring (Perez and Bigg, 1986). San Francisco Bay is near the southern limit of Herring's range and Herring are less prominent in predator diets there than in the northern CCE (Szoboszlai and others, in revision).

Table F-2. Known predators (83) of adult Herring and Herring roe from the CCE (Szoboszlai and others, 2015): **bold** indicates duplication for 8 species.			
A) Summer (April-September) studies of predator diets (does not overlap winter diet during Herring spawning migrations).			
Spiny Dogfish	29%	Jack Mackerel	2%
Humpback Whale	13%	Fin Whale	2%
Pacific Hake adults	11%	Harbor Porpoise	2%
Black Rockfish	10%	Sperm Whale	2%
Chinook Salmon	9%	Marbled Murrelet	2%
Coho Salmon	9%	Pacific Hake juveniles	1%
Caspian Tern	7%	Sablefish	1%
Common Murre	7%	Least Tern	<1%
Northern Fur Seal	7%	Cassin's Auklet	<1%
Rhinoceros Auklet	6%	Sooty Shearwater	<1%
Harbor Seal	5%	L-B Common Dolphin	<1%
California Sea Lion (*Zalophus californianus*)	4%	S-B Common Dolphin	<1%
Double-Crested Cormorant	2%		
B) Predators of adult Herring not assessed in Szoboszlai and others (in revision) study.		C) Spawn-eating predators (Bayer, 1980; Weathers and Kelly, 2007).	
Ancient Murrelet	Lingcod	American Coot	Lesser Scaup
Arctic Loon	Mew Gull	American Widgeon	Long-Tailed Duck
Arrowtooth Flounder	Orca Whale	Barrow's Goldeneye	Mallard
Bat Ray	Pacific Cod	Black Brant	**Mew Gull**
Blue Shark	Pacific White-Sided Dolphin	Black Scoter	Northern Pintail
Bonaparte's Gull	Pelagic Cormorant	**Bonaparte's Gull**	**Pelagic Cormorant**
Brandt's Cormorant	Pigeon Guillemot	**Brandt's Cormorant**	**Red-Breasted Merganser**
California Gull	Red-Breasted Merganser	Bufflehead	Redhead
Chum Salmon	Sei Whale	Canvasback	Ring-Billed Gull
Common Merganser	Shortspine Thornyhead	Common Goldeneye	Ruddy Duck
Copper Rockfish	Soupfin Shark	Common Loon	Surf Scoter
Cutthroat Trout	Steller Sea Lion	Eurasian Wigeon	**Western Grebe**
Dall's Porpoise	Western Grebe	**Glaucous-Winged Gull**	**Western Gull**
Glaucous-Winged Gull	Western Gull	Greater Scaup	White-Fronted Goose
Gray Smoothhound	Yelloweye Rockfish	Harlequin Duck	White-Winged Scoter
Gray Whale	Yellowtail Rockfish	Hooded Merganser	
Jumbo Squid		Horned Grebe	

Herring Predation in California

In order to understand the impact of the San Francisco Bay Herring fishery on predators, it is important to focus on studies that overlap temporally and spatially with the San Francisco Bay Herring population (Table F-2). There are limited data from central California, particularly during winter when Herring gather in dense schools near to and inside San Francisco Bay and are likely to be most important to predators (Szoboszlai and others, in revision; Szoboszlai and others, 2015). The winter data for central California suggest the potential for strong seasonal dependencies. The best winter predator diet data on Herring exists for Chinook Salmon in the Gulf of the Farallones (GOF), just outside San Francisco Bay (Table F-2).

Herring were dominant in the diet of salmon collected from coastal Herring holding areas during winter (Merkel, 1957). Herring totaled 13% of salmon diet (by mass) based on the average of ten months during one year (Merkel, 1957). However, the amount of Herring observed in the salmon diet was higher in the winter, with salmon consuming ~50% Herring in February and March (Merkel, 1957). Herring in winter salmon diet peaked at roughly 20% in a similar study in the early 1980s (Thayer and others, 2014). High feeding rates during prey pulses, and the subsequent increase in growth may be one way juvenile salmon increase survival through early marine phases (Litz and others, 2018).

Table F-2. Herring in predator diets in California, with focus on localized data in time and space surrounding Herring spawning in San Francisco Bay (SFB). The GOF is just outside SFB. Monterey Bay (MB) is south of the GOF. Herring spawn in winter months peaking from December to March. For GOF diet, percentage of Herring in the diet is indicated by an average value with range in parentheses if data from more than one study was available. The range is important because averaging dampens extremes and does not reflect importance to predators during prey pulses. Months of available diet were provided in the source column unless diet data was collected in all seasons. Light gray shading denotes related winter data for California; dark gray shading denotes predators for which higher Herring consumption in California appears to occur in the non-winter months.

Herring predator	Diet from California	Winter diet central CA	CCS summer diet[1]	Summer California diet	Winter California diet	GOF (Sep-Dec) diet	GOF (Oct-Mar) diet	GOF-MB (Dec-Mar) diet	GOF (Feb-Mar) diet	GOF (Mar-Apr) diet	Source - Winter diet central California (years)
Chinook Salmon	x	x	9%	4%	27%	3% (1-5%)	16% (5-27%)	29% (10-49%)	29% (10-49%)	24% (9-39%)	1955 GOF (Merkel, 1957); 1980-86 GOF (Thayer and others, 2014)
Humpback Whale	x	x	~13%	x[3]	~19%	~5%		~33% (26-40%)			1920, 1922 Dec-Mar MB (Clapham and others, 1997); 1988, 1990 Sep-Dec GOF (Kieckhefer, 1992)
Common Murre	x	x	7%	0%	6%		20% (12-28%)			28%	1974-75 Sep-Apr MB (Baltz and Morejohn, 1977); 1985-88 coastal GOF only[2] (Ainley and others, 1996)
Harbor Seal	x	x	6%	8%	1%						1968-1973 cen CA (Jones, 1981); 1991-2 SFB, MB, Elkhorn Slough (Oxman, 1995; Torok, 1994; Trumble, 1995); 2007-8 SFB (Gibble, 2011)
Pacific Hake	x		11%	7%							1989 (Jul-Sep) Pt Conception. - Cape Blanco (Buckley and others, 1999)
Rhinoceros Auklet	x	x	6%	1%	1%						1974-75 Sep-Apr MB (Baltz and Morejohn, 1977)
California Sea Lion	x	x	4%	1%	1%						1998-9 Feb-Apr MB (Weise and Harvey, 2008); 2009 Nov-Dec MB (Robinson and others, 2018)

[1]Data from Szoboszlai and others (in revision).

[2]Outer continental shelf diet samples did not contain the level of Herring that coastal samples did, so coastal samples were used for GOF maximums.

[3] Some data on humpback summer diet in California was available from the early 1920s but was not summarized, as levels of Herring were lower than in winter, which was summarized.

Regional Forage for Herring Predators

While there are limited data available with which to assess the extent to which predators utilize the San Francisco Bay Herring resource, it is possible to glean insight into what other forage species are eaten by predators of Herring. Based on the available data, regional forage species also consumed by predators of Herring in central California primarily include other small pelagic fishes (Pacific Sardine, *Sardinops sagax*, and Northern Anchovy, *Engraulis mordax*); invertebrates including krill (Euphausiidae) and Market Squid, *Doryteuthis opalescens*; juvenile rockfish, *Sebastes* spp.; and to a lesser extent juvenile groundfish (Pacific Hake, *Merluccius productus*, and sanddabs, *Citharicthys* spp.). Some of these species are consumed year-round, while other species are more important in winter, when Herring are concentrated for spawning and more available as prey. However, given the limited number of studies, specifically those that overlap spatially and temporally with the San Francisco Bay population of Herring, more information is needed to understand the relative importance and suitability of other regional forage species to predators (particularly during winter months). Therefore, caution is necessary for adjusting management measures based on forage indicators.

Regional Forage Availability

Considering regional forage dynamics provides a view of overall ecosystem condition with regard to mid- and upper-trophic level predator diet requirements. Understanding the status of other forage species within the region, and particularly when the abundance of these species is low, can indicate when there is a potential for increased predation on Herring. The Catch Per Unit Effort (CPUE) of regional forage (Northern Anchovy, Pacific Sardine, krill, Market Squid, juvenile rockfish, juvenile sanddabs, and juvenile Pacific Hake) in the central CCE (defined as the nearshore region of the eastern Pacific between Crescent City Harbor and Point Conception) is measured annually using National Oceanic and Atmospheric Administration (NOAA) fisheries-independent trawl surveys in spring/summer (Sakuma, 2017). These data are publicly available at the NOAA California Current Integrated Ecosystem Assessment (CCIEA) website, and summarized to describe an index of the availability relative to the long-term mean (defined as the mean of each index from 1990 to 2017, the most recent year of available data) and upper and lower standard deviations. The Department can use these indices to determine when the status of each of these regional forage species is unusually low or unusually high (as defined in Table F-3) relative to the last 30 years. This index can be produced by National Marine Fisheries Service (NMFS) staff as early as August or September each year (C. Harvey pers. comm.; J. Field pers. comm.) for use in the San Francisco Bay fishery quota setting procedure.

An analysis of correlations between the regional forage indicators and environmental conditions between 1990 and 2012 found that a significant amount of the variation seen in these forage indicators could be attributed to a complex set of regional and basin-scale variables such as temperature, salinity, upwelling, and sea-level, which is a proxy for the magnitude and direction of water transport in the CCE (Ralston and others, 2015). During years that are characterized by colder water, higher salinity, early and strong upwelling, and high transport, the central CCE forage assemblage is dominated by increased numbers of Young of the Year (YOY) groundfish, krill, and Market Squid, likely due to higher survival of juveniles in these high nutrient conditions (Ralston and others, 2015; Santora and others, 2017). In years that are characterized by warmer water, lower salinity, delayed upwelling, and low transport, the central CCE region experiences reduced numbers of those species and greater representation of coastal pelagic species, such as sardine and anchovy (Ralston and others, 2015; Santora and others, 2017). This suggests that, under normal ecosystem function, the central CCE fluctuates between "cold water" and "warm water" assemblages, and similar patterns can be seen in Table F-3.

Table F-3. Historical status of prey species within the central CCE from NOAA's annual rockfish trawl surveys. The status was classified as "High" (in green) if the index for that year was >1 standard deviation (s.d.) above the long term mean (defined as the mean index between 1990 and 2017), "Moderate" (in yellow) if the index was within ∓1 s.d.) of the long-term mean, and "Low" (in red) if the index was >1 s.d. below the long-term mean. For Pacific Sardine and Northern Anchovy, in which the wide s.d. resulted in negative values for 1 s.d. below the long-term mean, the status was classified as "Low" if the index was >50% of the long term mean. Data were accessed on 08 November 2018 at https://www.integratedecosystemassessment.noaa.gov/regions/california-current/cc-indicator-status-trends.

	Regional Prey Indices						
Year - Fall	**Pacific Sardine**	**Northern Anchovy**	**Pacific Hake**	**Rockfish**	**Sanddab**	**Market Squid**	**Krill**
1990	Low	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate
1991	Low	Low	Moderate	Moderate	Moderate	Moderate	Moderate
1992	Low	Moderate	Moderate	Moderate	Moderate	High	Low
1993	Low	Moderate	High	Moderate	Moderate	Moderate	Moderate
1994	Low	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate
1995	High	Moderate	Low	Moderate	Moderate	Moderate	Moderate
1996	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Low
1997	High	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate
1998	High	Moderate	Low	Low	Low	Low	Low
1999	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate
2000	Moderate	Low	Moderate	Moderate	Moderate	Moderate	Moderate
2001	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate
2002	Low	Low	Moderate	Moderate	High	Moderate	Moderate
2003	Low	Low	Moderate	Moderate	Moderate	Moderate	Moderate
2004	Moderate	Moderate	High	Moderate	Moderate	Moderate	Moderate
2005	High	High	Low	Low	Low	Moderate	Moderate
2006	High	High	Low	Low	Low	Low	Moderate
2007	High	Moderate	Low	Low	Low	Low	Moderate
2008	High	Low	Moderate	Moderate	Low	Low	High
2009	Moderate	Low	Moderate	Moderate	Moderate	Moderate	Moderate
2010	Low	Low	Moderate	Moderate	Moderate	Moderate	Moderate
2011	Low	Low	Moderate	Moderate	Moderate	Moderate	High
2012	Low	Low	Moderate	Moderate	Moderate	High	High
2013	Low	Low	Moderate	High	High	High	High
2014	Low	Low	Moderate	High	High	High	High
2015	Low	Low	High	High	High	High	Moderate
2016	Low	Low	High	High	Moderate	Moderate	Moderate
2017	Low	Low	Moderate	Moderate	Moderate	High	High

While the complex interplay of variables makes it difficult to predict exactly how predators will respond to changing forage assemblages in a given year, the available data suggest that many top predators are able to switch between warm and cold water forage assemblages as necessary. For example, a study of Humpback Whale diets over a 20-year period in the CCE found that diets were dominated by krill during periods characterized by cool sea surface temperature (SST), strong upwelling and high krill biomass, and dominated by Northern Anchovy and Pacific Sardine when the SST was warmer and seasonal upwelling was delayed (Fleming and others, 2016). Breeding colonies of Common Murres in the GOF feed primarily on YOY rockfish when they are abundant and switch to target Northern Anchovy when YOY rockfish are unavailable (Ainley and Boekelheide, 1990; Sydeman and others, 2001). California Sea Lion diet composition data collected in Monterey Bay between 1997 and 1999 showed that Pacific Sardines, which had high abundances in the central CCE at that time, made up 47.3% of sea lions' diet by mass, while rockfish were the second most important prey species (28.6%) (Weise and Harvey, 2008). This suggests that these alternating forage assemblages may play the same functional role (mid-trophic level forage) in the CCE, and that shifts between these two assemblages represent natural fluctuations. However, while Northern Anchovy and Pacific Sardine are considered "high energy" forage and krill (Figure F-1), YOY groundfish, and Market Squid are considered "medium energy" (Figure F-1), Common Murre colonies have been found to have lower rates of breeding success when the forage assemblage is dominated by coastal pelagic species (Field and others, 2010; Wells and others, 2017). More information is needed to understand the relative importance of forage species to various predators, and caution should be applied when adjusting management measures based on forage indicators.

Climate change may further complicate attempts to predict how forage indices will fluctuate in response to environmental changes. Between late 2013 and early 2016 an anomalous warm water event, termed the North Pacific Marine Heatwave (NPMH), occurred, resulting in delayed upwelling, warmer waters, and lower productivity in the region (Gentemann and others, 2017). During this period YOY groundfish, krill, and Market Squid relative availability remained moderate to unusually high while sardine and anchovy remained low (Figure F-1). Meanwhile, krill abundance declined sharply in 2015, following an unusually stable trend of high abundance in preceding years (Figure F-1). In 2016 oceanic conditions in the northeastern Pacific began to return to normal, but this unusual response of prey species to the NPMH highlights the fact that more information is needed on how forage indices respond to environmental changes.

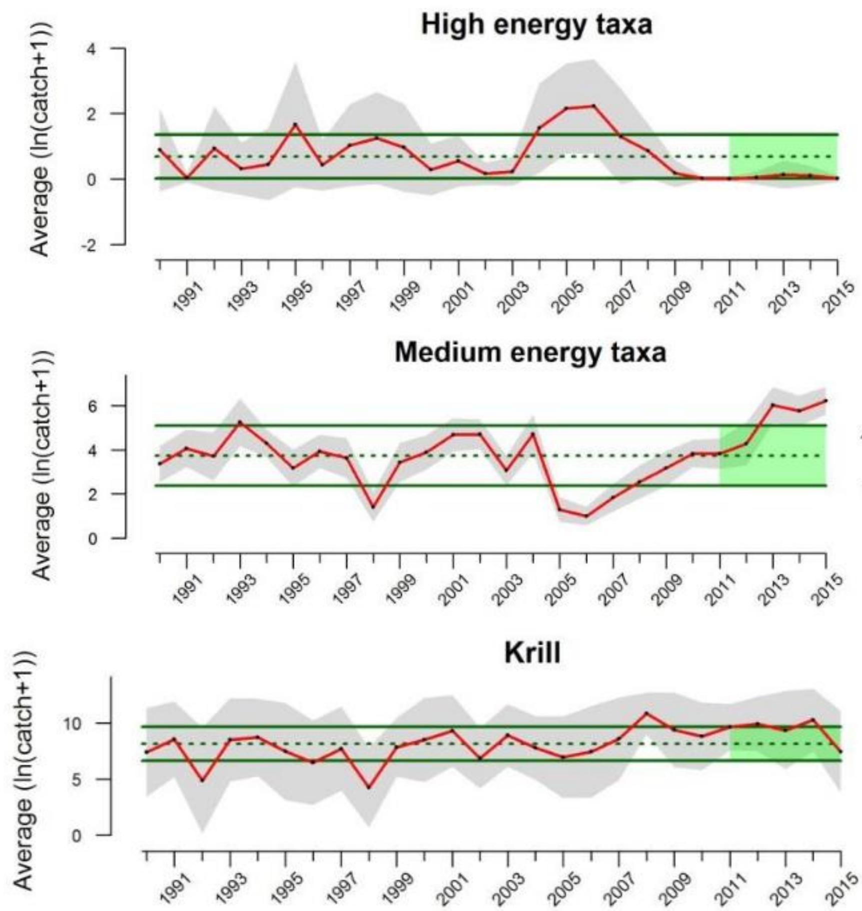


Figure F-1. Geometric mean CPUEs (#/haul) of key forage groups in the central CCE. High energy taxa includes sardine and anchovy, while medium energy taxa includes Market Squid and YOY groundfish. Horizontal lines show the mean (dashed line) ± 1.0 s.d. (solid lines) of the full time series. Arrows at upper right indicates whether data over the last five years (green shaded areas) had a positive trend, a negative trend, or no trend. Symbols at lower right indicates whether the mean over the past five years was greater than (+), less than (–), or within 1 s.d. (•) of the mean of the full time series (Reproduced from Harvey and others (2017)).

The information presented in Table F-3 represents a first step towards understanding the relative forage availability within the central CCE in a given year. While these indices are designed to indicate only whether the status in each year is high or low relative to the observed time series, the patterns that have emerged (Ralston and others, 2015) suggest that, while fluctuations between the high productivity and low productivity assemblages are natural, low levels in both forage assemblages simultaneously might indicate a regional decline in forage availability, and such a decline might indicate a need for additional management response. There are a number of limitations that suggest that these data should be interpreted cautiously. Because the time series begins in 1990, “high” and “low” are only defined relative to this period. Additionally, given the paucity of studies in the central CCE on Herring predation, it is difficult to know whether the indices in Table F-3 actually represent alternative forage for Herring predators. The data for these indicators are collected in trawl surveys conducted farther offshore than Herring are believed to occur, and Herring do not show up in the surveys in notable amounts. As such, they may provide a snapshot of offshore, rather than nearshore, forage availability. However, they represent the best available data at this time, and there is some evidence linking Herring predators to these species.

Indicators on Predator Population Health

The main predator species in central California for which diet data on Herring exist are Chinook Salmon, Common Murre, Humpback Whale, Harbor Seal, Pacific Hake, and Rhinoceros Auklet (Table F-2). Sources of time series for these predators, including population size, reproductive success, and survival were assessed to determine their availability and suitability for use as indicators of predator population health (Table F-4).

For many species of marine wildlife (e.g., marine mammals, seabirds, and large fish), population size may not respond immediately to reduced prey availability due to delayed maturation and the ability of adults to buffer against poor conditions by searching a larger area for food, relying on fat stores, or abandoning pups (Costa, 2008). Instead, predator population changes often show up several years after the change in forage availability. Thus, indicators summarizing predator population size may not be useful for setting Herring quotas. Furthermore, population estimates for many of the key Herring predators are not always available (Table F-4). There are two sources of data, however, that may be useful to evaluate the health of Herring predators before a season of interest.

The first data source is the forecasted oceanic abundance of Sacramento River fall-run Chinook Salmon (SRFC), which is the largest central California Chinook Salmon stock (O'Farrell and others, 2013). Herring are very important to SRFC, as shown by available winter diet data. Chinook are relatively short-lived, at approximately 3-5 years, so their population more readily tracks changes in forage (i.e., Herring) availability. The SRFC population abundance has been tracked yearly since 1983 (Figure F-2). In 2008 and 2009 the fishery was closed because projected spawner escapement in the absence of fisheries was below the minimum escapement threshold of 122,000-180,000 fish set by the PFMC. The collapse of the SRFC was attributed to poor ocean conditions in 2005 and 2006, with weak upwelling and warm temperatures that resulted in limited prey availability and low survival for the 2004 and 2005 brood years (Lindley and others, 2009).

Table F-4. Herring predators and available local indices of predator health including population size, productivity, and survival.[1] The Sacramento River flows into San Francisco Bay (SFB). Southeast Farallon Island (SFI) is approximately 30 miles offshore, and Año Nuevo Island (ANI) is approximately 55 miles to the south of SFB. Abbreviations for organizations/agencies include Pacific States Marine Fisheries Commission/Regional Mark Processing Center (PSMFC/RMPC), NMFS, US Fish & Wildlife Service (USFWS), the National Park Service (NPS), and the Pacific Fisheries Management Council (PFMC).

Herring predator	Predator Index	Predator Index Source	Notes
Chinook Salmon	Sacramento fall run survival	Raw data CWT release and recovery from PSMFC/RMPC database (no online updates)	Analysis needed to estimate survival (Data obtained from Alex Letvin, CDFW)
Humpback Whale	Stock assessment/population size CA/OR/WA	J. Calambokidis/Cascadia Research; NMFS marine mammal stock assessment	http://www.nmfs.noaa.gov/pr/sars/
Common Murre	SFI population size, productivity	USFWS/Point Blue (no online updates)	Pop. size may no longer be updated annually
Harbor Seal	SFB population size, marine mammal mortality events	SFB state of estuary report, NMFS mortality event updates, SF NPS for more regional population size?	http://www.sfestuary.org, http://www.nmfs.noaa.gov/pr/health/mmume/events.html, http://www.sfnps.org
Pacific Hake	Stock assessment CA/OR/WA	PFMC stock assessment	https://www.pcouncil.org/groundfish/stock-assessments/by-species/pacific-whiting-hake/
Rhinoceros Auklet	SFI, ANI population size, productivity	USFWS/Point Blue (no online updates), Oikonos	http://oikonos.org/wp-content/uploads/2013/06/2016-ANI-report-2016_reduced_size.pdf

[1] Note that population size of upper-trophic predators usually does not vary in response to environmental influences in the same year that the population is measured (due to delayed maturity, etc.), except in the case of very extreme events which cause adult die-offs. Similarly, adult survival is fairly invariant except during extreme events which predators cannot buffer. Therefore, these are rarely good annual indicators.

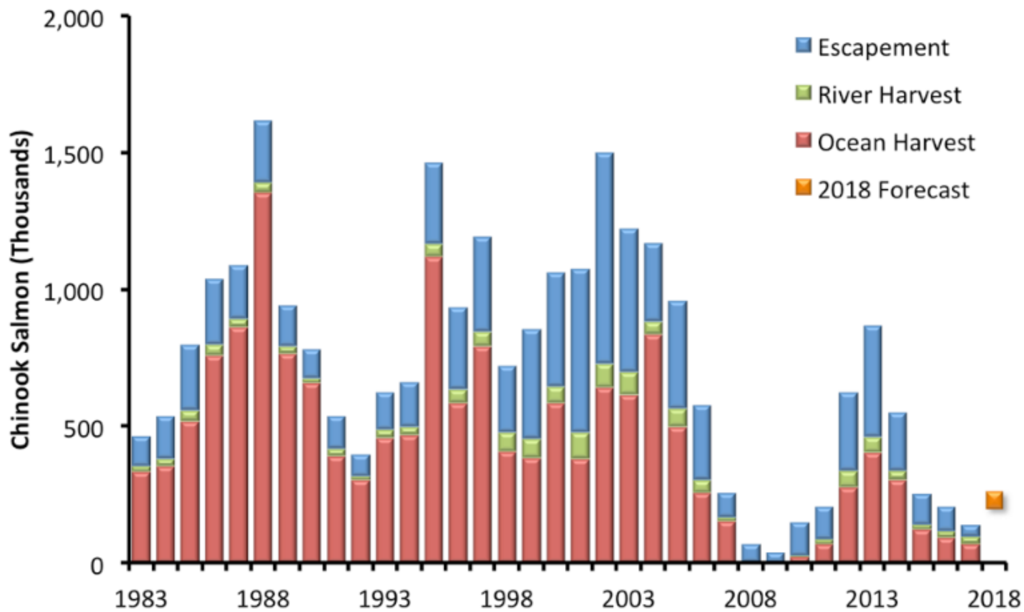


Figure F-2. Sacramento River fall-run Chinook Salmon population index, composed of escapement, river harvest, and ocean harvest (Reproduced from https://fishbio.com/field-notes/the-fish-report/poor-returns-2017-salmon-season).

While population abundance estimates are not available until after the season, Chinook Salmon pre-season ocean abundance forecasts for the SRFC are available in late February/early March from the Department, NMFS, and the PFMC. A comparison of these forecasts to the escapement thresholds set by the PFMC would provide an indicator of exceptionally poor years for Chinook Salmon. Low populations may be caused by issues other than available forage. For example, low population levels in 2015 through 2017 were attributed in part to drought, warm weather, warm streams and 95% below-normal snow-water equivalent storage (Harvey and others, 2017). However, Ralston and others (2015) found a strong relationship between the forage assemblages in the central CCE and the SRFC population index, suggesting that forage availability plays a strong role in population abundances. Given the high levels of Herring observed in Chinook Salmon diet compositions, the SFRC index may provide a useful indicator with which to track the health of a Herring predator.

The second data source available for tracking how predator populations may be impacted by low forage availability is the reporting of seabird and marine mammal Unusual Mortality Events (UME). Under the Federal Marine Mammal Protection Act, an unusual mortality event (UME) is defined as "a stranding that is unexpected; involves a significant die-off of any marine mammal population; and demands immediate response" (16 U.S. Code 1421h Section 410). UMEs are easily-observed phenomenon, generate substantial public interest, and may be related to food availability in the ecosystem. Specifically, for long-lived seabirds and pinnipeds, UMEs can signal the failure of buffering efforts and food stress, and result in juvenile and adult mortality measurable in real-time (Melin and others, 2010; Soto and others, 2004) Table F-5 provides a list of all documented UMEs for Common Murre and Rhinoceros Auklet in California since 1982 (the earliest year data was available). These species were selected as potential indicators because Herring have been found in the stomachs of these birds in the central CCE region (Table F-2). These data are available in a searchable database maintained by the United States Geological Survey (USGS), where various agencies can report UMEs, their locations, and their causes. This resource enables the Department to easily monitor any ongoing UMEs in the central CCE region, as well as help determine whether they may be caused by a lack of forage.

Table F-5. Unusual Mortality Events in California for Common Murre (CM) and Rhinoceros Auklet (RA). Data from USGS Wildlife Health Information Sharing Partnership (WHISPers) database. Accessed at https://www.nwhc.usgs.gov/whispers/searchForm on 10 November 2018. Search terms were California + Common Murre and California + Rhinoceros Auklet.					
Start Date	**End Date**	**Number Affected**	**Location**	**Species**	**Event Diagnosis**
9/16/82	9/16/82	122	San Mateo, CA	CM	Open [suspect], Emaciation (NOS)
8/24/83	8/26/83	550	San Mateo, CA	CM	Open [suspect]
7/12/89	8/9/89	4000	Marin, CA	CM	Emaciation (NOS), Trauma (NOS)
2/7/90	2/19/90	563	Orange, CA	RA	Toxicosis (petroleum, NOS)
7/1/94	9/1/94	30	San Mateo, CA	CM	Open [suspect]
7/7/95	8/10/95	1500	Marin, CA; San Francisco, CA; San Mateo, CA; Santa Cruz, CA; Monterey, CA	CM	Emaciation (NOS)
1/1/05	8/31/05	1563	Santa Cruz, CA; Monterey, CA; Del Norte, CA; Humboldt, CA; Mendocino, CA	CM, RA	Emaciation (starvation)
2/4/07	2/18/07	100	Orange, CA	RA	Undetermined [suspect]
3/1/07	6/1/07	550	Monterey, CA	CM	Emaciation (starvation)
7/14/07	9/15/07	300	Humboldt, CA; Lincoln, OR	CM, RA	Emaciation (starvation) [suspect]
11/7/07	12/2/07	500	Santa Cruz, CA; Monterey, CA	CM, RA	Toxicosis (domoic acid) [suspect], Airsacculitis
4/15/09	6/20/09	1000	San Mateo, CA; Marin, CA; San Francisco, CA; Alameda, CA; Monterey, CA; Santa Cruz, CA	CM	Emaciation (starvation)
10/1/11	3/30/12	350	Ventura, CA; Santa Barbara, CA	CM	Emaciation (NOS)
8/14/14	2/28/15	3500	Grays Harbor, WA; Clallam, WA; Lincoln, OR; Clatsop, OR; Coos, OR; Sonoma, CA; San Luis Obispo, CA; Monterey, CA	RA	Emaciation (starvation), Parasitism (gastrointestinal/hepatic), Avian Pox [suspect]
8/4/15	11/1/15	5150	Marin, CA; San Francisco, CA; San Mateo, CA; San Luis Obispo, CA; Monterey, CA; Santa Cruz, CA	CM	Emaciation (starvation)
7/22/16	7/29/16	32	Humboldt, CA	CM	Undetermined
4/1/17	4/24/17	547	Ventura, CA; Santa Barbara, CA; Los Angeles, CA	CM	Toxicosis (domoic acid)
7/29/17	8/5/17	156	Humboldt, CA	CM	Emaciation (NOS), Toxicosis (domoic acid)

Herring were found to occur in the diets of two central CCE pinnipeds, California Sea Lions and Harbor Seals, and Table F-6 lists the UMEs observed in California, including those for California Sea Lions and Harbor Seals. There are a number of studies documenting Herring in the diets of Harbor Seals, though the available information suggests that Herring may be a more important prey species for Harbor Seals in the summer, when Herring school in feeding grounds such as in Monterey (Oxman, 1995). Two studies, one in 1991-1992 and one in 2007-2008, found no evidence of Herring in the diets of San Francisco Bay Harbor Seals, though seals have been observed eating Herring during fishing activities (R. Bartling pers. comm.). These studies also found that Herring occur less frequently in Harbor Seal diets than would be expected based on the relative abundance of Herring in local waters, and suggesting that Harbor seals preferentially target cephalopods and flatfish rather than Herring (Gibble, 2011; Trumble, 1995).

There are limited data for California Sea Lions, with the only published study finding that in Monterey Bay, Herring made up 0.1% of winter diets and 0.6-0.08% of spring diets, with no Herring observed in the summer or fall (Weise and Harvey, 2008). Unlike Harbor Seals, who have their pups at various rookeries throughout the state, including at sites in San Francisco Bay, in the spring (Gibble, 2011), California Sea Lions breed mainly on offshore islands ranging from southern California to Mexico, although a few pups have been born in central California locations (Lowry and Forney, 2005). For this reason, California Sea Lions may not be the best predator indicator for use in management of Herring because their most vulnerable life stage occurs in southern California and northern Mexico (Costa, 2008; National Oceanic and Atmospheric Administration, 2014a), a region with different prey availability and environmental conditions. Despite these limitations, Department staff have also observed California Sea Lions preying on Herring within San Francisco bay during the Herring fishing season (R. Bartling pers. comm.), and so they can be considered an indicator predator.

Based on data from other locations, it is possible that other California pinnipeds such as the Guadalupe Fur Seal and Northern Fur Seal eat Herring, but this has not been shown in diet studies from the central CCE, likely due to the lack of winter sampling. Such samples may demonstrate the importance of Herring to central California pinnipeds during this period, as has been shown for other pinnipeds such as Steller Sea Lions in Alaska (Willson and Womble, 2006; Womble and Sigler, 2006), and future research is needed to understand the significance of Herring to pinnipeds in the central CCE.

Mortality events caused by reasons other than poor forage conditions are unlikely to be improved by reductions in quota. Tables F-5 and F-6 show that a number of mortality events have been attributed to biotoxins or infectious disease. Brevetoxin and domoic acid are the most common biotoxins associated with marine mammal mortality events, primarily in California Sea Lions. Some of these biotoxin outbreaks, such as domoic acid, are more likely to occur in warm water events such as the UME for California Sea Lions during the 1998 El Nino (Table F-6). While forage conditions may have been poor in that year as well, the primary reason for the die off was attributed to the biotoxin. In addition, many of the events listed in these data sets occurred in areas outside of the central CCE, and thus may reflect poor forage conditions in other areas of the state. For example, the UME affecting California Sea Lions between 2013-2017 was centered primarily around rookeries in Southern California. This highlights the importance of considering the cause and location of UMEs prior to making management decisions.

Table F-6. Unusual mortality events for marine mammals in California. The species, year(s) of occurrence, and cause of the mortality event (if determined) are listed. Accessed on 6 November 2018 from https://www.fisheries.noaa.gov/national/marine-life-distress/active-and-closed-unusual-mortality-events.

Year	**Species Affected**	**Cause of Mortality Event**
2013 – 2017	California Sea Lion	Ecological factors
2008	Harbor Porpoise	Ecological factors
2007	Cetaceans	Undetermined
2007	Large whales	Human interactions
2006	Harbor Porpoise	Mortality undetermined
2003	Sea Otters	Ecological factors
2002	Common Dolphins, California Sea lions, Sea Otters	Biotoxins
2000	California Sea Lions	Biotoxins
2000	Harbor Seals	Infectious disease
1999-2001	Gray Whales	Mortality undetermined
1998	California Sea Lions	biotoxins
1997	Harbor Seals	Infectious disease
1994	Common Dolphins	Undetermined
1992-1993	Harbor Seals, California Sea Lions	Ecological factors
1991	California Sea Lions	Infectious disease

Description of Decision Tree Process and Assessment Criteria

The information summarized above was used to develop a decision tree process to assist Department staff in considering ecosystem indicators in a transparent, reproducible method when setting quotas each year using the Harvest Control Rule (HCR). Given that the HCR is designed to protect the forage needs of predators through the use of a harvest cutoff, conservative harvest rates, and a quota cap, one of the primary objectives for this decision tree is to provide a means of alerting Department staff when conditions in the central CCE are unusually poor and a further reduction in the HCR harvest rate might be advisable to account for predator needs. Another primary objective is to identify when conditions in the region are such that a small harvest rate increase may be warranted. Finally, given the size and participation levels in the San Francisco Bay Herring fishery, staffing constraints, as well as the level of precaution already built into the HCR, there was a desire to utilize available data that were already summarized and readily available within the quota setting time frame.

With these objectives in mind, a decision tree was developed to identify which indicators should be considered during the quota setting process and the criteria for determining when quota changes (increases or decreases) may be warranted based on ecosystem conditions (Table F-7). This decision tree is designed to guide Department staff through analysis of the available information on predator population health and regional forage availability. The indicators included were carefully chosen to reflect the best available science on the interactions between Herring and their predators in the central CCE and the other forage species in the region.

The decision tree presented in Table F-7 is to be utilized after the Spawning Stock Biomass (SSB) of the San Francisco Bay Herring population is estimated (Section 7.6), and a preliminary quota has been identified using the HCR (Section 7.7.1). Department staff will apply the decision tree, beginning with Step 1, to determine whether an increase or decrease to the preliminary quota should be considered based primarily on changes in predator and regional forage indicators in the central CCE at the time of quota setting (late summer or early fall).

Step 1: Herring Spawning Stock Biomass

The first step in the decision tree assesses whether the current estimated SSB of the San Francisco Bay Herring population is greater than 20,000 short tons(t). Adjustment to the preliminary quota is not recommended when the SSB is less than 20,000t. When the stock is between 15,000 and 20,000t, a set quota of 750t is reserved to maintain access and viability to the commercial fishery while minimizing ecological impacts of harvest. When the stock is below 15,000t, the quota is zero and there is no need for adjustment. Alternatively, if SSB is greater than 20,000t, a change to the preliminary quota via a 300 ton (272 metric ton) adjustment may be recommended, and predator populations should be assessed by proceeding to the second step of the decision tree.

<table>
<tr><td colspan="4">Table F-7. Decision tree to assess predator-prey conditions in the central CCE.</td></tr>
<tr><td rowspan="2">Herring</td><td rowspan="2">1. Is the biomass estimate greater than 20,000t?</td><td>No</td><td>Do not adjust quota.</td></tr>
<tr><td>Yes</td><td>Proceed to 2.</td></tr>
<tr><td rowspan="8">Predators</td><td rowspan="2">2. Is there an unusual mortality event in progress in California for one of the following species: Common Murre, Rhinoceros Auklet, Harbor Seals, or California Sea Lions?</td><td>No</td><td>Proceed to 5.</td></tr>
<tr><td>Yes</td><td>Proceed to 3.</td></tr>
<tr><td rowspan="2">3. Is the mortality event occurring in Central California (e.g., Sonoma, Marin, San Francisco, San Mateo, Santa Cruz, Monterey counties)?</td><td>No</td><td>Proceed to 5.</td></tr>
<tr><td>Yes</td><td>Proceed to 4.</td></tr>
<tr><td rowspan="2">4. Is the cause of the mortality event attributed to or exacerbated by lack of forage, and the Herring biomass estimate is < 40,000t?</td><td>No</td><td>Proceed to 5.</td></tr>
<tr><td>Yes</td><td>Consider reducing quota.</td></tr>
<tr><td rowspan="2">5. Is the forecasted ocean abundance of Sacramento River Fall Run Chinook Salmon < 180,000, and the Herring biomass estimate < 40,000t?</td><td>No</td><td>Proceed to 6.</td></tr>
<tr><td>Yes</td><td>Consider reducing quota.</td></tr>
<tr><td rowspan="7">Regional Forage</td><td colspan="2">6. Calculate whether YOY Hake, YOY Rockfish, YOY Sanddab, Market Squid, and krill in the central CCE are more than 1 standard deviation below the long term mean. These indicators are classified as "unusually low".</td><td>Proceed to 7.</td></tr>
<tr><td colspan="2">7. Calculate whether central CCE Adult Pacific Sardine and Adult Northern Anchovy are below 50% of the long term mean. These indicators are classified as "unusually low".</td><td>Proceed to 8.</td></tr>
<tr><td colspan="2">8. Calculate the number of forage indicators that are more than 1 standard deviation above the long term mean. These indicators are classified as "unusually high".</td><td>Proceed to 9.</td></tr>
<tr><td rowspan="2">9. Are there currently > 5 forage indicators that are unusually low, and the Herring biomass is < 40,000t?</td><td>No</td><td>Proceed to 10.</td></tr>
<tr><td>Yes</td><td>Consider reducing quota.</td></tr>
<tr><td rowspan="2">10. Are there currently > 3 forage indicators that are unusually high, and the answer to lines 2, 5, and 6 is no?</td><td>No</td><td>Do not adjust quota.</td></tr>
<tr><td>Yes</td><td>Consider increasing quota.</td></tr>
</table>

Steps 2-5: Predator Indicators

The next set of criteria (Steps 2-4; Table F-7) assess whether a quota reduction is advisable due to UMEs in predator populations that may be caused by lack of forage. Based on the available dietary studies linking predators in the central CCE to Herring, as well as the available data with which to assess predator population health, a suite of known Herring predators including Common Murre, Rhinoceros Auklet, Harbor Seals, and California Sea Lions were chosen (Table F-2). Humpback Whales have been observed to eat Herring in central and northern California, though in far smaller quantities than either krill or sardines (Clapham and others, 1997). Humpback Whales were not included as indicator species due to their long-distance migration patterns and large foraging grounds, which would make it difficult to link a mortality event to a specific region.

With respect to the decision tree, UMEs are limited to those that primarily occur in the central CCE region and those that are attributable to starvation. However, it is important to note that UMEs are also caused by non-forage factors, including infectious diseases or exposure to biotoxins such as domoic acid (Table F-6). Non-forage related UMEs would not warrant a reduction in the quota because it may take a long time to determine the cause of the UME due to laboratory processing of samples, or to even detect whether a UME has occurred. In the event of a UME where the cause is undetermined, no quota reduction is warranted. Without direct evidence of a forage-related cause, there would be no rationale to reduce the quota and limit fishing opportunity. Should the criteria outlined in questions 2, 3, and 4 all be met, the decision tree recommends that the Department consider a quota reduction via a 300 ton (272 metric ton) decrease in the harvest rate under the HCR.

For question 5, there is strong dietary evidence linking Chinook Salmon to Herring in the central CCE. Question 5 assesses the SRFC population, and recommends a decrease in the Herring quota if the forecasted oceanic abundance is below the upper limit (180,000 fish) of the target escapement range set by the PFMC (Pacific Fishery Management Council, 2011). The PFMC escapement target for the SRFC population is set annually, typically in April. The SRFC population is intensively managed, and pre-fishery ocean abundance forecasts are primarily driven by ecological conditions, as fishing is yet to occur (Pacific Fishery Management Council, 2019). There is no immediate way to determine whether low oceanic abundance is due to a lack of forage, but since Chinook Salmon are known predators of San Francisco Bay Herring, reducing the Herring quota may help maintain forage needs for the Chinook Salmon population should the pre-season ocean abundance salmon forecast fall below the escapement target range.

Steps 4 and 5 recommend quota reductions in response to predator UMEs and low salmon forecasts only when the SSB is less than 40,000t. When the SSB is larger than 40,000t, the Herring stock is at 40-50% of the average estimated unfished biomass (Appendices B and M) and will likely meet Herring predator forage needs without additional reductions in catch. However, at an SSB below 40,000t it may be warranted to reduce the quota if ecosystem conditions suggest that forage conditions in the central CCE are unusually low (as defined in Table F-3 and Table F-7).

Steps 6-10: Regional Forage Indicators

Steps 6-10 are designed to guide the Department through the process of assessing regional forage availability in the central CCE, and to determine if forage indicators confirm that prey conditions in the central CCE are unusually low or unusually high. The regional forage indicators rely on data publicly provided annually by the CCIEA project, and the rationale behind the use of these indicators and how the thresholds to define "unusually high" and "unusually low" indices are discussed in detail above (Table F-3). "Cold water/medium energy" taxa (defined as juvenile rockfish, juvenile Pacific hake, juvenile sanddabs, Market Squid, and krill) and "warm water/high energy" taxa (defined as Pacific Sardine and Northern Anchovy) fluctuate as the dominant forage assemblage over time (Ralston and others, 2015; Santora and others, 2017), and predators are adapted to switch between the two (Ainley and Boekelheide, 1990; Field and others, 2010; Sydeman and others, 2001; Weise and Harvey, 2008; Wells and others, 2017). For this reason, in years when more than five forage indices are unusually low, a quota reduction (via a 300 ton decrease in harvest rate under the HCR) may be warranted at SSBs less than 40,000t, because this would signal that both cold water taxa and warm water taxa are low, and that forage conditions are poor in the central CCE. Alternatively, if four or more indices were unusually high, this would signal that forage conditions are favorable in the central CCE, and a quota increase (via a 300 ton increase in harvest rate under the HCR) may be warranted.

Retrospective Analysis to Assess Performance of the Decision Tree

To assess whether the management recommendations produced by the decision tree are in line with the current management objectives for this fishery , a retrospective analysis was conducted in which the decision tree was applied to the available data each year from 1991-2015. The results are summarized in Table F-8 and discussed here. Note that for many of the indicators, data were only available to 1991, which was therefore the first year of this retrospective analysis.

This analysis indicates that the decision tree would have recommended quota reduction in one season (1995-96), based on a predator mortality event affecting Common Murre in central California, if the predictive model's SSB estimate of 23,500t had been used that year. However, had the previous season's (1994-95) SSB estimate of 40,000t been used, no quota reduction would have been recommended. The analysis also indicates that the decision tree recommended a quota increase for one season (2013-14), whether either the predictive model or previous season's empirical SSB estimate was used. This was due to high forage counts co-occurring with high SSB estimates that season.

The criteria used to determine when the quota should be reduced to account for very poor forage conditions is intended to detect situations in which both cold and warm taxa are unusually low, which would signal that the central

CCE is not functioning as it normally does (fluctuating between warm and cold water forage assemblages) and the possibility of an extreme lack of forage in the region is high. According to this framework, the lowest observed forage conditions occurred in 1998, when all five cold-water forage species were low. However, the Pacific Sardine and Northern Anchovy indices were high to moderate that year, so there was still some forage available, though it may not have been the preferred forage type for predators with more northern ranges. It should be noted that during this year the SSB of Herring was one of the lowest ever observed, because Herring have responded negatively to warm, low nutrient conditions in much the same way as other cold-water taxa in the central CCE. Had the management framework proposed in this FMP been applied that year the Herring quota would have been zero based on the estimated Herring SSB.

During the unprecedented NPMH in 2014 and 2015, in which waters were warm for an extended period of time, Pacific Sardine and Northern Anchovy remained unusually low while cold water taxa, in particular the juvenile rockfish indices, were unexpectedly high. As a result the decision tree did not indicate the need for a forage-based reduction in quota. However, during this period a number of indicator predators experienced forage related UMEs, suggesting a lack of forage despite the fact that the juvenile groundfish indices were high. This highlights the benefits of having multiple different indicators when using incomplete information, and points to a possible mismatch in the locations where these regional forage indicators are collected (primarily offshore) and the nearshore areas where predators of Herring are likely to be foraging, especially during the predator's breeding season when their movements are restricted. At this time however, these regional forage indicators represent the best available science, and more research is needed to develop indicators that more accurately capture forage availability in nearshore areas.

Table F-8. Decision tree retrospective analysis (1991-2015) results. “Yes” means the criteria were met, “No” means the criteria were not met, and Yes* means that the criteria were potentially met but it is difficult to determine what information would have been available at the time of quota setting. Gray-shaded cells indicate years where SSB was <20,000t. The numerals in rows 6-8 show the number of forage indices that met the criteria for those steps. Where applicable (steps 1, 4, 5, and 9), criteria were evaluated for SSBs derived from both the predictive model and previous season’s empirical estimates. **indicates that either no SSB prediction for upcoming season, or no estimate for previous season was available.

	Step		Year (Fall)																								
			1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Biomass > 20,000 short tons	1	prev. SSB	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	**	Yes	Yes	Yes	No	No	No	Yes	Yes	Yes	Yes	Yes	No
		model	Yes	No	No	Yes	Yes	Yes	No	No	Yes	No	No	Yes	Yes	Yes	Yes	**	No	No	No	Yes	Yes	Yes	Yes	No	No
Predator Mortality Events	2	Mortality event?	Yes	Yes	No	No	Yes	No	Yes	Yes	No	Yes	No	Yes	No	No	Yes	No	Yes	No	Yes	No	No	No	Yes	Yes	Yes
	3	In Sf Bay Area?	Yes*	Yes*	No	No	Yes	No	Yes*	Yes*	No	Yes*	No	No	No	No	Yes	No	Yes	No	Yes	No	No	No	No	Yes	Yes
	4	prev. SSB	No	No	No	No	No	No	No	No	No	No	No	No	**	No	No	No	Yes	No	Yes	No	No	No	No	No	Yes
		model	No	No	No	No	Yes	No	No	No	No	No	No	No	No	No	No	**	No	No	Yes	No	No	No	No	No	Yes
Salmon	5	prev. SSB	No	No	No	No	No	No	No	No	No	No	No	No	**	No	No	No	No	Yes	Yes	No	No	No	No	No	No
		model	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	**	No	Yes	Yes	No	No	No	No	No	No
Forage Counts	6	Cold water taxa	0	1	0	0	1	1	0	5	0	0	0	0	0	0	3	4	4	2	0	0	0	0	0	0	0
	7	Warm water taxa	2	1	1	1	0	0	0	0	0	1	0	2	2	0	0	0	0	1	1	2	2	2	2	2	2
	8	High forage	0	1	1	0	1	0	1	1	0	0	0	0	0	1	2	2	1	2	0	0	1	2	4	4	4
Low forage	9	prev. SSB	No	No	No	No	No	No	No	No	No	No	No	No	**	No	No	No	No	No	No	No	No	No	No	No	No
		model	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	**	No	No	No	No	No	No	No	No	No
High Forage	10	> 3 high forage?	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	Yes	Yes	No
Years with recommended quota change		prev. SSB													**										Increase Quota		
		model					Reduce Quota											**							Increase Quota		

Altogether, this analysis suggests that the decision tree has the ability to inform the Department of unusually poor or productive conditions without being over-reactive. In a changing and highly variable ecosystem, it is impossible for a decision tree that is built on 25 years of historical observation to capture every possible combination of events. More information is needed to understand the relative importance and suitability of regional forage and predator indicators (particularly during winter). Therefore, precaution is appropriate when using ecosystem indicators to adjust management measures. This underscores the importance of Department discretion in considering potential ecosystem-based quota adjustments. Additionally, it will be necessary for the Department to update the indicators and thresholds underlying this decision tree as more research is done and our understanding of this system improves. In the meantime, however, management decisions must be made, and the information presented here suggests that the decision tree can serve as a useful framework for: a) incorporating ecosystem considerations into Herring management, and b) alerting fishery managers to unusual ecosystem conditions that may warrant further attention.

Appendix G Gears Used in the California Pacific Herring Fishery

Fishing technique has evolved somewhat in the Pacific Herring (Herring), *Clupea pallasii,* fishery since its inception. Two gear types (gill nets and purse seines) have been primarily used in the Herring roe fishery, though other types have also been used. This section describes the different types of gears used to target Herring.

Gill nets

While drift gill nets were used in the very early years of the roe fishery the legalization of set gill nets occurred in 1977 and set gill nets have been the primary gear used to take Herring. Gill nets are single panels of net that are set (anchored) and left to capture Herring by entanglement. Weights (along the bottom line) and floats (along the top line, also known as the cork line) hold the panel of webbing in a vertical position, to form a curtain-like wall of mesh. Since the 1998-99 fishing season, gill nets have been the only fishing gear allowed in the Herring roe fishery, following a regulation change that converted all round haul permits to gill net permits.

Purse seines

Purse seines are a type of round haul gear. A single panel of net is rapidly laid out from a vessel and positioned to encircle Herring. A small powered skiff aids in the encirclement process. Once encircled, the bottom-weighted line is pursed to create a bag. The bag volume is reduced by hauling the net onboard to concentrate the Herring to the point where they can be tested for roe quality, and if acceptable, removed with a large scoop net or submersible pump. Fish of unacceptable quality can be released. Purse seines were prohibited for use in the Herring roe fishery in 1998 over concerns about take of younger/smaller fish and mortality rates associated with testing and discarding unripe Herring.

Lampara

Lampara is a round haul gear that is set in a circle around a school of fish. It has no purse rings, and fish are forced into a bag by retrieving both ends of the net simultaneously. Lamparas are most effective in shallow water when the lead line rests on the bottom. Lampara boats are small, between 33 and 51 feet (ft) (10 to 16 meters (m)). The smaller boats use lighters (storage barges) with a capacity of 20 to 30 tons (18 to 27 metric tons) of fish. Lampara nets were used in the roe fishery until the early 1990s.

Beach Seines

Beach seines are fishing nets with floats at the top and weights at the bottom to keep them open. Nets are set in up to 10 ft (3 m) of water and dragged to shore along the ocean bottom. These were primarily used to catch bait and fresh fish during the early years of the fishery.

Cast Nets

Cast nets are 4 to 12 ft (1.2 to 3.7 m) radius panels of mesh webbing with a leadline attached to the circumference and a handline used to purse and retrieve the net. The net is thrown, or cast, by hand. The net opens up in midair and sinks when it hits the water, trapping the fish inside. Cast nets are only allowed in the sport fishery and are legal for recreational fishing north of Point Conception, but are prohibited in southern California because of their high efficiency. However, commercial fishermen have expressed to both California Department of Fish and Wildlife and the Fish and Game Commission that they are interested in using cast nets for the take of fresh fish. Cast nets are thought to produce a higher quality of fish compared to gill nets. However, the cast nets used in the sport fishery generally have a smaller mesh size than the current mesh size requirements for the gill net fishery, which can increase the number of smaller/younger fish selected.

Hook and Line

Hook and line gear is only used in the sport fishery, usually as part of rod and reel tackle from piers or jetties.

Open Pound (Herring Eggs on Kelp)

The San Francisco Bay Herring Eggs on Kelp (HEOK) fishery suspends giant kelp, *Macrocystis pyrifera,* from lines attached to rafts for Herring to spawn on in shallow water areas. The kelp is harvested near the Channel Islands or in Monterey Bay and then transported to San Francisco Bay. The kelp is then trucked to San Francisco and cut into approximately 6-inch lengths and hung on suspension lines on the rafts. A raft is defined as a temporary, mobile structure with a metal, wood or plastic frame not to exceed 2,500 square feet in total surface area. Timing is critical because cut kelp only lasts 8 to 10 days in San Francisco Bay waters before it begins to deteriorate.

The movement and maturity of Herring schools that enter the bay during the spawning season are monitored. Once a probable spawn location is determined a raft is towed by a vessel to the site and anchored. After a sufficient amount of eggs have been laid on the kelp, the blades are harvested, processed and exported to Japan.

Appendix H Timeline of Events in the Tomales-Bodega Bays Roe Herring Fishery

1972-73

The Tomales Bay Pacific Herring (Herring), *Clupea pallasii*, roe fishery got underway on 06 January 1973. The California State Legislature (Legislature) assumed control of the fishery over concerns of an unrestricted fishery, when the Governor signed the emergency legislation on 17 January 1973. Emergency legislation established a temporary (61 day) catch quota of 750 tons (681 metric tons) for Tomales Bay and San Francisco. Catch was made with round haul gear.

1973-74

With the last season's emergency regulations expired, the Legislature passed legislation establishing a 450 ton (408 metric ton) quota for the 1973-74 and 1974-75 season.

The Department of Fish and Wildlife (Department) was asked to conduct a 2-year (yr) study and assess the spawning biomass in Tomales Bay and San Francisco. At the end of the 2-yr study, regulatory authority of the fishery would revert to the Fish and Game Commission (Commission) who would set quotas based on the field studies. The concern for the safety of other bay users led to limiting the number of Herring permits. A lottery was conducted for the five Herring permits issued for Tomales Bay.

1974-75

In the 1974-75 season the quota was increased to 500 tons (454 metric tons) and was exceeded by 18 tons (16 metric tons). Only five permits were issued for the relatively small quota. Three lampara boats, one purse seiner, and one drift gill netter were drawn by lottery for the Tomales Bay roe fishery. However, there was concern that one large vessel could dominate the fishery. Therefore, no permittee was allowed to take more than 150 tons (136 metric tons). This represented the first step toward catch allocation.

1975-76

Legislative control expired after the 1974-75 season and regulatory authority over the Herring roe fishery reverted to the Commission. During the 1975-76 season, the Tomales Bay fishery expanded and a 600-ton (544 metric ton) quota was allocated to each vessel on an individual basis. Round haul vessels received 100 tons (91 metric tons) each and gill net vessels received 25 tons (23 metric tons) each. Round haul vessels were allocated a higher quota because of the larger crews and higher operating costs.

Five special permits were issued for Tomales Bay for Herring bait and fresh fish markets. There was a total of fourteen Herring permits issued for Tomales Bay. The Bodega Bay fishery began without a catch quota or permit limit.

1976-77

The Commission obtained control of the Herring fishery in all state ocean waters. Individual vessel quotas were eliminated for the 1976-77 season in favor of group or gear quotas. The Tomales Bay quota was increased to 825 tons (749 metric tons), and most of the quota increase in the 1976-77 season went to new gill net permittees. Seventeen Herring permits were issued for Tomales Bay (five round haul, seven gill net, and five special-gear permits (beach seine)) available on a first come, first serve basis. The seven Tomales Bay gill netters received 250 tons (227 metric tons) while the round haul quota was increased to 550 tons (499 metric tons). The Commission changed the 25-ton special bait and fresh fish allocation to a gear allocation for beach seines.

A separate quota of 350 tons (318 metric tons) was established for 24 new Bodega Bay permittees. Due to concerns regarding potential conflicts with other bay user groups, weekend fishing in Tomales Bay and Bodega Bay was prohibited from noon on Friday to sunset on Sunday. Anchored or "set" gill nets were allowed.

1977-78

Largely due to public sentiment, round haul vessels were permanently prohibited from participating in the Tomales Bay fishery. The total quota of 1,175 tons (1,066 metric tons) was allocated evenly between Bodega Bay and Tomales Bay. The 25-ton beach net allocation was included in the Tomales Bay quota, but a 10-ton fresh fish allocation was retained with five 2-ton permits.

1978-79

Tomales and Bodega Bays were combined into one permit area. The permit area was split into two platoons that fished alternate weeks. A spawning ground survey for Tomales Bay was not conducted this season. A maximum amount of 130 fathoms (fm)(two shackles; one shackle of net is 65 fm) of gill net was allowed for Tomales Bay.

1979-80

Tomales-Bodega Bay area Herring roe permits were capped at 69 permits. No new permits would be issued until the total permits fell below the cap. The depth of a gill net was restricted to no more than 120 meshes deep. No more than 260 fm (4 shackles) of net were allowed in Bodega Bay waters.

The Tomales and Bodega Bay quotas were combined for the 1978-79 season and the quota was increased to 1,200 tons (1,087 metric tons). Because 69 permitted fishing vessels would cause congestion on the fishing grounds, former Bodega and Tomales Bay permittees were split into two platoons and allowed to fish alternate weeks during the season. Each platoon was allocated 600 tons (543.5 metric tons).

1980-81

Tomales-Bodega Bay area Herring permits fell below 69 permits, when one permit was not renewed. The Commission then issued two new roe Herring permits. The Tomales gill net platoon system was modified to provide for an equitable catch. The first platoon was required to stop fishing when 100 tons (91 metric tons) were taken. The second platoon then fished until an additional 100 tons were taken, at which time the first platoon started fishing again, and so on until the quotas were met. Also, the fresh fish allocation was modified so that they could not be taken during the Herring roe fishery season.

Overcrowding on the fishing grounds in Tomales Bay was a problem. In order to minimize this problem, the number of Tomales Bay permits had to be reduced. The Commission created a 2-yr window of opportunity for Tomales Bay permittees to transfer to the San Francisco Bay Herring fishery. The intent was to reduce the number of Tomales Bay permits and combine the remaining permittees into one group for the 1982-83 season.

1981-82

Tomales-Bodega Bay area Herring permittees were allowed to exchange their permits for available San Francisco Bay permits to help alleviate crowding on Tomales Bay.

1982-83

Tomales-Bodega Bay area Herring permittees were allowed to transfer their permits to San Francisco Bay to help alleviate crowding on Tomales Bay. The number of Tomales Bay Herring permits was reduced to 41 permits, and no new permits would be issued, until there were less than 35 permits in Tomales Bay.

1983-84

The 41 permittees that chose to stay in Tomales Bay fished under a reduced quota of 1,000 tons (907 metric tons).

1985-86

Spawning ground surveys were conducted. However, due to the inability to locate spawning, which was usually indicated by bird and fishing activity, the spawning ground survey results were poor for this season. As a result, a cohort analysis was used to estimate the spawning biomass.

1986-87

The total gill net restriction in Bodega Bay was changed from 260 fm (four shackles) of gill net to 130 fm (two shackles) of gill net to make the amount of gear consistent in all permit areas. The provision for the use of drift gill nets was removed; therefore, only set gill nets were allowable.

1988-89

The Tomales Bay Herring fishery was closed after a record low 167 tons (152 metric tons) of spawning escapement in the season, which followed several seasons of low spawning and Herring abundance.

1989-90 to 1991-92

The Tomales Bay Herring fishery remained closed because spawning escapement did not exceed minimum escapement levels to support a fishery. Fishing was allowed to continue in the outer Bodega Bay. The outer bay fishery was modified by an increased closure zone around the mouth of Tomales Bay, and fishing was permitted only in Bodega Bay waters north of a line drawn due west, 240° magnetic, from the mouth of Estero de San Antonio. The closure zone around the mouth of Tomales Bay was designed to allow unimpeded access to Tomales Bay for spawning Herring. Department biologists speculated that Herring were displaced from Tomales Bay by unfavorable environmental conditions in the bay. Biologists hypothesized that Herring would return, if environmental conditions (such as, normal rainfall to reduce bay salinity) in Tomales Bay were more conducive for spawning.

1992-93

The season coincided with a remarkable return of spawning Herring to Tomales Bay, and the end of a 6-yr drought. The Tomales Bay fishery was re-opened for the 1992-93 season, when spawning ground survey results during the closure indicated improvement in spawning, and signaled that the spawning Herring population was potentially recovering. The Tomales Bay fishery was re-opened with conservative measures that included a quota based upon 10 percent (%) of the previous season biomass, an increase in the commercial gill net minimum mesh size to 2-1/8 inches (in), and a reduction of the maximum allowable amount of gill net used to one shackle (65 fm). An initial quota of 120 tons (109 metric tons) was established, with a maximum quota of 200 tons (181 metric tons), if the spawning surpassed the 2,000 ton (1,814 metric tons) escapement goal.

The outer Bodega Bay fishery was partially closed and the fishery was restricted to Bodega Bay and Tomales Bay waters south of line drawn due west, 240° magnetic, from the mouth of Estero de San Antonio.

1993-94 to 1996-97

Corresponding to the re-opening of the Tomales Bay fishery was the partial closure of the outer Bodega Bay fishery. In the 1993-94 season the Tomales Bay fishery boundary was confined within Tomales Bay, to District 10 waters south of a line drawn 252° magnetic, from the western tip of Tom's Point to the opposite shore. The outer Bodega Bay fishery was closed due to concern that this fishery intercepted potential Tomales Bay spawning fish. Additionally, the Department felt that an accurate estimate of the biomass of Herring that held in the outer bay could not be obtained, and that quotas for the outer bay fishery could not be based on a spawning biomass, as stated in management documents.

1997-98 to 2005-06

The 1997-98 El Niño event had a detrimental effect on Herring spawning populations throughout the state causing a loss of older age classes and a reduction in growth rates. Tomales Bay Herring fishermen expressed concerns that the 2-1/8 in gill net mesh size was no longer efficient in capturing Herring after the El Niño event and requested that the Department consider changing the minimum mesh size to 2 in. The industry stated that the increased number of "belly caught" Herring indicated that the 2-1/8 in mesh size was too large; a proper mesh size should capture Herring at the gills and not at the belly. The industry also pointed to poor catch rates caused by an improper mesh size, which reduced both the quality and quantity of the roe Herring landed. These two factors made the Tomales Bay fishery prohibitively unprofitable. The Department recommended to the Commission that a fleet wide gill net mesh study be done to assess the effects of a minimum 2-in mesh size on the current population structure.

2006-07

Thirty-five limited entry commercial Herring gill net permits were issued in Tomales Bay and the quota was set at 350 tons (318 metric tons) for the season. The quota was based on historical spawning biomass data. Two vessels actively fished during the 2006 to 2007 season. On 30 December 2006, two landings were made with a total of 1.2 tons (2,436 pounds (lb)) and a roe count of 12.1%. This was the only landing made for the season. Low market price and high operating costs attributed to the low effort. No commercial Herring fishing in Tomales Bay occurred between the 2006-07 and 2018-19 seasons (the time this FMP was drafted).

Appendix I Review of Survey Methods Used Estimate Abundance in San Francisco Bay

State of California **The Resources Agency**

M e m o r a n d u m

To: Patricia Wolf **Date:** July 14, 2003
Cc Eric Larson
Fred Wendell

From: John J Geibel 650 631-6117
Department of Fish and Game B MR-7 - Belmont

Subject: Comparison of Herring Egg spawn biomass estimates and Hydro-acoustic biomass estimates

I am presenting the results of my analysis of the two fishery independent herring spawning biomass estimators for the San Francisco Bay herring population with several options for future management of this fishery.

Background leading to this study

Two methods have been used to estimate the S.F. Bay herring spawning biomass, an egg deposition survey and a hydro-acoustic survey. Both surveys have been used in combination to try to arrive at the "best" overall estimate of herring spawning biomass. At times estimate based upon the two surveys has been greater than either survey alone. This can happen when each survey appears to have missed one or more schools of herring that the other found. At other times combining of the two surveys has resulted in biomass estimates between the two estimates. The biomass estimate used for setting the quota was greater than higher survey estimate 60% of the time, while 95% of the time the biomass estimate used for setting the quota was greater than the mean of the hydro-acoustic and egg spawn surveys (Table 1).

Requirements of the study

To compare the best estimator between two measurements requires either a true measure of the measurement being taken or a comparison of the two measurements against a third measurement. In the first case we can make a direct assessment of accuracy. In the second case we must look for consistency between the various measurements and conduct a more detailed analysis because we are now comparing three different measurements none of which is known to be better than the other. Consequently this analysis requires looking at both correlations and inconsistencies within and between measurements.

The Data

Data used in this analysis consisted of biomass estimates from two Coleraine model runs (a run with low maximum biomass and a run with high maximum biomass to encompass a range of possible spawning biomass estimates during the period from 1974 through 2002), biomass estimates from egg spawn surveys and from the hydro-acoustic surveys, the biomass estimates obtained from the combination of the egg spawn and hydro-acoustic surveys, and the egg spawn survey and hydro-acoustic survey with one year time lag (table1).

Coleraine – an age Structured Model

A description of data that were used to fit the model is included at the end of this memo. An age structured model, such as Coleraine, can be fit using all of the available data. The model fit is based upon a cohort reconstruction which is then compared to the age structured landings, both surveys, and CPUE index from the gillnet fishery. The advantage using the model is the lack of subjectivity in the model weighting and selection of data used in the fit. The cohort reconstruction also requires fitting of data between years to obtain the best fit through time.

Comparison Between and Among Estimators

I used excel to calculate correlations between all estimators and the estimators with the 1 year time lag. The lower modeled biomass run and the higher modeled biomass run had the highest correlation with a correlation coefficient of 0.98 (table 2). This very high correlation results from the two model biomass estimates following the same trajectory through time, even though the absolute difference in estimates was about 30%. This means that even if we are not confident in which model run to use for an absolute biomass estimate, the model runs are consistent in estimating the relative decline in the spawning biomass through time. The egg spawn survey has a slightly higher correlation with the lower biomass model run, 0.84 and 0.815 (table 2). The hydro-acoustic has low, non significant correlations with both model runs with a slightly higher correlation with the lower biomass model run, 0.206 and 0.158 (table 2). The biomass estimates obtained by combining the two surveys had a correlation coefficient in between those of the two surveys as one might expect, 0.49 and 0.453 (table 2).

Comparison of Survey with Themselves with a 1 Year Lag

The egg spawn survey compared with itself had a correlation coefficient of 0.707, $p < .0002$ (table 3). The hydro-acoustic survey biomass estimates with itself with a 1 year lag had a correlation coefficient of 0.19, $p > 0.4$ (table 3). And as expected the biomass estimates calculated from combining the two survey estimates with itself with a 1 year lag came out in between the other two estimates with a correlation coefficient of 0.33, $p > 0.13$ (table 3).

Discussion

The basic assumption in using an estimate of one seasons spawning biomass to set the quota for the next season is that the spawning biomass of year 1 will be a good estimator of the spawning biomass in year 2. If this assumption is not true, then there is little value of assessing the biomass from one year to the next. If this assumption is true then, we can examine how well each estimator can predict itself in the next season.

The regression of the egg spawn survey with itself with a 1 year lag can explain about 50% of the variability in the estimate. This leaves about 50% of the variation unexplained by the regression. Biomass estimates based on egg spawn survey are measured with error because we do not know the actual spawning biomass. Consequently both the dependent and independent variables are measured with error.

In addition the spawning biomass consists of the surviving older fish and new recruits. Differences in survival rates and recruitment between years will affect the actual biomass from one year to the next, so even if we could measure the spawning biomass in year 1 without error, we would not be able to predict spawning biomass in year 2 without error. In considering all of these factors, 50% seems reasonable.

The hydro-acoustic survey compared with itself with a 1 year lag can explain less than 4% of the variation from one year to the next and the regression slope is not significantly different from 0. Consequently if the hydro-acoustic survey can accurately estimate spawning biomass then we are left with the conclusion that biomass in year 1 is of little value in predicting biomass in year 2.

We do not know why the hydro-acoustic survey has these inconsistencies. One source of error could be multiple counting of some schools. Every effort is made to follow schools from the time they enter the bay, to the spawning areas, to their post spawning dispersal from the Bay. If herring were multiple spawners this could be a problem, but herring spawn only once. The assumption that the hydro-acoustic survey does not double count fish is difficult to test and is probably not true. But is it responsible for the occasional large discrepancy between itself from year to year and between it and the other estimators?

Age structured models will tend to underestimated true variance. For instance the effects of the 1997-98 El Niño in subsequent years was reduced by the model because the model accounted for the lack of older fish in the post El Niño years by reducing the number of fish in these cohorts in the pre El Niño years. Consequently the high correlations of the model runs and the same runs with a 1 year lag overestimate the ability of the model to predict the next years spawning biomass.

Conclusions

The hydro-acoustic survey is a poor estimator of itself. If the hydro-acoustic survey is unable to predict the next year's hydro-acoustic estimate, then it is of little help in establishing the quota for the following year's fishery. Likewise the correlation between the hydro-acoustic survey and the modeled biomass estimates is not significantly different from 0 and explains less than 4% of the variance of the model's historical reconstruction of the population (0.0369, Table 3).

The Egg spawn survey does a fair job of predicting itself in the next year (0.500, Table 3). In addition the egg spawn survey has a high correlation with the modeled biomass estimates, explaining 70% of the variance of the modeled biomass.

Recommendations

There are three options.

- Herring management can continue with the present spawn surveys and methodology.
- The hydro-acoustic survey can be discontinued.
- Both surveys can be discontinued being replaced by an age structured model.

The age structured model should be included with the first two options. The three options happen to fall out in order of costs. Conducting both surveys is the most expensive and also the most controversial. Whenever two different estimators are used, the higher estimator invariably is used resulting in a long term bias of overestimating biomass. In fact as was stated earlier, 60% of the time, the biomass used to set the quota was greater than higher spawning biomass estimate. And only in the first year of the hydro-acoustic survey was the biomass estimated used to set the quota less than the mean of the two estimates. Discontinuing the hydro-acoustic survey would probably cut field work cost by half. Eric Larson could come up with a more accurate estimate of cost savings.

Dropping both the hydro-acoustic and the egg spawn surveys and using an age structured model would be the most cost effective option. Considering the current fiscal crisis, this is the option that I would recommend. This option would eliminate the obvious bias in going with the higher of the two spawning biomass estimates or even worse of using the two estimates to produce a spawning biomass estimate greater than either of the two.

Regardless of options selected, commercial landings should still be sampled for age composition and other population parameters.

Description of data and parameters used in the herring assessment modeling

The CD contains several files with which the reviewers should become familiar. These are the excel input file, run8rec.xls, tracker.xls which lists the final model parameters used, and run8rec3o.xls which is one of the several files containing model output and graphs.

The input file – "run8rec.xls"

The input file is described in Appendix B of the Coleraine manual.

For the most part the excel input file is self explanatory with the labels describing the input data. The first three sections setup the excel file for data entry. For example the start year and end year set the range for catch data.

The next section names the gears used for the CPUE index, survey indices and commercial gears.

Projection Parameters

These values are used by the model to obtain projections based on the model parameters selected during the model run. I could not get this part of the model to work.

Priors

This section is explained in the model description and examples. This section lets the user determine the order that parameters are introduced into the model and the starting values with ranges to limit the model fits and CV's. The order of entry into the model is the first number. If that number is negative, the model uses the starting parameter value and does not try and fit within the given range. "Tracker.xls" also indicates the order of parameters entered and fit by the model using a color code. Red are those parameters fit in the first step, followed by yellow, green and then blue.
I set the selectivity for an asymptotic right side for both surveys and for the commercial catch by setting the initial value at 15 and -3 for fishing selectivity and -4 for survey selectivity.
I used several different orders for fitting of the parameters. Some would not work. However when the model could fit the parameters, the results were quite similar regardless of the order in which the parameters were entered and fit.

Likelihoods

These are described in Appendix B pp 49-50.

Fixed parameters

This is where the length-weight and length –age parameters are entered. We used a single sex model because the sizes are quite close.

The maturity ogive was 30% of 2's are mature and 85% of the 3's and 100% of all older fish.
I set the weight at age matrix to run from 1974 through 2003 with the first 10 years being an average weight over the entire period.

Data

Catch by method by year

Catch is in tons for round haul and for gillnet. The model does not handle zero catches. There was no gillnet fishery in 1974, so a minimal catch of 1 ton was used. Likewise since 1998 there has been no round haul fishery and so I again used 1 ton for these years.

CPUE

I used the CPUE from the gillnet fishery. The index was the total catch divided by the total number of landings. A constant CV of .5 was used for all years. This is a fairly rough estimator, but the model fit is quite good. I did not develop a CPUE index for the round haul fleet.

Fishery Independent Surveys

There are two spawning biomass surveys conducted in every years since 1982 and egg deposition survey and a hydro acoustic survey. The egg deposition survey goes back to 1979 and at least in recent years has had much lower variance than the hydro acoustic survey. Consequently although both estimators were used the CV was set a 0.5 for the egg deposition survey and 1 for the hydro acoustic survey. I tried setting the CV for the hydro acoustic survey equal to the egg deposition survey but the model would not fit the hydro survey until the CV was increased.

Catch at Age

This matrix contains 50 rows going from 1975 to 1997 for the round haul fishery and from 1976 to 2002 for the gillnet fishery. A constant sample size of 20 was used for all years.

Survey Catch at Age Data

In the first runs of the model, this data set was not used, but after our meeting with the fishermen, we decided to include this data set because it may give us some information of incoming yearclass strength. This data is derived from samples from the hydro acoustic survey. When added to the model it did indicate a small increase in herring biomass over the last two years.

We did not use the catch at length data. When first fitting the model, I did enter both catch at age and catch at length. However, I was advised that these two data sets would be highly correlated and should use only catch at age which I did. The model requires the last three catch at length dummy data sets,

The Output File “Tracker.xls”

The output file “Tracker.xls” is a file that keeps track of multiple model runs and parameters fits. The input file is listed for each run. The file listed is not the excel input file but a text file that is constructed from the excel input file for use by Coleraine.exe and model builder. I found this to be helpful because I could make small changes to the excel input file and then run the excel file to produce the text file which could be saved under a new name. This allowed me to have one working input file while saving the text files for documentation.
The fitted parameter values are listed with the order of entry to the model color coded with red indicating those parameters first fit followed by yellow, green, and blue. Parameters not fit by the model, the right hand side of the selectivity curves, are left uncolored.

Model Run Output Files

I have used a naming convention which adds an o to the name of the text input file to identify the excel output file. For example if the input file is named “run7.txt,” the excel output file would be called “run7o.xls”. This allows me to keep track of numerous model runs with their associated input files and output files. The workbook has the following spreadsheets.

General – graphs of general interest
SurNoSexCl
SurvC@L– Survey catch at length
CommC@L - Commercial catch at length
SurvS@A – Survey catch at age
ComC@A- Commercial catch at age
Surveys – Survey indices fits
SurSel – Survey selectivities
ComSel – Commercial selectivities
CPUE
Master – modeled data used to graph the results
Graphmaster – data used for general graphics

The catch at length spreadsheets are not of much use because we did not fit catch at length data. The main spreadsheet is “Master”. This contains all of the input data and data constructed from the modeled parameters such as the cohort reconstruction which is a matrix of numbers of fish at age by year for the period of the fishery being modeled. Other matrices produced are the spawning biomass, recruitment, etc. The graphs from each run make comparisons between runs very easy.

General Model Results

Maximum biomass estimates run from about 61,000 tons from “run8rec3o.xls” to 86,000 tons in “run11o.xls”. This would appear to be a reasonable range for maximum population of the San Francisco Bay herring population. The spawning biomass estimate for the 2002-03 from these model runs was respectively 16,600 tons and 24,300 tons. This gives us a present spawning biomass at about 27% of the maximum spawning biomass for “run8rec3o.xls” and 28% for “run11o.xls”.

The three factors that control the absolute size of the model population estimates are the natural mortality rate, the beginning population estimate and the maximum exploitation rates. By varying these parameters the population size can be varied. However even in runs in which the maximum population was over 100,000 tons the trajectory over time was quite similar indicating the present spawning biomass to be less than 30% of the maximum.

Confounding Factors El Niño

In 1995-96 and 1996-97 both the hydro acoustic survey and the egg spawn survey had relatively high spawning biomass estimates. The quota and the landings for the 1996-97 season were the highest in the history of the fishery. This would indicate that there actually was a high biomass of fish present in these years. However the strong El Niño of 1997-98 either displaced or killed most of these fish. In previous El Niño ’s the fishery experienced a significant decline in spawning biomass for that season, but adult fish seemed to return within the next year or two. This apparently did not happen following the 1997-98 El Niño .

The model can account for the loss of these fish in two ways. One would be to have a declining selectivity for these age groups following the El Niño . However I have run the model with an asymptotic right hand side of the selectivity curve. Consequently, when these older age fish do not show up in the fishery in the years following this El Niño , the model fits these age groups by lowering the numbers present in the years prior to the El Niño. This results in lower biomass estimates and high exploitation rates for those several years prior to this El Niño .

The bottom line would seem to be that the population will have to rebuild itself over a longer period than was the case with other El Niño’s. The model runs seem to indicate a slight rebuilding over the last three years. The two model runs indicate that the spawning population in 2002-03 has increased by 17% to 28% from the spawning biomass of 1999-2000.

Table 1. Biomass estimates by year for two model runs, egg spawn survey, hydro-acoustic, biomass used to set quotas, and egg spawn and hydro-acoustic with 1 year lag.

	Spawning Biomass Estimates								
Year	Low Coleraine Biomass Run	Low Coleraine Run 1 year lag	High Coleraine Biomass Run	High Coleraine Biomass Run 1 year lag	Egg Spawn Survey	Egg Spawn Survey 1 year lag	Hydro-Acoustic Survey	Hydro-Acoustic Survey 1 year lag	Biomass Used for Quota
1974	50,017	49,244	83,063	76,959					
1975	49,244	55,794	76,959	83,921					
1976	55,794	58,730	83,921	86,139					
1977	58,730	57,712	86,139	81,955					
1978	57,712	57,837	81,955	79,605		52869			
1979	57,837	58,368	79,605	79,810	52869	65441			52900
1980	58,368	56,059	79,810	74,690	65441	99495			65400
1981	56,059	44,956	74,690	60,140	99495	59243		67040	99600
1982	44,956	41,765	60,140	56,209	59243	40425	67040	29327	59200
1983	41,765	57,790	56,209	76,167	40425	46120	29327	29500	40800
1984	57,790	59,705	76,167	78,423	46120	49068	29500	36625	46900
1985	59,705	60,981	78,423	78,884	49068	56819	36625	40930	49100
1986	60,981	56,096	78,884	70,493	56819	68881	40930	58110	56800
1987	56,096	51,260	70,493	62,466	68881	66044	58110	65080	68900
1988	51,260	39,773	62,466	48,206	66044	63112	65080	58100	66000
1989	39,773	34,773	48,206	43,096	63112	45850	58100		64500
1990	34,773	29,318	43,096	36,544	45850	41020		32350	51000
1991	29,318	23,209	36,544	29,401	41020	13550	32350	18262	46600
1992	23,209	22,378	29,401	28,778	13550	23843	18262	40137	21500
1993	22,378	28,490	28,778	35,743	23843	20070	40137	33435	39900
1994	28,490	32,296	35,743	38,750	20070	57141	33435	92760	40000
1995	32,296	25,039	38,750	29,059	57141	41273	92760	88957	99000
1996	25,039	14,170	29,059	17,613	41273	5248	88957	17961	88520
1997	14,170	14,095	17,613	17,839	5248	13518	17961	42285	20000
1998	14,095	13,440	17,839	17,931	13518	12739	42285	21545	39500
1999	13,440	13,187	17,931	19,128	12739	12093	21545	46517	27400
2000	13,187	14,373	19,128	22,099	12093	15174	46517	36425	37300
2001	14,373	13,666	22,099	22,964	15174	13316	36425	40000	35400
2002	13,666		22,964		13316		40000		

Table 2. Correlation among different biomass estimators and among the egg spawn estimates and hydro-acoustic with one year lag

	Year	*Low Coleraine Biomass Run*	*Low Coleraine Run 1 year lag*	*High Coleraine Biomass Run*	*High Coleraine Biomass Run 1 year lag*	*Egg Spawn Survey*	*Egg Spawn Survey 1 year lag*	*Hydro-Acoustic Survey*	*Hydro-Acoustic Survey 1 year lag*	*Biomass Used for Quota*
Year	1									
Low Coleraine Biomass Run	-0.881	1.000								
Low Coleraine Run 1 year lag	-0.896	0.947	1.000							
High Coleraine Biomass Run	-0.934	0.980	0.956	1.000						
High Coleraine Run 1 year lag	-0.933	0.917	0.986	0.959	1.000					
Egg Spawn Survey	-0.776	0.840	0.657	0.815	0.633	1.000				
Egg Spawn 1 year lag	-0.776	0.868	0.840	0.864	0.815	0.707	1.000			
Hydro- Acoustic Survey	-0.072	0.206	-0.021	0.158	-0.061	0.600	0.146	1.000		
Hydro- Acoustic 1 year lag	-0.072	0.270	0.206	0.249	0.158	0.311	0.600	0.192	1.000	
Biomass Used for Quota	-0.367	0.490	0.270	0.453	0.239	0.821	0.397	0.936	0.353	1.000

Table 3. Regression analysis of three biomass estimator with themselves with a one year lag; egg spawn biomass, hydro-acoustic, and the combined biomass estimate.

Regression analysis of Egg Spawn Survey Biomass Estimates vs Egg Spawn Biomass Estimates with one year lag

Regression Statistics	
Multiple R	0.707318
R Square	0.500298
Adjusted R Square	0.476503
Standard Error	17890.18
Observations	23

ANOVA

	df	*SS*	*MS*	*F*	*ignificance F*
Regression	1	6729244919	6729244919	21.02505	0.00016
Residual	21	6721226894	320058424		
Total	22	13450471813			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*.ower 95.0%*	*Jpper 95.0%*
Intercept	9867.849	7634.755538	1.29249056	0.210229	-6009.497	25745.2	-6009.497	25745.2
Spawn Survey	0.72497	0.158107243	4.58530825	0.00016	0.396168	1.053773	0.396168	1.053773

Regression analysis of Hydro Acustic Biomass Estimates vs Hydro Acustic Biomass Estimates with one year lag

Regression Statistics	
Multiple R	0.192207
R Square	0.036944
Adjusted R Square	-0.023247
Standard Error	21644.55
Observations	18

ANOVA

	df	*SS*	*MS*	*F*	*ignificance F*
Regression	1	287544484.7	287544485	0.613773	0.444814
Residual	16	7495786800	468486675		
Total	17	7783331285			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*.ower 95.0%*	*Jpper 95.0%*
Intercept	35943.11	11731.88668	3.06371069	0.007423	11072.62	60813.59	11072.62	60813.59
Hydro	0.186868	0.238523931	0.78343668	0.444814	-0.31878	0.692516	-0.31878	0.692516

Regression of Biomass Estimates Used for Management vs the Same Biomass Estimates with one year lag *

Regression Statistics	
Multiple R	0.332904
R Square	0.110825
Adjusted R Square	0.066366
Standard Error	21473.38
Observations	22

ANOVA

	df	*SS*	*MS*	*F*	*ignificance F*
Regression	1	1149426132	1149426132	2.49276	0.130057
Residual	20	9222117795	461105890		
Total	21	10371543927			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*.ower 95.0%*	*Jpper 95.0%*
Intercept	34728.36	12373.70145	2.80662668	0.010896	8917.284	60539.44	8917.284	60539.44
Combined	0.338152	0.214176163	1.57884755	0.130057	-0.108612	0.784915	-0.108612	0.784915

* These biomass estimaes are a combination of the egg spawn survey and the hydro-acuastic survey.

Appendix J Allocation Table for San Francisco Bay

Table J-1. Quota allocation table for San Francisco Bay. All quotas are in short tons. Beginning with the 1998-99 season, both numbers of permits fished and permits renewed (in parentheses) are provided.

Season	Sector	Number of Permits	Sector Quota	Notes
1972-73	**Total**	**12**	**1500**	
	Round haul	12	1500	
1973-74	**Total**	**12**	**600**	
	Round haul	12	600	
1974-75	**Total**	**12**	**500**	
	Round haul	10		150/permit
	Gill net	2		
1975-76	**Total**	**58**	**3050**	
	Round haul	24		100/permit
	Gill net	24		25/permit
	Special	10		5/permit
1976-77	**Total**	**234**	**4000**	
	Lampara	27	1500	
	Purse Seine	39	1500	
	Gill net	165	1000	
	Fresh fish	3	15	5/permit
1977-78	**Total**	**290**	**5025**	
	Lampara	29	1500	
	Purse Seine	30	1500	
	Gill net	226	2000	
	Fresh fish	5	25	5/permit
1978-79	**Total**	**288**	**5020**	
	Lampara	31	1500	
	Purse Seine	27	1500	
	Even gill net	110	1000	
	Odd gill net	110	1000	
	Fresh fish	10	20	2/permit
1979-80	**Total**	**282**	**6020**	
	Lampara	27	1500	
	Purse Seine	27	1500	
	Even gill net	109	1500	
	Odd gill net	109	1500	
	Fresh fish	10	20	2/permit
1980-81	**Total**	**376**	**7250**	
	Lampara	24	1500	
	Purse Seine	29	1500	
	Even gill net	112	1500	
	Odd gill net	111	1500	
	December gill net	100	1250	
1981-82	**Total**	**383**	**10000**	
	Lampara	27	2185	
	Purse Seine	24	1875	
	Even gill net	116	2070	
	Odd gill net	116	2145	
	December gill net	100	1725	
1982-83	**Total**	**430**	**10399**	
	Lampara	21	1792	
	Purse Seine	22	1719	
	Even gill net	126	2166	
	Odd gill net	134	2400	
	December gill net	127	2322	
1983-84	**Total**	**430**	**10399**	
	Lampara	21	2260	
	Purse Seine	22	1875	
	Even gill net	127	2088	
	Odd gill net	135	2088	

	December gill net	125	2088	
1984-85	**Total**	**417**	**6500**	
	Lampara	21	1131	
	Purse Seine	22	1079	
	Even gill net	126	1408	
	Odd gill net	128	1485	
	December gill net	120	1397	
1985-86	**Total**	**416**	**7530**	
	Lampara	21	1260	
	Purse Seine	22	1320	
	Even gill net	128	1683	
	Odd gill net	129	1683	
	December gill net	116	1584	
1986-87	**Total**	**414**	**7530**	
	Lampara	21	1260	
	Purse Seine	21	1260	
	Even gill net	128	1683	
	Odd gill net	127	1683	
	December gill net	116	1584	
	Roe on kelp	1	60	8 (product)
1987-88	**Total**	**414**	**8500**	
	Lampara	21	1422	
	Purse Seine	21	1422	
	Even gill net	128	1900	
	Odd gill net	127	1900	
	December gill net	116	1788	
	Roe on kelp	1	68	15 (product)
1988-89	**Total**	**419**	**9500**	
	Lampara	9	681	
	Purse Seine	31	2346	
	Even gill net	127	2089	
	Odd gill net	128	2123	
	December gill net	117	1999	
	Roe on kelp	5	262	59 (product)
	Allotment A and B	2*		5 (product)
*Two of the roe-on-kelp permittees were the successful bidders for allotments (A and B)				
1989-90	**Total**	**413**	**9500**	
	Lampara	3	228	
	Purse Seine	33	2508	
	Even gill net	126	2144	
	Odd gill net	128	2178	
	December gill net	115	1940	
	Roe on kelp	8	492	110 (product)
1990-91	**Total**	**416**	**9500**	
	Round Haul	34	2584	
	Even gill net	127	2142	
	Odd gill net	130	2192	
	December gill net	115	1940	
	Roe on kelp	10	642	144 (product)
1991-92	**Total**	**406**	**7248**	
	Round Haul	31	2074	
	Even gill net	128	1728	
	Odd gill net	131	1768	
	December gill net	116	1564	
	Roe on kelp		114	
1992-93	**Total**	**413**	**5555**	
	Round Haul	31	1485	
	Even gill net	127	1260	
	Odd gill net	129	1290	
	December gill net	114	1140	
	Roe on kelp	10	380	85 (product)
	Special Ed.	2	20	

1993-94	**Total**	**276**	**2152**	
	Round Haul	31	541	
	Even gill net	81	499	
	Odd gill net	83	511	
	December gill net	69	445	
	Roe on kelp	10	156	35 (product)
	Special Ed.	2	8	
1994-95	**Total**	**418**	**4788**	
	Round Haul	29	1102	
	Even gill net	133	1143	
	Odd gill net	131	1160	
	December gill net	113	1003	
	Roe on kelp	10	380	85 (product)
	Special Ed.	2	17	
1995-96	**Total**	**423**	**6000**	
	Round Haul	26	1238	47.6 (per permit)
	Even gill net	133	1481	
	Odd gill net	136	1514	
	December gill net	116	1291	
	Roe on kelp	10	476	107 (product)
	Special Ed.	2	22	
1996-97	**Total**	**431**	**14841**	
	Round Haul	25	2925	117 (per permit)
	Even gill net	133	3668	
	Odd gill net	136	3751	
	December gill net	116	3199	
	Roe on kelp	11	1278	289 (product)
	Fresh Fish	10	20	
	Special Ed.	2	54	
1997-98	**Total**	**433**	**10748**	
	Round Haul	25	2125	85 (per permit)
	Even gill net	133	2649	
	Odd gill net	136	2709	
	December gill net	116	2310	
	Roe on kelp	11	935	209 (product)
	Fresh Fish	10	20	
	Special Ed.	2	40	
1998-99	**Total**	**457**	**3000**	
	Even gill net	126 (148)	934	
	Odd gill net	128 (152)	959	
	December gill net	116 (134)	846	
	Roe on kelp	11	241	54 (product)
	Fresh Fish	10	20	
	Special Ed.	2	12	
1999-00	**Total**	**456**	**5925**	
	Even gill net	126 (148)	1870	
	Odd gill net	148 (149)	1858	
	December gill net	134	1694	
	Mesh size study	3	38	
	Roe on kelp	11	445	99 (product)
	Fresh Fish	10	20	
	Special Ed.	1	25	
2000-01	**Total**	**452**	**2740**	
	Even gill net	129 (149)	864	
	Odd gill net	131 (149)	864	
	December gill net	88 (133)	771	
	Roe on kelp	11	221	49 (product)
	Fresh Fish	10	20	
2001-02	**Total**	**440**	**4474**	
	Even gill net	140 (150)	1411	
	Odd gill net	146 (147)	1440	
	December gill net	88 (133)	1277	

	Roe on kelp	10	326	73 (product)
	Fresh Fish		20	
2002-03	**Total**	**441**	**3540**	10%
	Even gill net	135 (150)	1108	
	Odd gill net	139 (147)	1138	
	December gill net	58 (133)	1016	
	Roe on kelp	10	258	58 (product)
	Fresh Fish	(1)	20	
2003-04	**Total**	**429**	**2200**	
	Even gill net	97 (143)	701	
	Odd gill net	98 (145)	691	
	December gill net	79 (130)	628	
	Roe on kelp	10	160	35 (product)
	Fresh Fish	(1)	20	
2004-05	**Total**	**417**	**3440**	
	Even gill net	98 (141)	1101	
	Odd gill net	97 (141)	1101	
	December gill net	58 (124)	967	
	Roe on kelp	10	251	56 (product)
	Fresh Fish	(1)	20	
2005-06	**Total**	**412**	**4502**	
	Even gill net	70 (141)	1503	
	Odd gill net	68 (141)	1503	
	December gill net	61 (124)	1322	
	Roe on kelp	5	152	34 (product)
	Fresh fish	(1)	20	
2006-07	**Total**	**410**	**4502**	
	Even gill net	51 (141)	1503	
	Odd gill net	45 (141)	1503	
	December gill net	11 (124)	1322	
	Roe on kelp	4	152	34 (product)
	Fresh fish		20	
2007-08	**Total**	**186**	**1094**	
	Even gill net	40 (60)	373	
	Odd gill net	38 (71)	404	
	December gill net	0 (45)	280	
	Roe on kelp	10	76	17 (product)
	Fresh fish		20	
2008-09	**Total**	**220**	**1118**	
	Even gill net	60 (79)	383	
	Odd gill net	61 (81)	393	
	December gill net	2 (50)	243	
	Roe on kelp	2 (10)	79	18 (product)
	Fresh fish		20	
2009-10	**Total**		**0**	Fishery closed
	Even gill net			
	Odd gill net			
	December gill net			
	Roe on kelp			
	Fresh fish			
2010-11	**Total**	**189**	**1920**	
	Even gill net	52 (92)	918	
	Odd gill net	52 (93)	927	
	Roe on kelp	0 (4)	55	12 (product)
	Fresh fish		20	
2011-12	**Total**	**194**	**1920**	
	Even gill net	44 (93)	913	
	Odd gill net	43 (88)	932	
	Roe on kelp	0 (8)	55	12 (product)
	Fresh fish	0 (5)	20	
2012-13	**Total**	**200**	**2854**	
	Even gill net	66 (96)	1375	

	Odd gill net	62 (92)	1280	
	Roe on kelp	10 (10)	179	41 (product)
	Fresh fish	0 (2)	20	
2013-14	**Total**	**198**	**3737**	
	Even gill net	68 (95)	1739	
	Odd gill net	70 (93)	1703	
	Roe on kelp	2 (10)	295	66 (product)
2014-15	**Total**	**201**	**2500**	
	Even gill net	4 (98)	1181	
	Odd gill net	2 (93)	1121	
	Roe on kelp	0 (10)	198	44 (product)
2015-16	**Total**	**183**	**834**	
	Even gill net	19 (90)	391	
	Odd gill net	20 (83)	360	
	Roe on kelp	0 (10)	83	19 (product)
2016-17	**Total**	**198**	**834**	
	Even gill net	68 (90)	391	
	Odd gill net	70 (83)	360	
	Roe on kelp	0 (10)	83	19 (product)
2017-18	**Total**	**201**	**834**	
	Even gill net	4 (84)	385	
	Odd gill net	2 (80)	366	
	Roe on kelp	0 (9)	83	19 (product)

Appendix K History of Round Haul Elimination

Synopsis of Herring Round Haul Conversion Issue - Its Developmental History, Analysis of the Round Haul Association's 1995 Proposal, And Pertinent Management Issues

I. Developmental History of the Conversion

The conversion of round haul permits to gill net permits in the San Francisco Bay Pacific herring fishery was adopted by the California Fish and Game Commission (Commission) in August 1994 and implemented by the Office of Administrative Law in September 1994, following a rather lengthy developmental history. The regulation provides for voluntary transfer to gill net gear with a multi-year series of decreasing incentives, followed by a mandatory conversion of remaining round haul permits in 1998 (five fishing seasons after regulation implementation). Voluntary conversion to a special gill net permit authorizes the permittee to fish for two gill net quotas for as long as the permit is held by the current permittee. The following synopsis explains the State's actions on this issue and demonstrates that ample opportunity was provided for public input and joint development of this regulation.

The California State Legislature gave the California Fish and Game Commission management authority for the Pacific herring fishery in 1973 (Fish and Game Code Section 8550). Five round haul permittees were the first participants at the inception of the roe herring fishery in San Francisco Bay in 1972, with fleet size peaking at 66 round haul permits in 1976-77. Gill nets were subsequently authorized for use in the herring fishery in 1974, and both gear types have been active participants since then. Beginning in 1977, the Commission has authorized the exchange of round haul permits for gill net permits.

The Commission began the phase-out of round haul permits in the 1979-80 season, by deciding that no new round haul permits would be issued in the future for San Francisco Bay. (The Commission had already prohibited the use of round haul gear in Tomales Bay in the 1977-78 season, largely due to public sentiment). The planned gradual reduction of the round haul fleet by attrition was hindered by the 1989 action by the California State Legislature to allow the transfer (sale) of herring permits to qualified applicants. Previously, herring permits could only be transferred to partners, heirs, or siblings. Consequently, the round haul fleet stabilized at 42 permittees (of which, ten are presently fishing, instead, in the herring eggs-on-kelp fishery). Currently, 374 gill net, 39 round haul, and 3 "CH", or converted round haul, permits are issued for San Francisco Bay roe herring.

As cited above, the Commission had expressed its intent to create a gill net-only roe herring fishery in 1979. Fishing industry and scientists' concerns about long-term improvements to the fishery and resource status, and the lack of round haul permit attrition because of permit transferability prompted the Department in 1992 to initiate a public dialogue on this subject.

Department managers have a long notable history of "partnership" with the herring industry, seeking input through the Director's Herring Advisory Committee (DHAC), formal public hearings, and informal town hall meetings. The Department continued this policy, requesting guidance from herring fishery members at the very earliest stages of development of a round haul conversion proposal. Unfortunately, members of the herring round haul industry only provided few general comments. In the ensuing months leading to regulation adoption in August 1994, Department staff received **no** response other than several phone calls by permittees voicing general opposition to any actions. The following chronology lists the public meetings at which this subject was discussed, and individuals could provide input.

March 17, 1992 - Director's Herring Advisory Committee Meeting, Belmont.

March 16, 1993 - Director's Herring Advisory Committee Meeting, Belmont.

April 5, 1993 - Public Meeting on Pacific Herring Fishery, San Rafael.

April 16, 1993 - Round Haul Fishermen's Meeting, Youth Center, Dennis the Menace Park, Monterey.

August 23, 1993 - Fish and Game Commission Public Meeting, Sacramento.

March 21, 1994 - Director's Herring Advisory Committee Meeting, San Francisco.

April 11, 1994 - Public Meeting on Pacific Herring Fishery, San Rafael.

June 1994. The informative digest (listing proposed regulation changes, including the round haul conversion) of the STATEMENT OF PURPOSE FOR REGULATORY ACTION was mailed to all herring permittees by the Commission.

August 5, 1994 - Fish and Game Commission Public Meeting, San Luis Obispo.

August 26, 1994 - Fish and Game Commission Public Meeting, South Lake Tahoe.

The adopted herring regulations implementing the round haul permit conversion represent the culmination of a carefully considered process of analyses on the biological, social and economic effects of the transition to an all-gill net herring fishery in San Francisco Bay and a concerted effort to work with the herring industry. The phase-in of such a conversion over a five-year period is intended to provide a planning horizon to permittees and to reduce the short-term economic dislocation that some individuals may suffer during this transition.

II. Department Comments on 1995 Proposal of San Francisco Round Haul Association

The Department has reviewed the Round Haul Association's proposal and finds the proposed regulatory measures to have minimal benefits regarding the management concerns previously identified by the Commission and the Department. This proposal ignores several of the principal reasons for the conversion, including longstanding Commission policy and fishery yield analyses, and offers critiques of four of the Department's original concerns regarding round haul fishing for herring. The Department has the following brief comments to the four issues identified in the Round Haul Association proposal.

1) Wrap-and-Release Mortality The Department agrees that immediate or latent mortality to herring concentrated in a round haul net and subsequently released has not been quantified. However, anecdotal comparisons of the Monterey sardine fishery, and its daily capture and release of thousands of tons of sardines, and the San Francisco herring fishery are not appropriate. Pacific herring do not have swim bladders, thus will generally sink when dead, except for spawned-out herring which will float. It seems unlikely that dead herring would wash ashore and accumulate due to strong tidal currents in the Bay or that complaints would be registered. The Department is unaware of any studies on wrap-and-release mortality, for other Pacific herring round haul fisheries on the west coast are very brief with little opportunity for "test" net sets.

2) Differing Age Composition of Round Haul vs. Gill Net Catches As outlined in the original conversion analysis, the size and age compositions of round haul and gill net catches have always been very different (See below and Figures 1,2, and 3). The comment that 2- and 3-year-old herring composed less than 2% of the round haul catch recently is spurious. In the three herring seasons since the Department's analysis, the differential harvesting characteristics of the gears remain. Additionally, fishing has negligible or little influence on the recent increase in numbers of 2-year-olds in the population which is generally attributed to favorable environmental conditions.

3) Round Haul Gear Effects on Herring Behavior This issue was originally raised by the Department as a minor aspect of round haul fishing. The Department has never alleged that round haul nets "dam or impede tidal influences". The alleged disruption of herring schooling behavior was merely cited as an often-repeated claim by gill net fishermen which has not been substantiated by Department staff.

4) Vessel Traffic Disruptions The Department agrees that potential obstruction of vessel traffic by round haul vessels while fishing has historically not been an area of concern.

Round Haul Association Management Proposal The Association's proposal appears to be a return to pre-conversion regulations, with two modifications. First, shortening the herring season by ten days will not buffer fluctuations in year class strength, as alleged, nor will it have a demonstrable effect on fishery practices. Round haul permittees are primarily regulated by individual catch quotas, and little herring spawning (and corresponding fishing effort) has taken place in the last ten days of a season (early March). For example, during seven of the last ten years **no** round haul landings occurred at all in the last ten days of a season, and in the remaining three seasons, landings in a season's last ten days only ranged from 1 to 21 tons (<1 to 1% of total landings).

Second, it is unclear to the Department what incidental gear conflicts are to be eliminated, as stated in the industry proposal, by the proposed 8% reduction in the length of an individual net from 240 to 220 fathoms. The proposed reduction in fishing power may reduce individual catch volumes, but it is the non-selective nature of a round haul net itself that is responsible in large part for the size and age composition of herring catches.

III. Management Issues Identified in Original Department Conversion Proposal

The size and age composition of herring catches by round haul and 2 1/8-inch gill nets in the San Francisco Bay fishery are very different (Figure 1). Ages two, three and four herring are only partially vulnerable to gill nets in San Francisco Bay and are completely vulnerable (recruited) to the fishery at age five (Figure 2). In contrast, herring are completely vulnerable (recruited) to round haul nets at age two; and two-, three- and four-year-old herring dominate round haul catches (Figure 3). The two gear types are thus differentially harvesting the various age classes in the population.

1) Wrap-and-Release Mortality. An additional and unquantifiable mortality of herring has occurred in the fishery

1) **Wrap-and-Release Mortality.** An additional and unquantifiable mortality of herring has occurred in the fishery due to the practice of wrap-and-release of inferior-quality roe herring by round haul vessels. The discard of less desirable fish, whether from small size, low roe count, poor condition, in order to retain higher-valued fish is a practice called "high-grading". Regulatory efforts to halt this practice have had mixed success. The prohibition on this activity is largely unenforceable at night and is extremely hard to enforce at other times, unless an enforcement officer can observe and subsequently document that the discarded, or released, fish were in fact herring. This has proven to be extremely difficult in practice. Wildlife Protection staff have been told by prosecutors that an observer is needed on board each vessel to determine intent to discard herring and to sample fish within the net in order to successfully enforce this regulation. As a result, the fleet itself must voluntarily terminate this practice; but as long as a price differential exists for higher roe-count herring, wrapping-and releasing of inferior-grade herring will probably occur. Conversion to gill net-only fishing would greatly reduce this "high-grading" practice.

2) **Egg Production-per-Recruit Analysis.** Egg production-per-recruit analysis indicated a substantial increase in population egg production as a result of a shift in recruitment from age two, the entry age into the round haul fishery, to ages three and four - the ages of first entry into the gill net fishery. (Age-three herring are only partially catchable with the present 2 1/8 inch gill net mesh size). At the target harvest rate of 15% of the stock, a 16% gain in egg production would result from a shift in recruitment to age three and a 31% gain by deferring recruitment to age four (Figure 4). Although the relationship between the parent population size and the size of an eventual recruiting year class of fish is unknown for herring, the calculated increase in the population's egg production (due to the increased biomass of older, more fecund herring) would provide an additional measure of safety to buffer oscillations in year class strength.

3) **Round Haul Gear Effects on Herring Behavior.** Herring fishermen have alleged that the elimination of the use of round haul gear would reduce the disruptive effects of the gear on the pre-spawning, schooling behavior of herring in the Bay. Department staff have not attempted to substantiate this claim of a behavioral effect; it was included here because of repeated contentions by the gill net fleet of such an impact. The veracity of their concerns and the impact of disrupted pre-spawning behavior are unknown.

4) **Weight Yield Per Recruit.** A standard analysis of yield in weight of herring per recruit to the population predicted lower yields by a shift in the age of recruitment to the fishery from

age two to ages three and four. In other words, an overall lower catch quota could result from a switch to an all-gill net roe fishery. At the target harvest rate of 15%, calculated weight yields would decline by 5 to 23% (Figure 5); but, given that only one-third of any annual quota is taken with round haul gear presently, this catch reduction would apply to only that part of the overall quota.

5) Roe Yield Per Recruit. Yield in terms of total weight of roe from the fishery would increase slightly by shifting recruitment to age three and decrease by as much as 13% by delaying recruitment to age four (Figure 6). An overall decrease in the tonnage of roe landed would probably be the expected outcome from conversion to an all-gill net fleet. The overall weight of roe may be less, according to this analysis, but actual roe counts (per ton, or per landing) would be higher. The quality of the resulting catch would be improved.

Social and Economic Aspects of the Proposal

1) Gear Conflicts. Gear conflicts between gill netters and round haulers would be eliminated. Historically, set gill nets and round haul gear have conflicted, particularly when spawning is underway or when herring are concentrated in small areas of the Bay.

2) Test Boat Program. The test boat program for the round haul fishery has reduced the prevalence of testing and releasing of low roe count fish, but the practice continues, according to Wildlife Protection staff. The inability to effectively enforce this regulation has diminished respect for other herring regulations, in particular, the gill net mesh regulation.

3) Individual Boat Quotas. Beginning with the 1981-82 season the total round haul quota was divided equally among the permittees and became individual allocations or quotas. These quotas ease competition among round haul vessels and increase the economic value of the catch, as permittees become more selective in their retained catch. But this selectivity encourages "high grading" of herring through wrap-and-release with resultant discard mortality of inferior fish. The fishing power of a seine or lampara net is considerable, and the mortality of many tons of herring at a time may occur due to wrap-and-release practices. Individual boat quotas are not routinely employed with the gill net fleet except occasionally to slow the pace of the fishery.

4) Fishing Power of Round Haul Nets. The catching power or capability of a herring seine or lampara net can greatly exceed a vessel quota at low quota levels. This may encourage the discard of surplus catch to ensure the attainment of an individual quota or may encourage the capture and landing of herring in excess of an individual quota. Anecdotal evidence suggests that such practices are commonplace, but documenting and citing permittees for such offenses is very difficult. The under-reporting of landings is also a problem with the gill net fleet, but the harvesting capacity of a gill net is considerably less than that of a round haul net.

5) Economic Value of Round Haul versus Gill Net Catches. The ex-vessel prices of round haul-caught herring are typically 33 to 60% less than an equivalent amount of gill net-caught herring (five-year averages were $631 and $1450 per ton for round haul and gill net catches), because gill net-caught herring typically are larger, with larger roe sacs and higher roe yields.

Appendix L Mesh Size Changes and Rationale

Gill net Mesh Size in the California Herring Fisheries
Historical Background Notes – Detailed Notes

This information is a summary of mesh size and mesh measurement changes to regulations for herring gill net fisheries in California from the 1976-77 season to 2003-04. The information covers all fisheries, Crescent City, Humboldt Bay, Tomales Bay and San Francisco Bay. In summary, none of the mesh size changes are based on experimental data or study conducted prior to regulatory change. All of the changes to the mesh size are on the minimum mesh allowed; the maximum has remained unchanged since a mesh size range was specified for the 1976-77 season. The maximum mesh size was stated, originally, in Fish and Game Code, and was most likely the source of establishing the limit; there is no reference in the files as to the rationale for a maximum mesh size. Many of the mesh size changes were at the request of the industry. The changes to the method of mesh measurement have been at the request of industry, Department enforcement and Department biologists.

The references for this information are the Director's Herring Advisory Committee (DHAC) meeting minutes and the Section 163, Title 14 CCR regulatory documents (Pre-publication of Notice/Initial Statement of Reasons, Pre-Adoption Notice and Final Document and regulations) unless otherwise noted. Information in quotation marks is a direct quote; all other information is paraphrased from the document referenced for that year. Personal names have been removed and replaced with "Industry", "Department staff", or "Department enforcement personnel" where appropriate. Information on regulations under each of the bulleted sections comes from Section 163 of Title 14 unless otherwise noted. Information under the section "Notes from the DHAC meeting minutes" is taken directly from the DHAC meeting minutes on file for that year. Information on regulatory changes is from DHAC meeting minutes and regulatory documents. See table at the end of this section for documents used for each year.

- 1975-76 Season. Draft regulations for this season are on file. There is no reference to minimum or maximum mesh size.

- 1976-77 Season. Mesh size regulations: The length of meshes of any gill net shall not be less than 2 inches or greater than 2 ½ inches. (Section 163, Title 14, CCR) The upper limit of 2 ½ inches for districts 11, 12 and 13 was stated in §8688 of the Fish and Game Code. "These changes will alleviate the concerns expressed by the commercial fishermen regarding the use of gill nets to take herring while still affording adequate protections to the herring resource as well as important sport species (October 6, 1976 letter from the Director to the Commission). The October 6, 1976 letter specifies a minimum of 1 ½ inches; a 2 inch minimum was specified in the regulations apparently as a result of earlier industry input and correspondence dated December 15, 1976.

- 1980-81 Season. Mesh size regulations: Provision for fresh fish mesh size of no more than 1 ¾ inches and distinction between roe fishery and fresh fish fishery. (Section 163, Title 14, CCR)

Notes from the March 17,1981 DHAC meeting minutes:

(Net measurement and mesh size) A survey questionnaire was distributed to gill net permittees prompted by the differences in production which resulted form the use of various mesh sizes. A DHAC member stated that many gill netters switched to smaller (2 inch) mesh nets this year because of the abundance of smaller fish and there was concern that extensive use of 2 inch mesh would impact the resource. Department staff presented the following results from the fish samples collected during the season:

Mesh size (inches)	Average Roe Recovery (Percent)	Percent Females	Ave. Length (cm)	Age Composition
2 ¼	18.1	75	20	93% of samples age 4-6
2 1/8	17.3	70	19.5	93% of samples age 3-5
2	14	58	?	84% of samples age 3-4

A lengthy discussion followed on the issue of minimum mesh size. It was decided to recommend 2 ¼ inch minimum mesh size for San Francisco Bay, Humboldt Bay and Crescent City and a 2 1/8 inch minimum mesh size for Tomales Bay, with a provision that would allow the Director to reduce the minimum mesh size to 2 inches after February1 if warranted.

- 1981-82 Season. Mesh size regulation unchanged. However in the August 12, 1981 Pre-Adoption Statement under “Summary of primary considerations raised in opposition to the proposed action and reason(s) for rejecting those considerations” in response to item 3, “Restrict the length of meshes of gill nets to 2 ¼ - 2 ½ inches”, the response reads, “Current regulations provide that the meshes of gill nets shall not be less than 2 inches or greater than 2 ½ inches. This request is based on a desire, by some fishermen and processors, to restrict the catch to larger herring which are economically more valuable in the marketplace. However, there is no biological justification for implementing more restrictive mesh size regulations and such considerations are beyond the scope and authority of the Department.”

File Notes: There are two interesting letters from industry that consider the option of increasing the minimum mesh size from 2 to 2 ¼ inches. There is a lot more information in both of these letters; here are excerpts from both:

“As you know, although 2 to 2 ½ inch has been the legal range of mesh size, the 2 ¼ inch mesh has been used by approximately 90 percent of the fishermen. This mesh size produces primarily five year olds and up herring and the best roe recovery available.” “The problems with the 2 inch mesh are several: 1. It harvests stocks down into the three-year age class. This defeats the idea of harvest by gill net to take mature, older age herring while allowing younger stocks to spawn and return to sea.” DHAC member, letter to the Director dated July 19, 1981.

“As a resource held as a public trust, the department should look beyond merely protecting the resource and assure that the maximum value is gained from this resource.” “Without the department making clear its intent soon on mesh sizes, there will be a mad dash for nets with fishermen being uncertain of what mesh size to purchase. The industry, by itself, cannot regulate mesh sizes, since there is one overall quota and each fisherman must work to catch as much as possible.” Industry Representative, letter to the Director dated July 10, 1981.

- 1982-83 Season. Mesh size regulations: In Tomales and Bodega Bay the length of the meshes of any gill net used in the roe fishery shall not be less than 2 inches or greater than 2 ½ inches. In all other permit areas the length of the meshes of any gill net used in the roe fishery shall not be less than 2 1/4 inches or greater than 2 ½ inches from November 28 through January 14. On or after such date the Director may, if the established fishing quotas are not filled and such action will not impact the herring resource, authorize the use of 2 1/8 inch or 2 inch minimum mesh for gill nets used in the roe fishery. (Section 163, Title 14, CCR)

Notes from the March 29, 1983 DHAC meeting minutes:

(Net measurement and mesh size) “A general discussion followed regarding minimum mesh sizes and current measuring techniques used by the Department’s enforcement personnel in determining mesh size. It was noted that present methods were not adequate for the highly elastic small mesh monofilament webbing used for herring gill nets. As a result, some fishermen were actually using nets which were constructed of webbing less than minimum size, although legal when measure by the standard means. The director stated that the Department would develop an alternative measuring method for herring nets which would ensure compliance with the minimum mesh requirements established by the Commission." (New paragraph) " It was also suggested, and agreed upon, that the minimum mesh size for gill nets used in the XH fishery would remain at 2 ¼ inches, with a minimum of 2 1/8 inch mesh provided for beginning with the opening of the regular season on January 2, 1984." (DHAC Meeting Minutes, March 29, 1983)

Complaints were registered, by enforcement and industry, of the use of undersize webbing and the possible development of a standard measurement device using knot to knot measurement. (April 14, 1983 Herring (Public) Meeting Minutes/Notes)

- 1983-84 Season. Mesh size and measurement regulations: In Tomales and Bodega Bay the length of the meshes of any gill net used in the roe fishery shall not be less than 2 inches or greater than 2 ½ inches. In all other permit areas the length of the meshes of any gill net used in the roe fishery shall not be less than 2 1/4 inches or greater than 2 ½ inches from November 27 through December 16. From January 2 through March 30 the length of the meshes of any gill net used in the roe fishery shall not be less than 2 1/8 or greater than 2 ½ inches. The meshes of any gill net used by the fresh fish permittees shall not be greater than 1 ¾ inches.
  Subsection (f)(2)(G) was added to read:
  (G) Mesh size of gill nets authorized to take herring will be determined by the following method: (1) Suspend a minimum of eleven meshes between a fixed point and a maximum of one pound weight. (2) At least 50% of the meshes, when measured between the knots of or inside the points at which the meshes are joined of each mesh, using a standard stainless steel wedge of appropriate gauge without force, shall not be less than the mesh size of nets authorized pursuant to subsection (f)(2)(B) of these regulations. (3) Beach nets may only be used in Tomales Bay. No permittee may fish more than 75 fathoms of beach net. (Section 163, Title 14, CCR)

Notes from the March 26, 1984 DHAC meeting minutes:

(Net measurement and mesh size) Industry brought up the issue of undersized nets used in the fishery and the measuring method and there was a general discussion as to whether it was appropriate, or necessary, to amend or change the existing regulations.

Industry also discussed the questionnaire sent out to all San Francisco Bay gill net permittees, and the responses (43) received to date:

Minimum mesh size	2 ¼ inch	2 1/8 inch	2 inch
December (XH)	56%	37%	7%
January - March	21%	62%	17%
Individual Quota (bag limit)	Yes = 67%	No = 33%	

One DHAC member recommended a minimum mesh size of 2 1/8 inches for the entire season, including the XH fishery. A general discussion followed on mesh size, manufacturer's specifications, lead time when changing mesh size regulation, etc. The general consensus of the group was to retain the current regulations.

Subsequent results of this questionnaire (183 responses/386 questionnaires sent = 47%. This is broken down into December and Odd/Even Platoon responses:

XH returned 54 responses

Minimum mesh size	2 ¼ inch	2 1/8 inch	2 inch
December (XH)	28%	54%	19%
January - March	9%	52%	17%

Odd/Even returned 129 responses

Minimum mesh size	2 ¼ inch	2 1/8 inch	2 inch
December (XH)	50%	29%	7%
January - March	11%	63%	20%

As a result of this questionnaire, the Department amended proposals for the 1984-85 season regulations to provide for the use of 2 1/8 inch minimum mesh for San Francisco Bay gill nets used in the December (XH) fishery. “The majority of permittees responding to the latest herring questionnaire clearly supported this proposal which will provide uniform mesh size requirements for al San Francisco Bay gill nets used in the herring-roe fishery.” (Letter from the Director to the DHAC members dated July 12, 1984)

In a letter dated July 3, 1984, Department biologists expressed the opinion that the minimum mesh size for the December fishery remain the same and provided rationale and catch curves from variable mesh gill nets and commercial catch in explanation.

- 1984-85 Season. Mesh size regulations: In Tomales and Bodega Bay the length of the meshes of any gill net used in the roe fishery shall not be less than 2 inches or greater than 2 ½ inches. In all other permit areas the length of the meshes of any gill net used <u>or possessed</u> in the roe fishery shall not be less than <u>2 1/8</u> inches or greater than 2 ½ inches. The meshes of any gill net used by the fresh fish permittees shall not be greater than 1 ¾ inches (Section 163, Title 14, CCR)

Notes from the March 19, 1985 DHAC meeting minutes:

(Net measurement and mesh size) There were no complaints about mesh size noted in the DHAC meeting minutes. Department staff noted the higher proportion of males and 3 year old fish in the December gill net catches were a reflection of the use of smaller mesh gear.

An increase to the fresh fishery mesh size from 1 ¾ to 2 inches was recommended by industry based on the difficulty of obtaining 1 ¾ inch mesh from local dealers and the use of 2 inch mesh would allow fresh fish permittees the opportunity to take larger fish for marketing purposes. “The Department has determined that the use of 2 inch mesh will not result in any adverse impact to the resource, and has proposed such an amendment in the 1985-85 herring regulations.” (Pre-Adoption Notice, July 8, 1985)

- 1985-86 Season. Mesh size regulations: In Tomales and Bodega Bay the length of the meshes of any gill net used in the roe fishery shall not be less than 2 inches or greater than 2 ½ inches. In all other permit areas the length of the meshes of any gill net used <u>or possessed</u> in the roe fishery shall not be less than <u>2 1/8</u> inches or greater than 2 ½ inches. The meshes of any gill net used by the fresh fish permittees shall not be greater than 2 inches (Section 163, Title 14, CCR)

Notes from the March 4, 1986 DHAC meeting minutes:

(Net measurement and mesh size) A proposal was made by Department enforcement personnel to remove the language in subsections (f)(2)(G)(1) and (2) of Section 163, Title 14, CCR because the “method of measurement which is impractical and in conflict with Fish and Game Code Section 8602. Fish and Game Code Section 8602 has been upheld in court (Pennisi vs. California) and I see no benefit to the measurement described in Section 163.” (Memorandum dated March 4, 1986 from Enforcement personnel to the Department) Subsection (f)(2)(G)(3) remained in the regulations under subsection (f)(3). This language was removed for the 1986-87 season.

A DHAC member proposed to limit gill nets to 2 ¼ inch mesh size only in the Humboldt Bay fishery.

- 1986-87 Season. No changes to mesh size or mesh measurement methods in regulation.

Notes from the March 4, 1987 DHAC meeting minutes:

(Net measurement and mesh size) Department enforcement noted that following the seizure of an undersized net, a number of abandoned nets with undersized mesh were found on the docks the following day.

A DHAC member proposed establishing the minimum legal mesh size at 2 ¼ inches in Humboldt Bay and Crescent City, because essentially all existing permittees are using 2 ¼ inch mesh nets at the present time and they wish to insure that the quality of the fish remains the same in the future should new, or additional, permittees enter the fishery.

- 1987-88 Season. Mesh size regulations: In Tomales and Bodega Bays the length of the meshes of any gill net used or possessed in the roe fishery shall not be less than 2 inches or greater than 2 ½ inches. In Humboldt Bay and Crescent City Harbor the length of the meshes of any gill net used or possessed in the roe fishery shall not be less than 2 ¼ inches or greater than 2 ½ inches. In San Francisco Bay the length of the meshes of any gill net used or possessed in the roe fishery shall not be less than 2 1/8 inches or greater than 2 ½ inches. The meshes of any gill net used or possessed by fresh fish permittees shall not be greater than 2 inches. (Section 163, Title 14, CCR)

Notes from the March 25, 1988 DHAC meeting minutes:

(Net measurement and mesh size) Industry noted that "under the present system, 2 inch mesh can easily pass as 2 1/8 inch mesh because of the elasticity of the monofilament webbing".

- 1988-89 Season. No changes to mesh size or mesh measurement methods in regulation.

Notes from the March 20, 1989 DHAC meeting minutes:

(Older fish in catch) "The Department biologist noted that gill net catches were dominated by 4, 5 and 6 – year old fish, similar to the previous season (1987-88). However, it had been expected that the landing would be dominated by 5, 6, and 7 – year old fish. In the biologist's opinion, the fact that they were not is reflective of the need to go to larger mesh gill nets. Also, the landing showed a 50/50 sex ration when it should have been 60/40 (females to males) or higher. This is further evidence of the need for larger mesh gill nets." The minutes also note an abundance of 3 and 4 – year old fish in the Tomales Bay catch "reflective of the need for larger mesh gill nets".

(Net measurement and mesh size) "He (Department enforcement) noted that the elasticity of today's net material made it possible for 2 inch nets to easily meet the standards of a 2 ½ in net gauge." "(Department enforcement) said that the fishermen's concern is that next year some individual will use less than 2 inch mesh". "In his (DHAC member) opinion, the gill net mesh size is critical and 2 1/8 inch mesh is the absolute minimum that should ever be used. He favored a previous regulation of several years ago that require 2 ¼ inch minimum mesh in December through the first two weeks in January. After that date 2 1/8 inch mesh was allowed. He stated that much of the fleet was using 2 1/16 inch mesh and some were even using 2 inch mesh. He believes the Department need to change the "measuring" law and suggests that legislation be introduced to do so."

(Recommendations for 1989-90) "The first recommendation was to increase the minimum mesh size for gill nets to 2 ¼ inch, with at least #7 monofilament webbing, beginning with the 1990-91 season."

Two options were provided to the Commission to address the issue of the decrease in average size and quality of fish landed in the herring fishery ("apparently due to the increased use of smaller-mesh nets"). Option One: An increase in the gill net minimum mesh and twine size to 2 ¼ inch, using No. 7 monofilament for San Francisco Bay and 2 1/8, using No. 7 monofilament for Tomales-Bodega Bay, beginning with the 1990-91 season. Also, a gill net closure in south San Francisco Bay (i.e. "BANZAI") beginning with the 1989-90 season. Option Two: Individual gill net quota of 17 tons per permittee in San Francisco Bay. This option also would include provisions to restrict the number of herring buying locations to four areas (Sausalito, Oakland, Pier 33, and Pier 45 – San Francisco), prohibit the unloading of fish between 10 p.m. and 6 a.m., and shortening the overall fishing season by two weeks. It appears that neither of these options was chosen, and there is no justification reflected in the notes.

- 1989-90 Season. No changes to mesh size or mesh measurement methods in regulation. Apparently a new method of measuring mesh size was implemented, but is not reflected in the regulations or in the DHAC meeting minutes (Pre-Adoption Notice dated July 11,1990).

Notes from the March 14, 1990 DHAC meeting minutes:

(Net measurement and mesh size) The Department attributed an increase in roe count in the XH fishery to better compliance with the 2 1/8 inch mesh. A DHAC member noted that although the average roe counts were up during the past season, he attributed it to an influx of larger fish, rather than better enforcement of the minimum mesh size. He (DHAC member) believed that there was continue use of 2 inch mesh; Department enforcement personnel stated that many nets had been checked but there were no violations for undersize mesh. Apparently 2 1/16 inch multi-strand mesh would pass the measuring test. There was some discussion and some disagreement among industry members in attendance at the meeting as to whether the measuring technique was accurate and/or effective at eliminating the use of 2 inch mesh. There was no resolution on the matter reflected in the notes.

(Recommendations for 1990-91) Industry proposal to reduce all quotas by 30% and increase the minimum mesh size to 2 3/16 inches.

- 1990-91 Season. No changes to mesh size or mesh measurement methods in regulation. A letter dated October 24, 1990 states that "at the October 5, 1990 Fish and Game Commission meeting the Commission chose not to take any action on the proposed herring regulations for the 1990-91 season. <u>Therefore, the existing herring regulations that were in effect for the 1989-90 fishing season shall remain in effect and shall govern the fishery during the 1990-91 season</u>. The Commission chose this course of action because of threatened legal action based on a perceived failure to comply with California Environmental Quality Act (CEQA) requirements as regards the herring fishery."

Notes from the March 21, 1991 DHAC meeting minutes:

(Net measurement and mesh size) "Department enforcement personnel stated that enforcement had difficulty prosecuting cases involving the measuring of gill net mesh using the plastic "credit card" given to permittees. A Department enforcement officer demonstrated a measuring device that he felt would withstand a court challenge because it follows guidelines set forth by the Pennisi decision. He stated that near the end of the season, every net he measured (22) using this device was illegal. He also recommended restricting net to #7 twine and prohibiting the use of multi-strand nets. A Department biologist stated that the method of measuring mesh evolved from the trawl fishery, with four meshes stacked together. He added that the plastic card should work. An industry member reiterated the Department biologist's statement regarding the measuring of four meshes and wondered why the size of mesh was restricted for gill nets and not for round haul nets. Department enforcement personnel noted that the Alameda courts threw out cases involving illegal small mesh measured using the plastic cards. The criteria, bending of the card, were considered subjective." A discussion of multi-strand and single-strand gill nets followed with no resolution to the issue.

(Recommendations for 1991-92) In the July 11, 1990 Pre-Adoption statement, in response to an industry proposal for an increase in the minimum mesh size for gill nets from 2 1/8 inch to 2 3/16 inch, the Department responded that due to a new technique for measuring mesh, instituted prior to the 1989-90 season, which accounted for the elasticity of the net material, and an increase in the average size of the fish landed during the past season, there did not appear to be significant justification or support to increase the minimum mesh size at the present time.

A DHAC member proposed a two-week later opening date, bag limits, and that drift nets be allowed in Humboldt Bay and Crescent City.

- 1991-92 Season. No changes to mesh size or mesh measurement methods in regulation. The closure of the 'Banzai' area to gill nets from November 28 through February 14 is included in the regulations.

Notes from the March 17, 1992 DHAC meeting minutes:

(Net measurement and mesh size) "Department enforcement personnel stated that enforcement intended to look into a different net measuring procedure for next season in order to reduce the use of undersized mesh. The procedure that we are looking at involves the use of a weight and would be similar to the method employed in the State of Alaska." There was a short discussion of this method and the fact that enforcement was unable to make any cases involving mesh size with the current method. Following another lengthy discussion an industry member volunteered to work with enforcement and attempt to find a solution to the problem.

(Recommendations for 1992-93) "Enforcement to investigate potential alternative net measuring procedures."

"Increase the minimum mesh size for gill nets used in the Tomales Bay fishery from 2 inches to 2 1/8 inches." This proposal, along with a reduction in the amount of fishing gear allowed, "will reduce the potential take of younger, smaller fish, while a reduction in the amount of fishing gear will minimize potential disruption of herring schools and spawning activities." The Department and the herring industry agreed on this proposal. (June 4, 1992 Statement of Purpose for Regulatory Action)

- 1992-93 Season. Mesh size regulations: The minimum mesh size in Tomales and Bodega Bays was changed to 2 1/8 inches. No other changes to mesh size or mesh measurement methods in regulation in any other bays.

Notes from the March 16, 1993 DHAC meeting minutes:

(Net measurement and mesh size) Enforcement reviewed the problems associated with the measuring of small mesh gill nets. There was discussion that the courts had indicated that specific standards such as twine size needed to be established. Several industry members noted that it would take at least one year's notice for the manufacturers to supply new nets. The Department Deputy Chief stated that if the minimum mesh size was increased to 2 ¼ then those fishermen using the smallest nets would have to increase the minimum mesh that they used (in order to comply), and although it would resolve the problem it would improve the situation until such time that industry standards could be established and implemented. There was no resolution on this matter reflected in the notes.

(Recommendations for 1993-94) The Department recommended a 26,000 ton baseline spawn escapement as a threshold by which to open and close the fishery, which is equal to 50% of the average escapement value estimated over the 12 year period from the 1980-81 season through the 1991-92 season.

The allowance of beach seine gear in Tomales and Bodega Bays was removed because it was no longer necessary (no more beach seine permittees). (May 28, 1993 Statement of Purpose for Regulatory Action)

⇒ Note: Department staff introduced the proposal to encourage the transfer of round haul permits to the gill net fishery.

- 1993-94 Season. No changes to mesh size or mesh measurement methods in regulation.

Notes from the DHAC Meeting minutes:

There were no comments specific to problems with mesh size or measurement. There was a comment from industry that although the Commission had requested the conversion to an all gill net fishery in 1979, the Commission now consisted of entirely different members and they may not want the conversion. It was reiterated that the Commission had reaffirmed its position in August, 1993 when it directed the Department Deputy Chief, representing the Department, to submit a conversion proposal for consideration in 1994.

A proposal to amend Subsection 163 (b)(2) to provide for the voluntary conversion from round haul gear to gill net hear, followed by a mandatory conversion after October 2, 1998 for all remaining round haul permits was included in the Statement of Purpose for Regulatory Action.

- 1994-95 Season. No changes to mesh size or mesh measurement methods in regulation.

There were no comments specific to problems with mesh size or measurement, and there were no proposed changes to regulations specific to mesh size or measurement.

- 1995-96 Season. No changes to mesh size or mesh measurement methods in regulation.

Notes from the March 14, 1996 DHAC meeting minutes:

(Net measurement and mesh size) "Advisors were informed that the Department will vigorously enforce mesh size regulations, as a result of widespread use of undersized mesh and better net measuring procedures. Department staff spoke of salvaging a herring net, obviously in recent use, from a dumpster outside a herring buying stations. This problem is not one of a very minor decrease under the 2 1/8 minimum side, but of substantially smaller mesh. Advisors asked that the Department settle on a new measuring procedure as soon as possible and the measuring tools be easily obtained by the industry to ensure that they are ordering legal gear."

(Recommendations for 1996-97) Specify the method for measuring mesh size of herring gill nets. Following the receipt of public testimony and discussion of the regulations, the Commission modified subsection 163 (f)(2)(B) to include provisions that nets be measured "when wet after use," and that a three percent tolerance mesh measurement be allowed for the 1996-97 season only in Tomales and San Francisco bays. Language was also added to provide for research on mesh size.

The section language reads: "Length of the mesh shall be the average length of any series of 10 consecutive meshes measured from the inside of the first knot and including the last knot when wet after us; the 10 meshes, when being measured, shall be an integral part of the net as hung and measured perpendicular to the selvages; measurements shall be make by means of a metal tape measure while 10 meshes are suspended vertically from a single peg or nail, under one-pound weight. In Humboldt Bay and Crescent City Harbor, the length of any series of 10 consecutive meshes as determined by the above specifications shall not be les than 22 ½ inches or greater than 25 inches. In Tomales and San Francisco bays, the length of any series of 10 consecutive meshes as determined by the above specifications shall not be less than 21 ¼ inches or greater than 25 inches. For the 1996-97 season only, in Tomales and

San Francisco bays, a 3 percent tolerance will be allowed in the mesh measurement; thus, the length of any series of 10 consecutive meshes as determined by the above specifications shall not be less than 20 5/8 inches or greater than 25 ¾ inches."

There was considerable public comment during the regulatory process regarding the round-haul conversion. The following are some excerpts from the September 13, 1996 Final Statement of Reasons as to the biological benefits of the conversion.

"Two benefits are derived by reducing the catch of two and three-year-old herring: the reproductive potential of the population is increased, and management is improved because year-class strength (i.e., the size of an age group) can be assessed before that year class enters the fishery. The reproductive potential of the population is increased when young fish have the opportunity to spawn. Egg production-per-recruit analysis indicates a substantial increase in population egg production as a result of a shift in recruitment to the fishery (i.e., the age or size at which fish are first catchable by the fishing gear) from age two (age of recruitment to the round haul fishery) to four (age of recruitment to the gill net fishery).

The second improvement that results from reducing the take of two and three-year-old herring is that it allows managers to better assess the size of an incoming year class before it is fished. We don't know the size of a year class until the fish are three years old, because not all two year olds spawn. Round haul gear fishes on each year class for two seasons before the year-class strength is known. Conversion to a gill net only fishery will give managers a one year planning horizon to adjust harvest levels to protect weak year classes."

- 1996-97 Season. Mesh size and measurement regulations: Mesh measurement method implemented with 3 percent tolerance for one year only. Language was added to provide for three permittees to participate in a Department sponsored mesh size study in San Francisco Bay.

Notes from the March 21, 1997 DHAC meeting minutes:

(Net measurement and mesh size) Many members of the DHAC expressed the desire to have the 3 percent tolerance in measurements continue. One of the concerns expressed was that a net's mesh size varied considerably depending on whether it had been soaked recently or pulled hard. Opinion on net mesh size varied considerably; some spoke of the advantages of taking larger fish while others expressed concern over reduced catch rates. Concern was also expressed over the amount of herring roe that occurred on nets and the influence of mesh size on the rate of occurrence.

The Department was asked if this was still a resource question given current enforcement efforts directed toward detecting small mesh nets. In response, Department staff indicated that the goal was still to reduce the take of 2 and 3 year-old fish. Mesh size below that allowed by regulation does negatively affect the age structure of the catch. The discussion ended with general support for keeping the 3 percent tolerance and no resolution on changes to mesh size regulations.

(Recommendations for 1997-98) It was proposed to clarify that when measuring mesh size, the 10 meshes will not include "guard mesh".

- 1997-98 Season. Mesh size and measurement regulations: End of tolerance in mesh measurement; the length of any series of 10 consecutive meshes shall not be less than 21 ¼ meshes or greater than 25 inches. No other changes to mesh size or to mesh measurement methods in regulation.

Notes from the March 23, 1998 DHAC meeting <u>notes, not minutes:</u>

(Net measurement and mesh size) Concern over the lack of tolerance in mesh measurement was expressed by several DHAC members. Some members wanted the three percent tolerance in mesh measurement, some didn't, some members wanted 2 1/8 inch mesh, some didn't; in the end the discussion turned to proposing a mesh size study.

(Recommendations for 1998-99) There were no proposed changes to mesh size or mesh measurement method.

- 1998-99 Season. The round haul conversion was completed. No other changes to mesh size or mesh measurement in regulation.

Notes from the March 23, 1999 DHAC meeting minutes:

(Net measurement and mesh size) There was much discussion around the method of mesh measurement, and in summary, several industry members were felt that the problem in San Francisco Bay was not necessarily with the mesh size, but with the measurement method. Enforcement noted that although 200-250 nets were measured, only four nets were considered to be sufficiently undersized to warrant a citation and net seizure. In Tomales Bay, it was felt that the mesh size was too large. It was requested by that a mesh study be conducted as soon as possible, and it was agreed that fishermen would be included in a study design.

(Recommendations for 1999-2000) Language was proposed to allow four permittees to participate in a Department sponsored mesh size study in Tomales Bay.

- 1999-2000 Season. Mesh size regulations: Four permittees (designated by the department in writing) participating in department-sponsored research on mesh size in Tomales Bay may use gill nets approved by the department with mesh less than 2 1/8 inches.

⇒ Mesh study conducted in San Francisco Bay using 2 1/16 and 2 1/8 inch mesh. Four permittees (three odd, one special ed.) participated in the study using two-paneled nets, half 2 1/16 inch and half 2 1/8 inch mesh. The total catch for the study was 22 tons. The roe percentage was 13 and 14 percent for 2 1/16 and 1 1/8 inch mesh, respectively. A fish count of 91 and 85 per 10 kg sample of 2 1/16 and 2 1/8 inch mesh, respectively, was also recorded. These data, in general, indicate that smaller mesh catch smaller fish and larger mesh catch larger fish. The data collected represented a relatively small time period (six sampling days during a two week period), and a longer term, i.e. subsequent seasons, would be preferable.

Notes from the March 23, 2000 DHAC meeting minutes:

(Net measurement and mesh size) A Tomales Bay DHAC member expressed concern that they were using the wrong mesh size, and that since the increase in mesh size to 2 1/8 inches they have been unable to catch fish. Department staff explained that Department data indicated that Tomales Bay catch consisted of age four and older fish and that this is the management goal of the Department. The Tomales Bay DHAC member felt that 2 inch mesh would be more appropriate. A San Francisco Bay DHAC member expressed concern over the quantity of spawn seen on the gill nets, belly-caught fish and the length of time it now took to catch the quota. He felt that a mesh size reduction to 2 1/8 inches would address these concerns.

(Recommendations for 2000-01) The length of meshes of any gill net used or possessed in the roe fishery in Tomales Bay for the 2000-01 season only shall be no less than 2 inches or greater than 2 ½ inches. The proposed one-year amendment will allow the Department to evaluate the effect of reduced mesh length on the size and age composition of herring caught in 2 inch mesh gill nets. Preliminary aging of Tomales Bay herring suggested that reduced growth of herring in offshore waters and loss of older fish from the spawning population has resulted in a mean length of herring in the commercial catch below the 5-year average. However, the 1995 and 1996 year-classes are well represented and, by number, comprised more than 50 percent of the spawning population this season.

- 2000-01 Season. Mesh size regulations: Fleet-wide mesh size study conducted in Tomales Bay using a minimum 2 inch and maximum 2 ½ inch mesh.

Notes from the March 20, 2001 DHAC meeting minutes:

(Net measurement and mesh size) There was a brief discussion of the mesh size study in San Francisco Bay. Department staff explained that more data was needed in order to consider any further reduction in the mesh size. A DHAC member proposed contracting one of the herring boats to be used exclusively in the study, rather than having to compete with other gill-netters simultaneously, and he suggested increasing the quota for that boat to attract "high-liners". He also suggested that the Department keep a portion of the proceeds from the sale of product from the higher quota and use it to pay for Departmental research costs. The DHAC members supported this idea and one DHAC member volunteered the use of his boat.

(Recommendations for 2001-02) Amend subsection (f)(2)(B) to specify the size of peg or nail used on certified net measuring devices.

- 2001-02 Season. Mesh size and measurement regulations: Continuation of the fleet-wide mesh size study in Tomales Bay. Clarification of the size of peg and weight used in the measurement of mesh was added to Section 163, subsection (f)(2)(B) to read: …while 10 meshes are suspended vertically under one-pound weight, from a stainless steel peg or nail of no more than 5/32 inch in diameter ~~under on-pound weight~~. A provision was also added to subsection (g)(4)(B) to allow ten tons of the fresh fish quota to be transferred to gill net permittees participating in Department sponsored research.

Notes from the March 27, 2002 DHAC meeting minutes:

(Net measurement and mesh size) There was a discussion of re-initiating the mesh size study in San Francisco Bay for the 2002-03 season. A Department biologist stated that no funding was available for the Department to conduct the study and suggested that the industry form a subcommittee to discuss and form a proposal for a collaborative study with the Department. A DHAC member voiced concern that the mesh size being used could be harming the resource by not catching fish efficiently, i.e. causing latent mortality of the squeezed fish through the net and also increasing the fleet's fishing effort and subsequent disturbance of schools. He also questioned the biological rationale for enforcing the 2 1/8 inch mesh size. Department staff explained that the reason for the 2 1/8 inch mesh is to concentrate the fishing effort on herring in the 4-year and older age classes, and reducing the mesh size could increase the number of two and three year old herring in the commercial catches. Another DHAC member questioned why the data from the mesh size study in Tomales Bay could not be extrapolated for San Francisco Bay and Department staff explained that the Tomales Bay fishery was managed separately form the San Francisco Bay and has always had different environmental conditions and concerns. He detailed these differences, emphasizing the importance that the study be specific to San Francisco Bay and that any changes must be based on localized scientific data.

(Recommendations for 2002-03) Revise the individual quota provisions for permittees participating in a mesh size study in San Francisco Bay to 0.5 percent of the sac roe quota for each platoon to which a permittee is assigned, and increase the maximum number of permittees that may participate in a mesh size study in San Francisco Bay from three to six. Continue the provision to transfer ten tons of the fresh fish quota to gill net permittees participating in the Department sponsored research.

- 2002-03 Season. Mesh size regulations: Continuation of the Tomales Bay mesh size study. Subsection (g)(4)(A) was amended to read: …Each gill net permittee (designated by the department in writing) participating in research sponsored by the department shall be assigned an individual quota equal to 0.5 percent of the season gill net quota per assigned platoon, unless provided for pursuant to subsection (g)(4)(B) of these regulations.

Notes from the March 25 and 26, 2003 DHAC meeting minutes:

(Net measurement and mesh size) The Department discussed development of a model based on historical data rather than conducting a mesh size study, as was discussed at the pre-season DHAC meeting. Several DHAC members expressed concern that the use of 2 1/8 inch mesh in San Francisco was harmful to the resource, i.e. fish were squeezing through the nets and possibly injured or killed in the process. One member suggested that a smaller mesh size will help reduce egging on nets while allowing the fishermen to catch the population that exists. The concern of one DHAC member was that the fishery was not managed for economic viability. Several San Francisco Bay DHAC members noted that they used to use the 2 1/16 inch mesh without any problems belly-catching or scaling fish, but the change (in mesh) took place because of regulatory capabilities. Department enforcement personnel clarified that San Francisco fishermen are actually fishing with nets that are 2 3/32 inch which stretch to be 2 1/8 inch when they are wet. A discussion of the regulatory language ensued and it was agreed the two different interpretations could be drawn from the way the regulations are written, and that they should be clarified to eliminate contradiction.

A change to Title 14 was proposed on behalf of Cal Herring, a herring fishermen's association, to reduce the mesh size to 2 1/16 inch mesh measure dry. A previous Department study examining stretch length after 11-12 hours of soaking was cited as a basis for the dry measure. The stretch study found that the nets would stretch form 3/8 inch to 7/8 inch over ten mesh lengths. Later, other DHAC members expressed that a dry mesh measurement is important for the fishery management.

(Recommendations for 2003-04) Due to several concerns, expressed by the Department, regarding the status of the San Francisco Bay stock two quota options were given to the Fish and Game Commission to consider. Option one, the Department preferred option, was a fishery closure (zero quota). Some of the concerns regarding the status of the stock included a shrinking age class structure (fewer age classes represented in the population), a lack of strong recruitment to the fishery, a decline in catch per unit effort, and several years of below average biomass. The Department had been developing a stock assessment model, Coleraine, to evaluate both the status of the stock and the accuracy of the two survey methods used to estimate biomass. The model results indicated that the stock was at approximately twenty percent of its un-fished level. Given the above concerns, and the increasing divergence in both size and trend of the results from the two survey methodologies, the Department sought an independent peer review of the Coleraine model and the survey methodologies. The peer review results confirmed the Coleraine model results and enumerated several suggestions for improving the survey methodologies.

- 2003-04 Season. Continuation of the fleet-wideTomales Bay mesh size study. No other changes to mesh size or measurement in the other bays.

Notes from the March 25 and April 30, 2004 DHAC meeting minutes:

(Net measurement and mesh size) The format of the meeting minutes changed from a summary of the meeting discussions to bulleted comments on various topics. Comments on mesh size by DHAC and industry members included the desire to decrease mesh size to take a broader cross-section of the population, that the current mesh measurement method resulted in citations, a request for the Department to sell "official" standardized measuring devices, use existing data to reduce minimum mesh size to 2 inches, appreciation for implementing and enforcing a larger mesh size, a request for a response as to why the mesh measurement method was changed when the previous method was successful, and a proposal to go to 2 1/16 inch mesh or to 20 5/8 inch over ten meshes measured dry. The Department responded to all requests of the DHAC March 25 meeting in a detailed letter dated April 23, 2004. At the April 30, 2004 DHAC meeting, DHAC representatives were told that they could submit proposals for a mesh study directly to the Commission, or to the Department, for consideration. The Department received one proposal directly from a DHAC representative, and two proposals through the Commission process. In summary, two of the proposals outlined a fleet-wide study reducing the minimum mesh size to 2 1/16 inches measured dry. The third proposal outlined the used of a minimum mesh size of 2 inches measured wet and a change to the method of measurement (i.e. change in peg size).

(Recommendations for 2004-05) Continuation of the fleet-wide Tomales Bay mesh size study. No other changes to mesh size or measurement in the other bays.

Gill net Mesh Size in the California Herring FisherieHistorical Background Notes – Summary Table

Season	Regulation/Change/Why? (if no reference at to why indicated, none was found)
1976-77	The length of meshes of any gill net shall not be less than 2 inches or greater than 2 ½ inches (all bays). The upper limit of 2 ½ inches was specified for districts 11, 12, and 13 in the Fish and Game Code. Industry concern.
1977-80	No information on mesh change in files.
1980-81	Provision for fresh fish mesh size of no more than 1 ¾ inches and distinction between roe fishery and fresh fish fishery.
1981-82	No information on mesh change in files.
1982-83	In Tomales and Bodega Bay the length of the meshes of any gill net used in the roe fishery shall not be less than 2 inches or greater than 2 ½ inches. In all other permit areas the length of the meshes of any gill net used in the roe fishery shall not be less than 2 1/4 inches or greater than 2 ½ inches from November 28 through January 14. On or after such date the Director may, if the established fishing quotas are not filled and such action will not impact the herring resource, authorize the use of 2 1/8 inch or 2 inch minimum mesh for gill nets used in the roe fishery. Industry request.
1983-84	Date change to allow minimum 2 1/8 inch mesh, essentially, for the odd and even platoons in San Francisco Bay. A maximum mesh size was established for the fresh fish fishery. Language was also added on mesh measurement.
1984-85	Regulatory change to allow minimum 2 1/8 inch mesh for the XH fishery in San Francisco Bay, making the mesh size uniform in all areas (Crescent City, Humboldt and San Francisco) other than Tomales and Bodega bays. Decision made as a result of industry questionnaire.
1985-86	Increase in maximum mesh size in the fresh fish fishery to 2 inches. Industry request.
1986-87	Removal of subsection describing method of measurement for gill net mesh. Enforcement proposal.
1987-88	Minimum mesh for Humboldt Bay and Crescent City changed increased to 2 ¼ inches. Industry request.
1988-92	There are no changes to mesh size or mesh measurement methods in regulation. In 1991-92 the 'Banzai' area closure in San Francisco Bay was added to the regulations.
1992-93	The minimum mesh size in Tomales Bay was increased to 2 1/8 inches to reduce the potential take of younger, smaller fish and outer Bodega Bay was closed to fishing. There were no other changes to regulations in other bays. Tomales Bay had been closed to fishing since the 1989-90 season while fishing continued in Bodega Bay during this period.
1993-96	There are no changes to mesh size or mesh measurement methods in regulation.
1996-97	Mesh measurement method implemented with 3 percent tolerance for all herring fisheries in California. Language was added to provide for three permittees to participate in a Department sponsored mesh size study in San Francisco Bay.
1997-98	No tolerance included in mesh measurement; last season of round haul fishery.
1998-99	No changes to mesh size or mesh measurement in regulation.
1999-2000	Language was proposed to allow four permittees to participate in a Department sponsored mesh size study in Tomales Bay.
2000-01	Tomales Bay mesh size study using a minimum mesh of 2 inches. Study was provided to allow the Department to evaluate the use of this mesh length on the current population (shorter length at age) and assess whether increased CPUE could be obtained for the catch and still maintain the Department's management goal of a conservative 10 percent exploitation rate.
2001-02	Continuation of the fleet-wide Tomales Bay mesh size study. Clarification of the size of peg and weight used in the measurement of mesh was added to subsection (f)(2)(B).
2002-03	Continuation of the fleet-wide Tomales Bay mesh size study. Revised the quota designated for the mesh size study and increased the number of study participants from three to six in San Francisco Bay.
2003-04	Continuation of the fleet-wide Tomales Bay mesh size study. Peer review of San Francisco Bay stock and methodology (prior to season).

Appendix M Evaluation of Harvest Control Rules for the Pacific Herring Fishery in San Francisco Bay

While there are four stocks of Pacific Herring (Herring), *Clupea pallasii*, that are currently fished, the San Francisco Bay fishery has supported the majority of participants and landings and during the preparation of this Fishery Management Plan (FMP) it was the only actively fished stock. This fishery has been managed via a quota since its inception during the 1972-73 season, and one of the goals of the FMP process was to develop a Harvest Control Rule (HCR) for use in yearly quota setting.

Selection of a HCR for the San Francisco Bay Herring fishery is a process that requires objective and transparent evaluation of alternative approaches. We have tested a number of candidate HCRs using Management Strategy Evaluation (MSE), a procedure to evaluate the short- and long-term performance of management strategies via closed loop simulation under a range of alternative uncertainty scenarios. The operating model, candidate HCRs, uncertainty scenarios, and performance metrics were developed in consultation with Department of Fish and Wildlife (Department) biologists and a Steering Committee (SC) of stakeholders representing industry and conservation groups.

Initial analysis determined that continued harvest when the Spawning Stock Biomass (SSB) was below 5 to 10 thousand tons (Kt) (5 to 9 thousand metric tons (Kmt)), depending on the scenario examined, hindered the ability of the stock to recover quickly. This suggested the need for a cutoff, defined as a SSB level below which quotas would be zero in order to protect the Herring stock and promote recovery during low stock years. Based on these findings, we examined the effect of different cutoff levels on short- and long-term performance metrics. Above a cutoff of 15 Kt (14 Kmt) there was minimal improvement in the probability of being above the target biomass (80 percent (%) of B_{MSY}) or avoiding a low stock size. As the cutoff SSB increased, there was an increase in the probability of a fishery closure, which was one of the performance metrics chosen based on the economic objectives of the fishery. This suggested that both biomass and economic performance metrics were best met with a cutoff of 15 Kt (14 Kmt).

Prior to beginning the MSE process there was an agreement amongst stakeholders to continue the precautionary management approach that has been pursued by the Department since the early 2000s. This has included setting quotas to achieve harvest rates of no more than 10%. All of the HCRs tested had a maximum harvest rate of 10%. The HCRs that ramped up harvest from 5 to 10% had slightly better biomass outcomes than those that started at 10% right after the cutoff SSB, while having lower yields. Based on these findings the SC recommended the HCR in Figure M-1 (HCR 4 in the analysis presented here) to the Department for use in setting quotas for the San Francisco Bay Herring fishery.

This HCR was found to be robust to a wide variety of sources of uncertainty, including assumptions about the productivity and variability of the stock, the natural mortality rate, the selectivity of the fishing gear relative to the age at first maturity, long term declines in the size at age of Herring, and assumptions about the observation error in the survey. The analysis presented here demonstrates that this HCR is generally able to maintain a greater than 50% probability of the stock being above the target biomass, while minimizing the probability of dropping below a critical threshold.

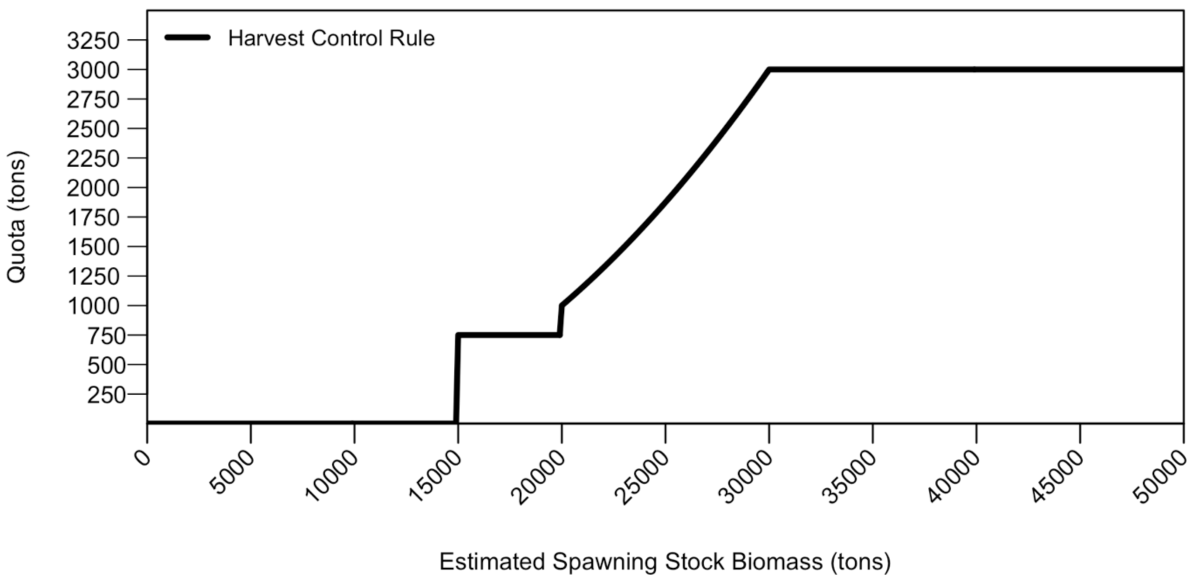


Figure M-1. Agreed on HCR for San Francisco Bay Herring.

Introduction

The Herring stock has historically supported a vibrant and important commercial fishery in San Francisco Bay. This fishery has been managed using an annual quota based on SSB estimates collected by Department biologists. While prior to the development of this FMP fishery management was precautionary due to sound commercial fishery leadership and a high level of collaboration between fleet leaders and the Department, there was an important need to transition the ad hoc annual quota-setting process into a more stable, less costly, and more efficient management system. To address this, one of the major goals of the FMP process was to develop a HCR that reflects precautionary management approaches for use in San Francisco Bay.

The Herring fishery in San Francisco Bay has been managed using a quota since its inception in 1972. Since that time, quotas have been set to achieve desired annual harvest rates (defined as the quota relative to the estimated SSB). However, the method for setting annual quotas was ad hoc, though generally quotas were set to achieve a harvest rate of about 15% of the total estimates SSB prior to 2004, and 10% or less after that time. While harvest rates of 15% may have been sustainable, the practice of merging two separate indices of SSB on an ad hoc basis between 1989-90 and 2002-03 may have led to overfishing. A retrospective analysis suggests that yearly harvest rates may have reached as high as 40% during this time, well over the 20% that is considered sustainable for Herring stocks (Pacific Fisheries Management Council, 1982).

In addition, changing quotas on a yearly basis required a change to Title 14 of the California Code of Regulations (CCR). This required that Department staff go through the full regulatory process each year, including public noticing at Fish and Game Commission (Commission) meetings and development of documents describing the environmental impacts of the recommended quota as well as the alternatives provided on an annual basis to be compliant with the California Environmental Quality Act. The work associated with this regulatory process made it arduous to change the quota each year, and constituted a barrier to a responsive management system. One of the primary goals of the FMP process is to develop a HCR to set quotas as a means of moving the authority to alter quotas to the Department Director.

HCRs provide a pre-determined and structured approach for making annual management decisions based on current stock status, as well as ensuring that those decisions are in line with long-term management objectives. An HCR is just one part of the larger fishery management process that includes yearly data collection, analysis of that data to determine current stock status, and determining the appropriate fishery regulations for the following year. The process for developing and testing HCRs relies on a simulation tool known as MSE, which models every step of the fishery management process in order to understand how each candidate HCR is likely to perform given the current understanding about the fishery. Performance of each HCR is assessed against metrics that reflect management objectives, and are often expressed as the probability, or "risk" of an undesirable outcome. The performance of each candidate HCR is assessed under different assumptions about the dynamics of the system, and tradeoffs between HCRs are examined to determine a preferred HCR.

Though a conservative SSB indicator and harvest rates has been applied to the San Francisco Bay stock since 2004, the observed SSB has exhibited higher variability than was seen during the 1980s, when the stock was considered to be high and stable and observed SSB was consistently greater than 40 Kt (36 Kmt), and frequently in the 60 to 70 Kt (54 to 64 Kmt) range. MSE provides a forum to test these various hypotheses, and to ensure that the HCR chosen for use in management is robust to various potential factors, even if we don't know which factors may be operating on our stock. The goal of this MSE analysis is to help select an HCR that will maximize the various management objectives for this stock.

Management Strategy Evaluation

MSE involves the construction of simulation model designed to imitate, albeit in a simplified manner, the dynamics of a fish stock, the fishery exploiting it, and the monitoring, assessment, and management framework that is used to manage the fishery. A key aspect of the MSE approach is that the simulation includes the full management cycle: data collection, analysis, and recommendation and application of a management policy which is then fed back into the system and used to update the stock and fleet dynamics in the next time-step (Walters and Martell, 2004). Simulation models with the property of a feedback loop, where the simulated management policy is updated based on the perceived state of the system, are known as 'closed loop' (Walters and Martell, 2004), and are distinct from risk assessment models that are commonly used to evaluate the implications of an unchanging management regulation (Punt, 2015). The main advantage of the closed-loop simulation approach is that it allows direct comparison and evaluation of alternative management procedures against the known state of the system; something that is usually impossible in the real world (Walters and Martell, 2004).

The primary aim of an MSE is to identify the emergent behavior of alternative management strategies, and to describe the various trade-offs that are likely to arise among conflicting management objectives (Punt and others, 2016). Rather than attempt to identify an optimal management approach, an MSE aims to provide decision-makers with the information they require for a rational and defensible decision on the management of the fishery, that balances management objectives and acceptable level of risk (Smith, 1993). Additionally, MSE can be used to develop and test new management strategies, either for a specific fishery or more as generic methods for general application, as well as identify classes of management methods that are unlikely to perform well and thus be generally rejected as candidates for management (Butterworth, 2007).

Stakeholder Engagement

MSE is intended to facilitate a process of decision-making that is deliberate, transparent, and reproducible (that is, independently testable). MSE is not intended to yield a single correct result, but rather to elicit a thoughtful discussion of management objectives that guide the evaluation of different possible management procedures and the inherent trade-offs, benefits, and risks they present. As such, MSE can be a powerful tool for engaging stakeholders and increasing buy in the results of the analysis.

Periodic meetings were held throughout the process with the SC, which was composed of representatives from industry, conservation groups, and Department biologists. During the early meetings, information on the MSE process and the vocabulary used was provided to ensure that all participants had an understanding of the process and felt able to interpret results and participate in discussions. A brainstorming exercise was conducted to develop management objectives for the fishery, and these were narrowed to include only those objectives that were directly influenced by the HCR (rather than another management measure, such as the number of participants in the fleet).

These objectives were converted to a set of quantitative performance metrics, which were tracked during each simulation run. The results of these simulations were presented to the SC for feedback, and were ultimately used in the final decision about which HRC to recommend to the Department.

SC members also participated in the iterative development of the operating model and uncertainty scenarios. For example, an age-structured stock assessment model was commissioned for the San Francisco Bay Herring stock by the Centre for Environment, Fisheries and Aquaculture Science (Cefas). Prior to the completion of the peer review process, an operating model was developed based on that stock assessment model, albeit with a less optimistic stock recruitment curve. Members of the SC expressed concern about some of the assumptions in the operating model, and participated in evaluating whether the simulation model was able to accurately recreate historical conditions. These discussions contributed to which uncertainty scenarios were ultimately considered.

MSE Design and Analysis

This MSE was conducted using the Data Limited Methods Toolkit (DLMtool) package in R (Carruthers and Hordyk, 2017). The DLMtool is an open-source software package designed for conducting MSEs, and is highly customizable. The MSE framework within the DLMtool is comprised of three key components: 1) an operating model that is used to simulate the stock and fleet dynamics, 2) an observation model that simulates the expected imprecision and bias in the fisheries data that are typically observed and used in management, and 3) an assessment and harvest control rule model that uses the simulated fishery data from the operating model to provide management recommendations (a quota). The relevant equations underlying this analysis are provided in Appendix M-A.

Operating Model

In order to simulate a fishery and understand its expected performance when managed under each candidate HCR, it is necessary to build an operating model (OM) that describes the best available information about the biology of the stock and the socio-economic dynamics that govern fleet behavior. Ideally, the OM is based on a stock assessment that has analyzed historical data to estimate population dynamics that are difficult to measure. The Department, in collaboration with the San Francisco Bay Herring Research Association, commissioned Cefas to complete a stock assessment, with the intent of using that model as the base-case operating model. However, the model had difficulty fitting a few key parameters, and an independent review panel felt that more work was necessary before the model could be considered the best representation of what is known about the San Francisco Bay Herring stock dynamics. Despite the Cefas model not being recommended for use as an operating model, it did represent a great deal of work to analyze the available data for this fishery, and some parameter values were used to inform the OM, especially for parameters like estimates of historical fishing mortality or recruitment deviations. This OM was developed in consultation with Department biologists in an attempt to capture the best available information about the San Francisco Bay Herring stock.

The DLMtool is a stochastic modeling platform, and most input parameters are required to be specified as a range (a minimum and maximum value). The model randomly draws parameter values from a uniform distribution with bounds specified by these input parameters for each simulation. This allows the simulation model to fully incorporate the level of uncertainty associated with each parameter. Some derived parameters in the OM may also vary by year, either randomly or as a gradient, depending on how they are parameterized. For each uncertainty scenario we ran 500 simulations, each with its own set of randomly drawn parameters from the distributions below. All of the parameter distributions and functional forms used in the base model can be viewed the figures in Appendix M-B.

Here we describe the parameters used in the base model. These parameters are used in all scenarios unless otherwise specified (for example, in an uncertainty scenario exploring an alternative selectivity ogive, the selectivity is altered and all other parameters are as described in the base model).

Maximum Age

The maximum age observed for Herring in California is 11 from the Humboldt Bay stock in 1974-75, when the roe fishery for Herring began (Rabin and Barnhart, 1986). The maximum age observed in San Francisco Bay is nine (Spratt, 1981). The maximum age declines with latitude in Herring, and it is likely that few fish live past ten in central California. For this reason, ten was assumed to be the maximum age. There is no plus group in the DLMtool, and all fish die once they are older than the maximum age.

Natural Mortality

There are no direct estimates of the instantaneous natural mortality rate (M) available for California Herring stocks. Based on the observed maximum age, average M is likely to be between 0.45 and 0.6 for California stocks. Initial simulations assumed that M was uniformly distributed between 0.4 and 0.65 (corresponding with value of 0. 53+/- 20%), with the randomly drawn value being static over all ages and all years of each simulation. We then explored the impacts of a number of different assumptions about M in the uncertainty scenarios to ensure that the preferred HCR is robust to these assumptions.

Growth

Length at age was simulated using the von Bertalanffy growth equation. Parameter estimates were derived from fitting a model to length at age data from San Francisco Bay collected between 1984 and 2016. From this model fit, a variance-covariance matrix was generated and this was used to draw correlated sets of Linf, k, and t0 for use in the simulations. In the base model it was assumed that the growth parameters did not vary over time.

The weight-length relationship parameters a and b were estimated from data sampled from the research catch between 1984 and 2016. The units are in millimeters (mm) (length) and short tons (ton) (weight). These parameters are assumed to be known without error and a point value rather than a range is specified for each.

Maturity at Age

There are no direct estimates for maturity at age from California Herring stocks. The values used in the base model were borrowed from Hay (1985) for British Columbia stocks.

Recruitment

Stock recruitment is assumed to follow a Beverton-Holt stock recruitment relationship. The steepness of the stock-recruitment curve is defined as the level of unfished recruitment at 20% of unfished spawning biomass. The steepness value for San Francisco Bay Herring is unknown, and thus a wide range of values was used for this analysis to reflect that uncertainty. We specified a range of 0.49 to 0.86 for the steepness parameter for the base model based on a meta-analysis of steepness for clupeids (Myers and others, 1999). A recent stock assessment for Herring in British Columbia estimated steepness values ranging between 0.58 and 0.89 (Fisheries and Oceans Canada, 2016), with median values in the 0.7 to 0.81 range, which is slightly higher than the range we assumed. However, it is possible that Herring in San Francisco Bay, which are at the lower end of their range, may exhibit lower productivity than Herring in British Columbia.

It was also necessary to specify the magnitude of annual recruitment deviations. Herring demonstrate high variability in annual recruitment deviations. The Cefas stock assessment found that a value of 0.7 maximized the joint log-likelihood, with a 95% confidence interval between 0.55 and 0.95, and we used this range in the base model. The Cefas model showed patterns of autocorrelation in the recruitment residuals, and estimated autocorrelation to be equal to 0.739. For this analysis we assumed that auto-correlation ranged between 0.7 and 0.8 in the base model.

The level of unfished recruitment was chosen to scale historical catches and population sizes to those observed in San Francisco Bay between 1973-74 and 2016-17.

Stock Depletion

The OM requires parameters specifying the current stock depletion (defined as the stock size relative to the unfished stock size, B0) for use in forward simulations. The current depletion for Herring is unknown. The average unfished levels are highly uncertain for stocks such as Herring due to their relatively short lifespan as well as the fact that total biomass is strongly driven by recruitment. In addition, it is likely that shifts from cooler, high productivity regimes to warmer, lower productivity regimes influence the level of unfished biomass the ecosystem can support.

The Coleraine stock assessment model suggested that when the analysis was performed in 2003, the stock was somewhere between 20 and 25% of the 1970s biomass (Observed SSB 2003 = 13 Kt (12 Kmt)). This suggests that the spawning biomass in the early years of the fishery was 50 to 60 Kt (45 to 54 Kmt). Observed SSB estimates over the past 4 yr have ranged from 15 to 18 Kt (14 to 16 Kmt). Following the Coleraine model estimate, it was assumed that this stock size corresponds to a 20 to 30% range for the base model; corresponding with unfished stock sizes of 50 to 90 Kt (45 to 82 Kmt).

Spatial Distribution

The model was assumed to have no spatial structure.

Historical fishing mortality

The DLMtool uses estimates of historical fishing effort rates and an optimized catchability parameter to simulate historical conditions while achieving the current specified depletion range. Yearly fishing mortality rates are specified using a uniform distribution. We used the estimates from the Cefas stock assessment, which estimated fishing mortality rates back to 1992, to inform the range of historical fishing effort sampled for those years. Prior to that, we assumed that given the low quotas in the very early years of the fishery that initial fishing effort was low, but that it ramped up quickly and may have been very high in the late 1970s and 1980s.

The mean trend of fishing effort is sampled, and then log-normally distributed error is added to simulate interannual variability in fishing effort. We assumed that effort varied between 0.03 and 0.012 (the standard deviation of the time series of fishing mortality estimates from the Cefas stock assessment). We assumed no trends in fishing efficiency given that the amount and type of gear is highly regulated in this fishery, and assumed that the parameter governing increases in catchability ranged between -0.1 and 0.1, while the parameter governing the interannual variability in catchability ranged between 0.0 and 0.05.

Selectivity

Historical selectivity was estimated from the yearly size distribution of the catch and converted to selectivity at age. Prior to 1998, both round haul and gill net gears were used, and so slightly more age three fish were selected prior to that time. To capture this change in the historical selectivity we used a yearly age-based selectivity ogive. In the base model the future selectivity was assumed to be the current selectivity. We explore a number of different selectivity assumptions in the uncertainty scenarios.

Observation Error

The HCRs tested depend on an estimate of the total SSB each season. San Francisco Bay Herring has a spawning survey that acts as an index of absolute abundance (Bt). The coefficient of variation of that survey over the last 45 yr has been 0.75. It is unknown how much of this variation is due to process error vs. observation error. In the base model, we assumed that the surveys are relatively precise, with observation error distributed between 0.0 and 0.2. We also assume no directional bias, though it is assumed that the surveys provide an underestimate of the true spawning biomass due to difficulties in sampling the full extent of every spawning event in a timely fashion. We explored these assumptions in the uncertainty scenarios.

Implementation Error

The DLMtool currently assumes that all recommendations (catch limit, size limits, and so forth) from the management procedures are perfectly implemented. This is a reasonable assumption for the commercial sector, where catches are closely monitored to determine when the quota has been reached.

Uncertainty Scenarios

Due to the natural variability exhibited by Herring stocks, there are a number of sources of uncertainty for the San Francisco Bay fishery, despite the fact that it has been intensively monitored since the mid-70s. Some primary sources of uncertainty were identified during the data analysis process to develop an OM for Herring and the Cefas stock assessment review process. We have tried to examine as many sources of uncertainty as possible given the time and budgetary constraints of this project. For each type of uncertainty we define an “uncertainty scenario” as the combination of assumptions regarding the biological, fishery, or management aspects of the system. The uncertainty scenarios are listed in Table M-1.

Table M-1. Uncertainty scenarios presented in this report.

	Number	Scenario name	Description
Base	1	Base model	Parameters are as described in the OM section of the text
Natural mortality	2	Age-Dependent M	M increases linearly between ages 3 and 10
	3	Variable M	M varies from year to year within each simulation (sd between 0.0 and 0.1)
	4	Sloping M	M increases with each year of the simulation
Selectivity relative to maturity	5	Lower maturity	Assumes San Francisco Bay Herring mature earlier than BC Herring
	6	Selectivity matches maturity	Assumes San Francisco Bay Herring mature earlier than BC Herring, and that all mature fish are vulnerable to the gear
	7	Domed selectivity	Assumes that selectivity is domed shaped
	8	Uniform selectivity	Assumes that all fish age 3-plus are vulnerable to the gear
Productivity	9	Low Productivity	Assumes that steepness is between 0.4 and 0.6
	10	Lower Autocorrelation	Assumes that autocorrelation in recruitment deviations is lower
	11	High Autocorrelation	Assumes that autocorrelation in recruitment deviations is higher
	12	Low Productivity-High Autocorrelation	Assumes that steepness is lower and autocorrelation is higher
Depletion	13	Lower Current Depletion	Assumes that the stock is currently between 0.15 and 0.20% of B0
Decline in size	14	Decreasing length at age	Assumes that there has been a linear decline in the maximum length achieved
Observation error	15	High Error	Assumes the error in the survey estimate ranges between 0.2 and 0.6
	16	Negatively Biased	Assumes the survey routinely underestimates the true SSB
	17	Positively Biased	Assumes the survey routinely overestimates the true SSB

Mortality

In the base model, natural mortality was assumed to be constant for all ages and years. However, there is evidence that M is quite variable. The Cefas stock assessment assumed a fixed estimate of natural mortality (M; 0.53 in the final preferred run, model 19). However, the 95% confidence interval for this estimate was between 0.24 and 0.98. This wide range may be attributable to attempting to fit a single parameter value to describe a process that likely shows considerable temporal variability due to environmental and ecosystem conditions. In addition, estimates of yearly M for British Columbia Herring stocks suggest that M has fluctuated between values of 0.2 to 1 (Fisheries and Oceans Canada, 2016), and may be increasing. Increasing M over time might also be a factor in the lack of older fish observed in the stock between 2004 and 2015. This might also be explained by a recent increase in M as fish get older, as was suggested by the Cefas review panel.

To examine the impacts of these uncertainties we ran uncertainty scenarios with three different formulations of M. In the first one we modeled interannual variability in M by up to 10% (essentially, a random walk). In the second, we modeled mortality that increases linearly from age three, when fish are mature, to age ten. Finally, M was simulated as a time-varying parameter with a consistent increase in M between 0.0 and 2.5% per year (Figure M-2).

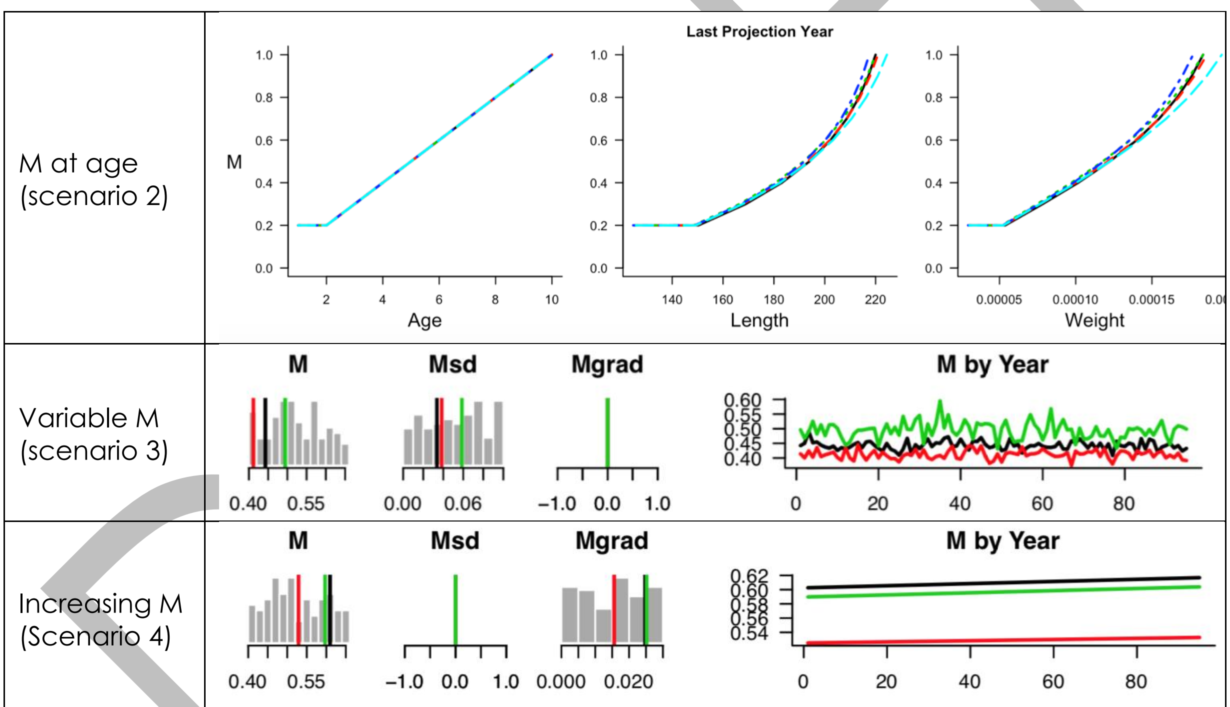


Figure M-2. Parameter distributions associated with scenarios 2, 3, and 4.

Selectivity Relative to Maturity

The sustainability of the stock under various HCRs is bolstered by the assumption that the selectivity of the gill net gear used in the Herring roe fishery allows fish to spawn prior to becoming vulnerable to the fishing gear. However, there are no direct estimates of the age at maturity available for San Francisco Bay Herring, and the best available estimates are borrowed from a study conducted in British Columbia (Hay, 1985). There is a known latitudinal cline in vital rates of Herring stocks along the west coast of North America, and it is possible that San Francisco Bay Herring mature at a younger age than British

Columbia Herring. The assumption of the British Columbia maturity ogive in combination with estimated selectivity ogive means that, in the base simulation, the biomass vulnerable to the fishing gear is only half the total SSB. It is likely that the age at maturity varies from cohort to cohort, and in some years a larger number of age two fish come into the bay and end up in the commercial catch, suggesting that part of why they appear not to be vulnerable to the gear is that many age two fish don't return to spawn. Given the uncertainty in the age at maturity we explored a slightly lower age at maturity (Table M-2), as well as additional selectivity formulations. These uncertainty scenarios are also informative should the selectivity of the gear change in the future.

Table M-2. Maturity and selectivity ogives tested in uncertainty scenarios 5-8.

Age	Current selectivity	Domed shaped	Uniform	British Columbia maturity (Hay, 1985)	Lower age at maturity
1	0.00	0.03	0.05	0.00	0.00
2	0.01	0.25	0.12	0.36	0.60
3	0.19	0.95	1.00	0.94	1.00
4	0.65	1.00	1.00	1.00	1.00
5	1.00	0.79	1.00	1.00	1.00
6	1.00	0.30	1.00	1.00	1.00
7	1.00	0.05	1.00	1.00	1.00
8	1.00	0.05	1.00	1.00	1.00
9	1.00	0.05	1.00	1.00	1.00
10	1.00	0.05	1.00	1.00	1.00

Current Depletion

The current depletion for Herring is unknown. The average unfished biomass are highly uncertain for stocks like Herring due to their relatively short lifespan as well as the fact that total biomass is strongly driven by recruitment. Given the uncertainty surrounding these estimates and the fact that observed SSB was frequently above 60 Kt (54 Kmt) during the 1980s despite heavy fishing pressure, we tested the assumption that the current depletion ranges between 15 and 20% of unfished, which means that SSB0 is between 75 and 120 Kt (68 and 109 Kmt).

Changes in Productivity and Variability of the Stock

Herring are known to be a highly productive stock, with the ability to increase from very low stock sizes when environmental conditions are favorable. However, given their sensitivity to environmental changes, it is also possible that external factors can reduce the productivity of the stock. We explored a low productivity scenario, in which steepness ranges from 0.45 to 0.6. This scenario was intended to simulate recruitment under a warm water conditions or other environmental changes that might contribute to reduce survival of eggs, larvae, or juvenile Herring, and thus lower recruitment to the stock.

We also explored the extent to which autocorrelation and recruitment error impact the performance of our candidate HCRs. We ran a scenario with lower autocorrelation and higher recruitment variability, in which each year's recruitment is less governed by the recruitment in the years before and more by random processes, because the Herring stock has exhibited higher variability since the early 1990s. We also simulated a higher level of autocorrelation, which is similar to cyclical regime changes that can have long-term impacts on Herring. Finally, we combined high auto-recruitment and low productivity in a true "worst case scenario" approach to understand how the HCR would perform under very low productivity conditions (Figure M-3).

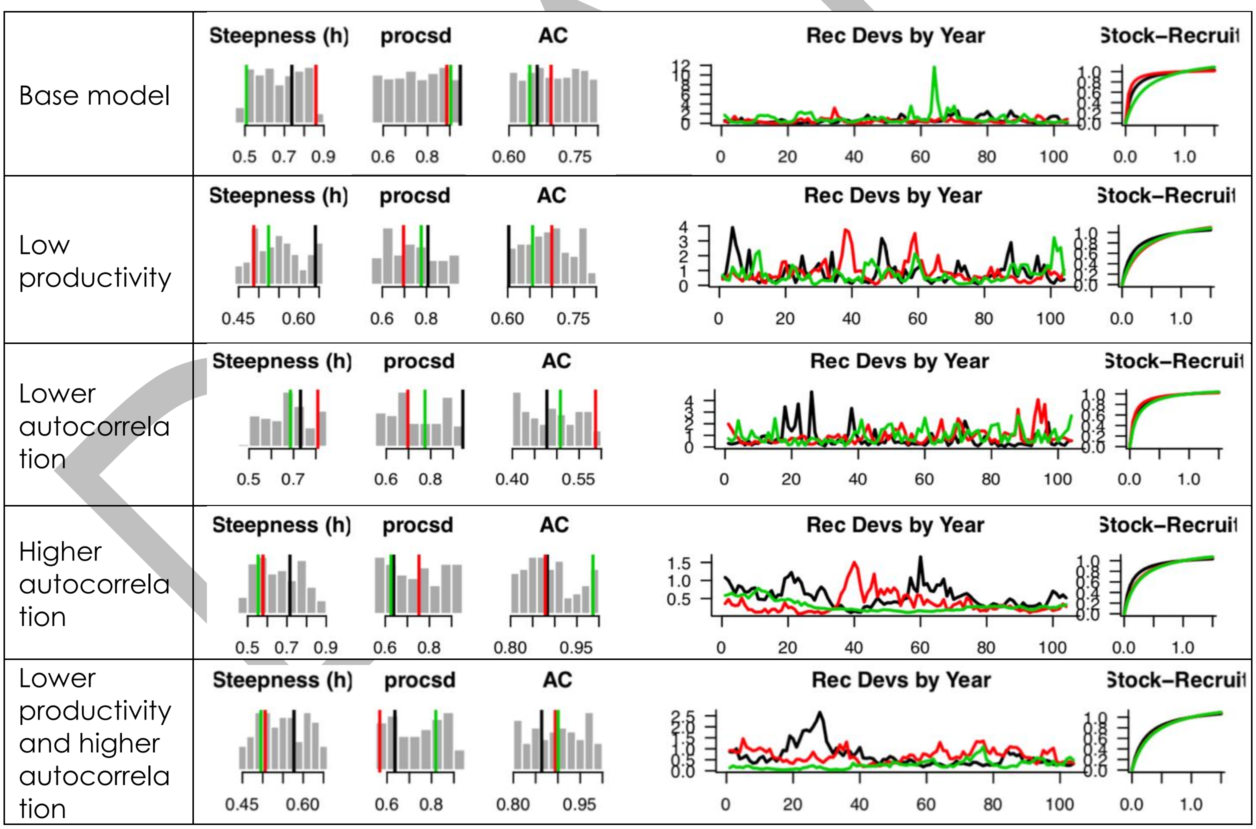


Figure M-3. Parameter distributions associated with Scenarios 1 and 9-12.

Changes in Size at Age

Since the fishery began there has been a decline in the mean length at age of Herring observed in the research catch, particularly in age five and older

Herring (Figure M-4). A similar trend in the mean weight at age as well as the condition index has also been observed, though these metrics have shown more year-to-year variability. Exploitation rates ranged from 0 to 5% since the 2009-10 season, but at the time of development of this FMP, fish had not increased in size, though the age structure demonstrated a return of age 7 and 8 yr old fish in the 2016-17 and 2017-18 seasons. This lack of larger fish caused concern that there has been a fundamental change in the phenotypic expression of length at age in San Francisco Bay Herring, either due to the selective pressures of fishing or to some environmental change. We tested the impact this type of change would have on the performance of our candidate HCRs by modeling a 5 to 10% (uniform distribution) decline in asymptotic length between 1972 and 2016. Growth in the early years of the fishery was estimated from growth values reported by Spratt (1981) in San Francisco Bay, while growth rates in recent years was estimates by fitting a von Bertalanffy growth model to data length at age data from 2009-10 through 2016-17 (Figure M-5).

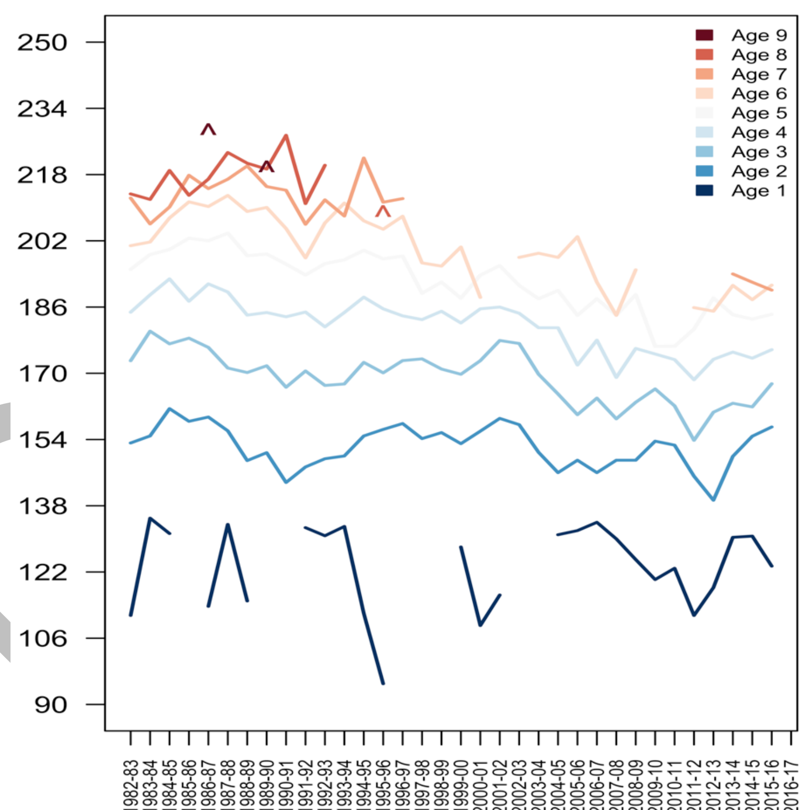


Figure M-4. Mean length at age of San Francisco Bay Herring observed in the research catch between 1982-83 and 2016-17.

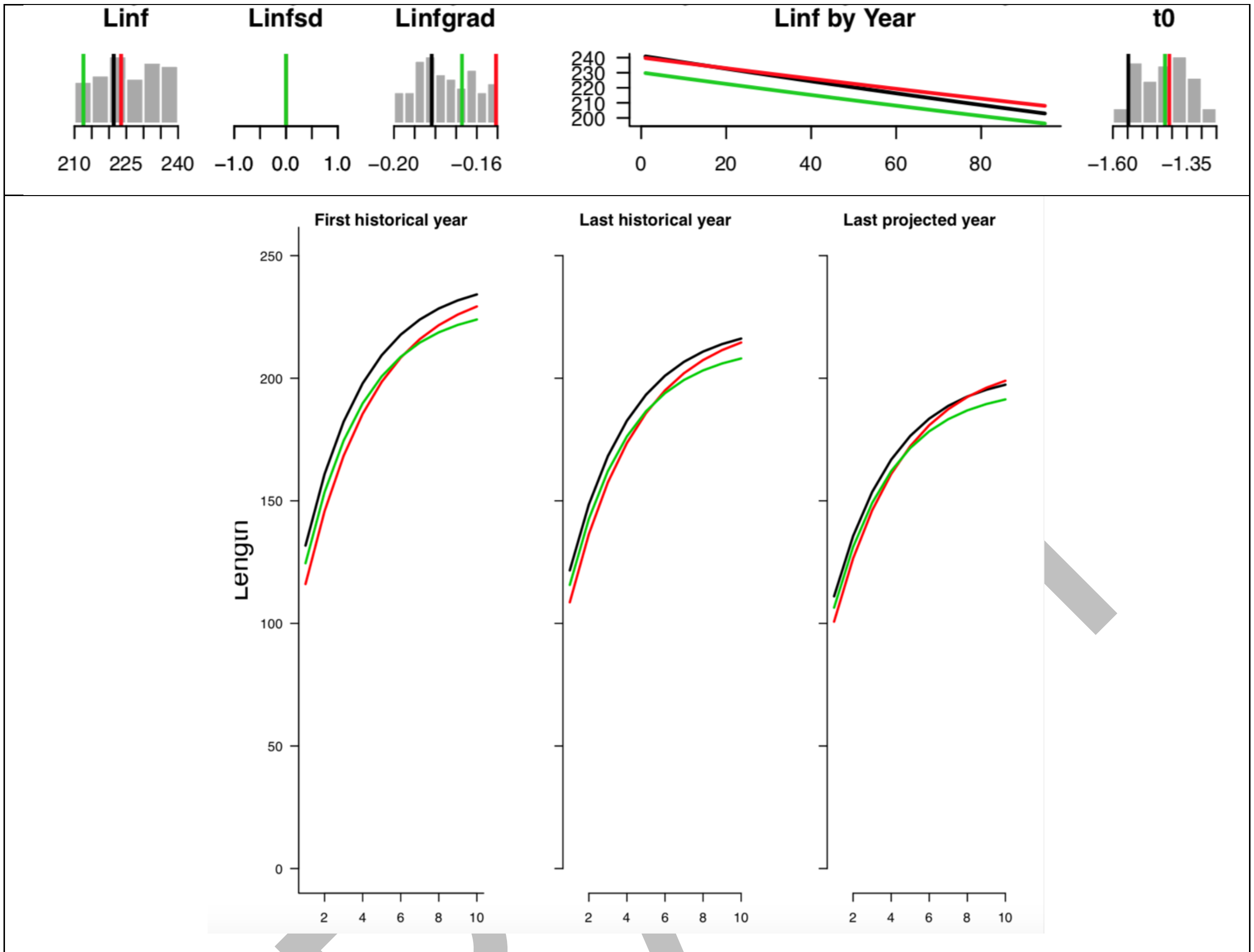


Figure M-5. Sampled growth parameters for decreasing growth (top panel), and the derived length at age for three random samples in the first historical year, last historical year, and last year of the projected simulations.

Observation Error

A 2003 review of the survey methodologies employed by the Department found that the egg deposition survey currently used by the department routinely underestimated the biomass by 10%. The Cefas stock assessment model estimated catchabilities for the spawn deposition surveys that were 0.5 or less in order to fit the available time series of data, suggesting that greater numbers of Herring are present in the stock than come into the bay to spawn or are detected by surveys. While it is unknown by how much, the spawn deposition surveys are generally considered to be conservative estimates due to the likelihood of missed spawning events, and they are made more conservative by the fact that they are treated as an absolute abundance. However, the survey methodology likely adds observation error, and in some years that observation error may be very large, as may have been the case in the 2005-06 season, when a record high SSB estimate greater than 140 Kt (127 Kmt) was produced. Given the uncertainty around the surveys we explored three alternative types of error. The first was a much higher observation error, and the second two include either under or over estimations via the bias parameters (Figure M-6).

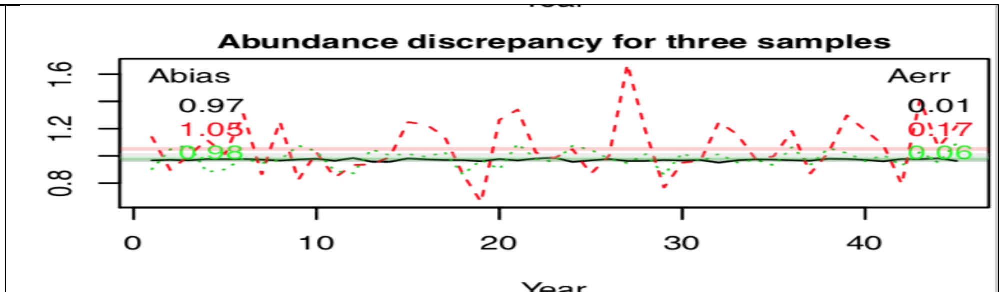
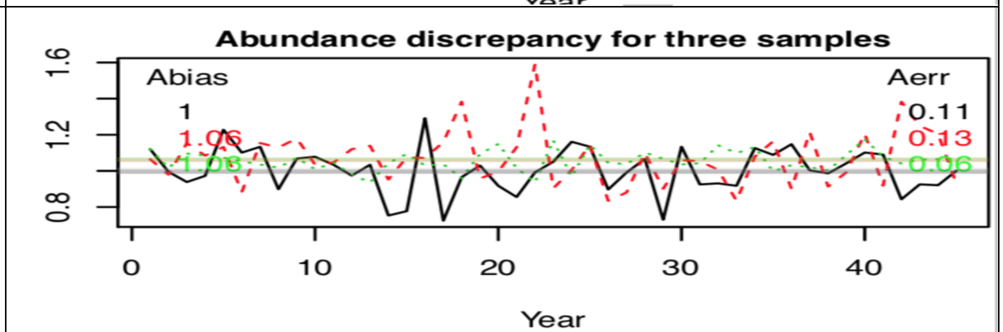
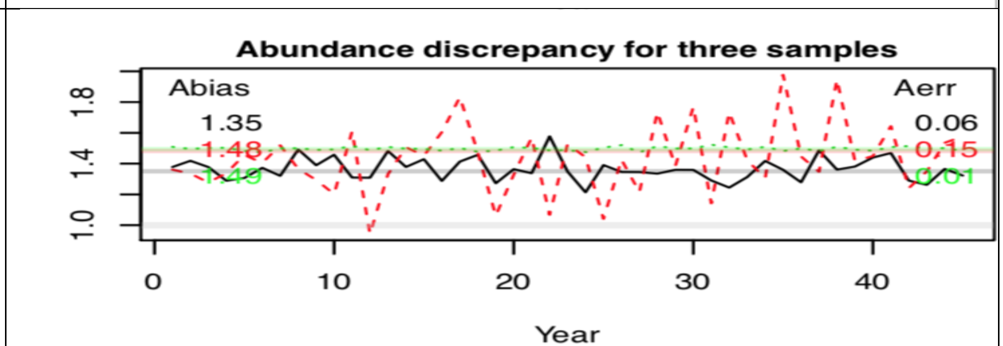
Higher error (Scenario 15)	
Negatively biased (Scenario 16)	
Positively biased (Scenario 17)	

Figure M-6. Randomly drawn sample illustrating different functional forms of observation error.

Candidate HCRs

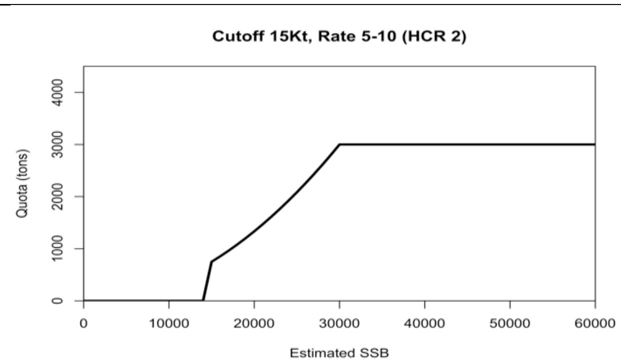
In the early phase of this project we explored a wide range of HCR formulations that met the criteria agreed upon by the SC. These included HCRs with harvest rates that ramped up to meet their target (hockey stick formulation), HCRs with only two harvest rates depending on whether the stock was above or below a certain SSB, and HCRs formulated similarly to those used in the sardine fishery off California, in which the harvest rate is applied to the stock above a minimum escarpment biomass. Initial simulations were conducted over a wide range of biomass cutoffs and harvest rates, and were narrowed down as the simulations provided additional information on the emergent properties of each type of HCR.

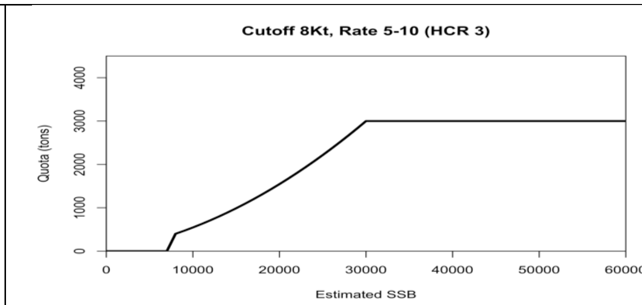
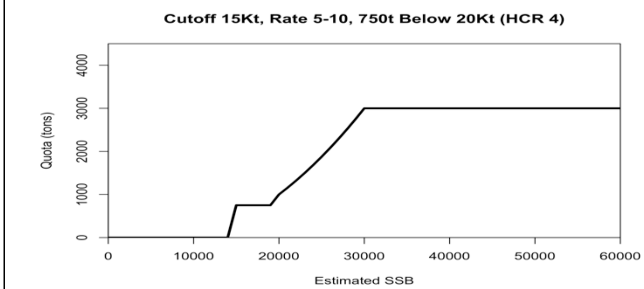
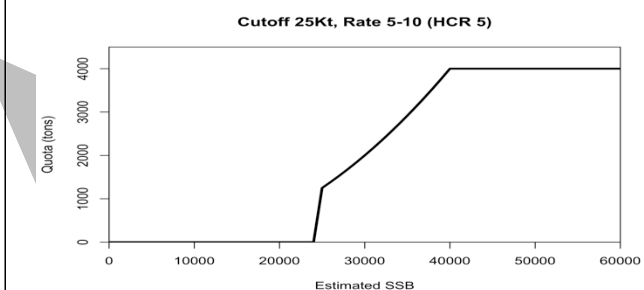
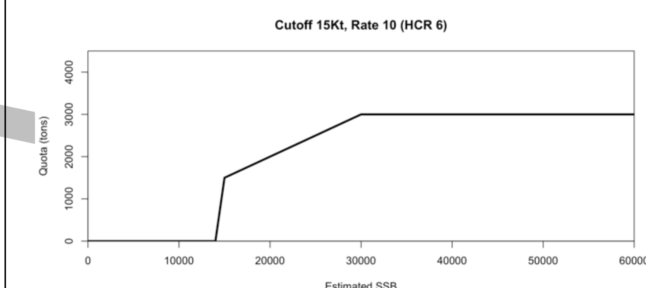
In this analysis we present the results of seven different potential HCRs (Table M-3). HCR 1 is Total Allowable Catch (TAC) that is permanently set to zero, which provides context about the probability of achieving targets and limits even under no harvest, and HCR 7 is fishing at the fishing mortality rate that would provide the maximum sustainable yield (FMSY). HCRs 2 through 6 provide a range of the different HCRs that were considered by the SC at some point. These HCRs are the results multiple iterations of presenting simulation results to the SC, and them providing feedback on changes or additional formulations they would like to see.

Early simulations showed that continuing fishing when the stock was at a very low biomass (less than 8 to 12 Kt, (7 to 11 Kmt) depending on the productivity assumptions) resulted in delayed recovery of the stock to levels around or above BMSY. Additionally, the quotas resulting from harvest rates in the 5 to 10% range (the range preferred by the SC) when the stock was below 8 Kt (7 Kmt) resulted in quotas below the level that is considered the minimum economically viable quota by industry representatives (about 750 tons (681 metric tons)). We have included HCR 2, which has a cutoff at 8 Kt (7 Kmt), to illustrate the relative difference in performance from those HCRs that have higher cutoffs such as 15 Kt (14 Kmt).

HCR 5 has a 25 Kt (23 Kmt) cutoff, as well as a higher maximum quota of 4 Kt (4 Kmt). While early simulations showed that cutoffs above about 12 to 15 Kt (11 to 14 Kmt) provided adequate protection for the Herring stock, this HCR was considered due to concerns about maintaining an adequate forage base for predators of Herring. A recent study has suggested that one-quarter to one-third of biomass should be left unfished to meet predators needs (Cury and others, 2011). The unfished biomass of the San Francisco Bay Herring stock is unknown, and likely fluctuates a great deal based on environmental conditions, but given that the second highest SSB ever observed was 99.4 kt (90.2 Kmt), it was used as a proxy for unfished biomass, and that cutoffs higher than 15 Kt (14 Kmt) should be considered.

Table M-3. The Harvest Control Rules presented in this document. Note that HCRs 1 and 7 are included for reference only, because it is useful to compare the performance of other HCRs relative to no fishing or fishing under Maximum Sustainable Yield (MSY).

HCR number	HCR description	HCR graph
1	No Fishing (quota is always zero). Included for reference only.	No Visual – Quota is always zero
2	Quota is zero when biomass is below 15Kt. When SSB is between 15Kt and 30kt the harvest rate ramps up linearly from 5-10%. When SSB is >30Kt the quota is 3,000t.	

3	Quota is zero when biomass is below 8Kt. When SSB is between 8Kt and 30kt the harvest rate ramps up linearly from 5-10%. When SSB is >30Kt the quota is 3,000t.	
4	Quota is zero when biomass is below 15Kt. Quota is 750t when SSB is between 15Kt and 20Kt. When SSB is between 20Kt and 30kt the harvest rate ramps up linearly from 5-10%. When SSB is >30Kt the quota is 3,000t.	
5	Quota is zero when biomass is below 25Kt. When SSB is between 25Kt and 40kt the harvest rate ramps up linearly from 5-10%. When SSB is >40Kt the quota is 4,000t	
6	Quota is zero when biomass is below 15Kt. When SSB is 15Kt or more the harvest rate is 10% or 3,000t, whichever is lesser.	
7	The harvest rate is FMSY, and is included only for reference	No Visual – FMSY varies by scenario

We consider three different HCRs with cutoffs at 15 Kt (14 Kmt). HCR 3 ramps up harvest rates linearly from 5% at 15 Kt (14 Kmt) to 10% at 30 Kt (27 Kmt). HCR 4 is similar to HCR 3, but between 15 Kt and 20 Kt (14 to 18 Kmt) quotas are static, and set to 750 tons (681 metric tons). This static quota at biomass estimates between 15 Kt and 20 Kt (14 to 18 Kmt) was a feature the SC asked to test as a compromise in an attempt to balance concern about the effect of 5-plus % harvests below 20 Kt (18 Kmt) would have on predators of Herring and the effect of a 20 Kt (18 Kmt) or higher cutoff would have on the fishing industry. HCR 6 has a 15 Kt (14 Kmt) cutoff, and then a 10% harvest rate is applied until the SSB is 30 Kt (27 Kmt). This HCR was included to provide an understanding of how harvest rates as high as 10% (which was recommended as a harvest rate that would allow for rebuilding by the 2003 review panel) would impact the San Francisco Bay Herring stock. This is useful because the proposed HCR framework allows increased harvest rates up to 10% when ecological indicators suggest that forage conditions in the region are healthy, and it is necessary to understand the implications that has for the Herring stock.

HCRs 2, 3, 4, and 6 have with a maximum quota of 3,000 tons, (2,722 metric tons) a feature that was agreed to by the SC. This maximum quota is based in part on the capacity of the fleet once it reaches the fishing vessel cap being proposed as part of this FMP of 30 vessels, each of which are expected to average up to 100 tons (91 metric tons) per season. This cap also leaves additional forage for Herring predators in years when the Herring stock is large. In boom years, Herring may experience greater predation because of its increased availability.

Developing Performance Metrics

It is necessary to define performance metrics in order to compare the relative performance of alternative HCRs. These performance metrics should reflect the management objectives for the fishery, as well as any existing sustainability mandates from the managing agency. The Marine Life Management Act (MLMA), which is the basis for fishery management in California, list the following objectives for the management of California fish stocks:

> *The fishery is conducted sustainably so that long-term health of the resource is not sacrificed in favor of short-term benefits. In the case of a fishery managed on the basis of maximum sustainable yield, management shall have optimum yield as its objective (FGC §7056a)*
>
> *Depressed fisheries are rebuilt to the highest sustainable yields consistent with environmental and habitat conditions (FGC §7056c)*

This provides a mandate for sustainable management, but does not define "sustainability" in terms of biomass targets or limits, nor does it define a risk tolerance for achieving targets or avoiding limits. In the absence of any quantitative mandates we worked with Department biologists and the SC to define management objectives and to develop quantitative performance metrics around those management objectives. This discussion recognized that different stakeholders may have different objectives, or may weight objectives differently. We also provided information on the definitions of target and limit thresholds used by other management agencies, as well as simulation results of the projected stock performance under no fishing as well as fishing at MSY to help provide context for the discussion. Table M-4 shows the agreed upon management objectives for San Francisco Bay Herring, as well as the performance metrics associated with each objective.

Table M-4. Management objectives and corresponding performance metrics for San Francisco Bay Herring.

Management objective	Performance metric tracked
Maintain the stock at healthy long-term biomass	Probability that the stock is greater than 80% BMSY
Minimize the number of years the stock is in a depressed state	Probability that the stock is less than10% of B0
Maximize catch to the extent possible	Average Annual Catch
Minimize variability in yearly quotas	Average Annual Variation in Catch
Minimize the number of fishery closures (years where the quota is zero)	Percent of Years the HCR recommends a quota of zero

Assessing Tradeoffs

There are generally two accepted methods for evaluating the results of a MSE and choosing a preferred HCR. The first, known as satisficing, involves specifying minimum performance standards for all (or a subset) of the performance measures and only considering management strategies that satisfy those standards (Punt, 2015). The second, known as trading-off, acknowledges that any minimum performance standards will always be somewhat arbitrary, and that decision-makers should attempt to find management strategies that achieve the best balance among performance measures (and hence objectives). For this analysis we recommended that the SC use a combined approach, in which minimum performance thresholds are used only to eliminate methods that are entirely unacceptable to all stakeholders, and then to examine the trade-offs in the remaining methods to identify those that best meet the management objectives. For example, any HCR that resulted in high probabilities of being below 10% of B0 were universally unacceptable to all participants and were excluded.

Results

This section summarizes the results of a subset of the HCRs that were considered over the course of the FMP development process. Based on the results presented here, as well as additional preliminary analysis, the SC agreed that HCR 4, with a 15 Kt (14 Kmt) cutoff, a 750 ton (681 metric tons) quota between 15 Kt and 20 Kt (14 and 18 Kmt), and a harvest rate that increased from 5 to 10% between 20 Kt and 30 Kt (18 and 27 Kmt) was their preferred HCR, and recommended that the Department adopt it for use in Herring management. In the following results, we will refer to HCR 4 as the "agreed on" HCR.

For each uncertainty scenario we tracked the performance of each HCR. Figure M-7 shows boxplots of each performance metric. The probability of being above the biomass target and limit during the last 10 yr period of this analysis are shown. By looking at the last ten years, it is possible to see the performance of each HCR without the impacts of the current conditions.

Each of the HCRs with 15 Kt (14 Kmt) cutoffs have a 96% probability of being above 10% of the unfished biomass (B0) in the last years analyzed. A 25 Kt (23 Kmt) cutoff only increases that probability by 1%, while the HCR with an 8 Kt (7 Kmt) cutoff has a 94% chance of achieving this metric.

All of the HCRs have a greater than 50% probability of being above the target biomass (80% of B_{MSY}) in the last 10 yr. The HCR with an 8 Kt (7 Kmt) cutoff has a 55% probability of being above the target. The conservative features of this HCR, including the 15 Kt (14 Kmt) cutoff, a harvest rate that ramps up to 10% rather than starting at 10%, and the slightly target, in contrast to the agreed on HCR, which has a 60% probability of reduced harvest between 15 and 20 Kt (14 and 18 Kmt) contribute to the higher performance. A 25 Kt (23 Kmt) cutoff provides additional biomass benefits and has a 64% probability of being above the target. Note that, due to the inherent variation in the system, the No Fishing reference HCR only results in a 67% of being above the target biomass. None of the HCRs (other than the FMSY HCR) indicate that there is any likelihood of overfishing.

The average catch at in the short term (first 10 yr of the simulation) at FMSY is just over 3,700 tons (3,358 metric tons) under the base model assumptions. This is less than the average historical catch that has occurred in the fishery, which is 4 Kt (4 Kmt). The HCR with a 25 Kt (23 Kmt) cutoff has the lowest average catch despite having a higher maximum quota (4 Kt) (4 Kmt) than the other HCRs, which have a maximum quota of 3 Kt (3 Kmt). This low average catch is due to the high number of years that the biomass is below the cutoff, resulting in fishery closures.

The agreed on HCR has an average catch of 1,257 tons (1,141 metric tons). This is slightly less than the HCR that begins fishing at 5% above 15 Kt (14 Kmt). Both the HCR with the 8 Kt (7 Kmt) cutoff and the HCR with a 15 Kt (14 Kmt) cutoff but initial harvest at 10% have average catches that are in the 1,500 tons (1,361 metric tons) range. The average catches increase for the long-term projection (last 10 yr of the simulation). Catches are inversely related to variation in yield, which is higher under those HCRs that have lower average yield, and vice versa. This is due to closures during years when the stock is below the cutoff.

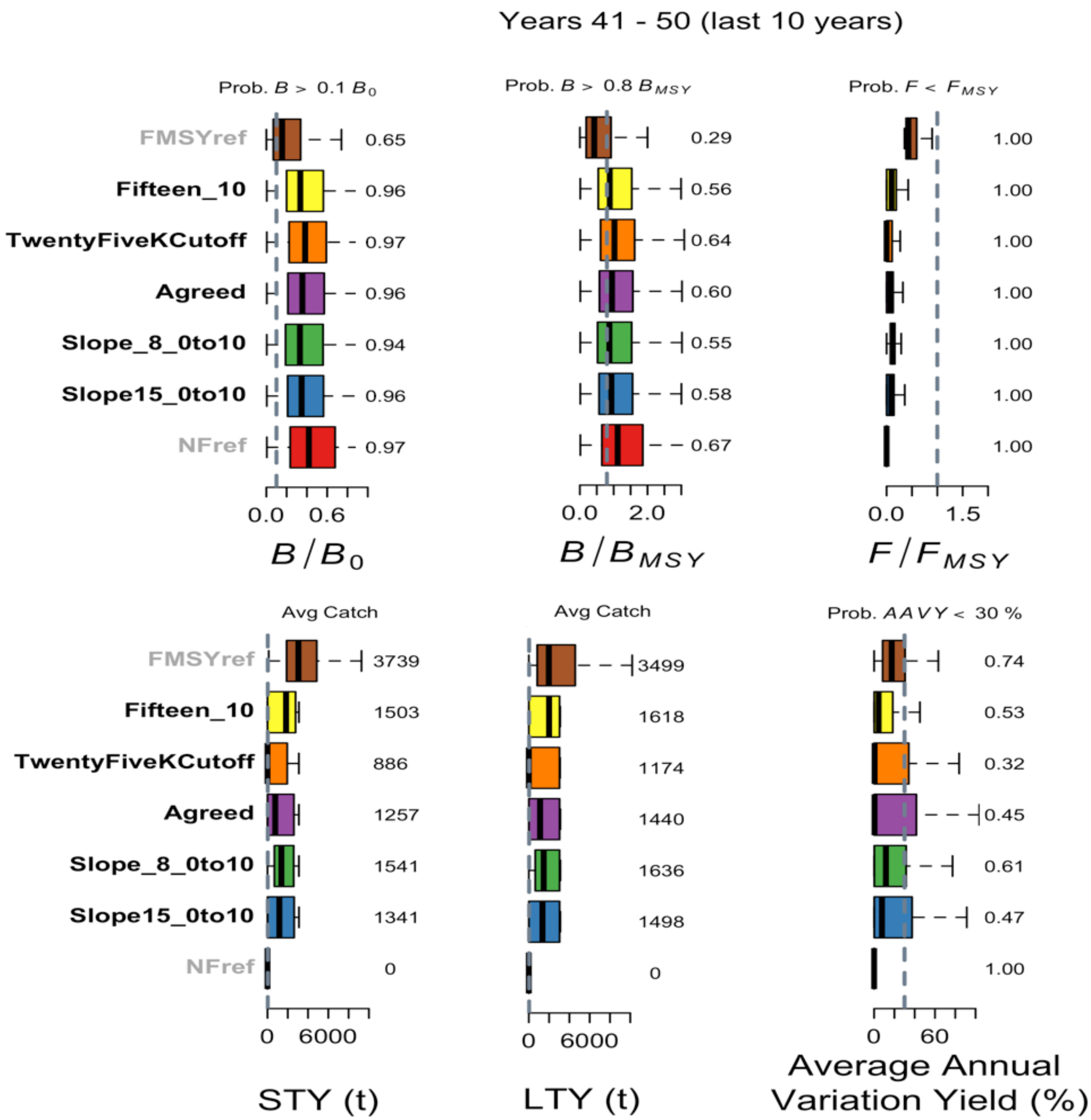


Figure M-7. Boxplots of performance metrics under the base model assumptions. The vertical dashed lines represent performance matrix thresholds.

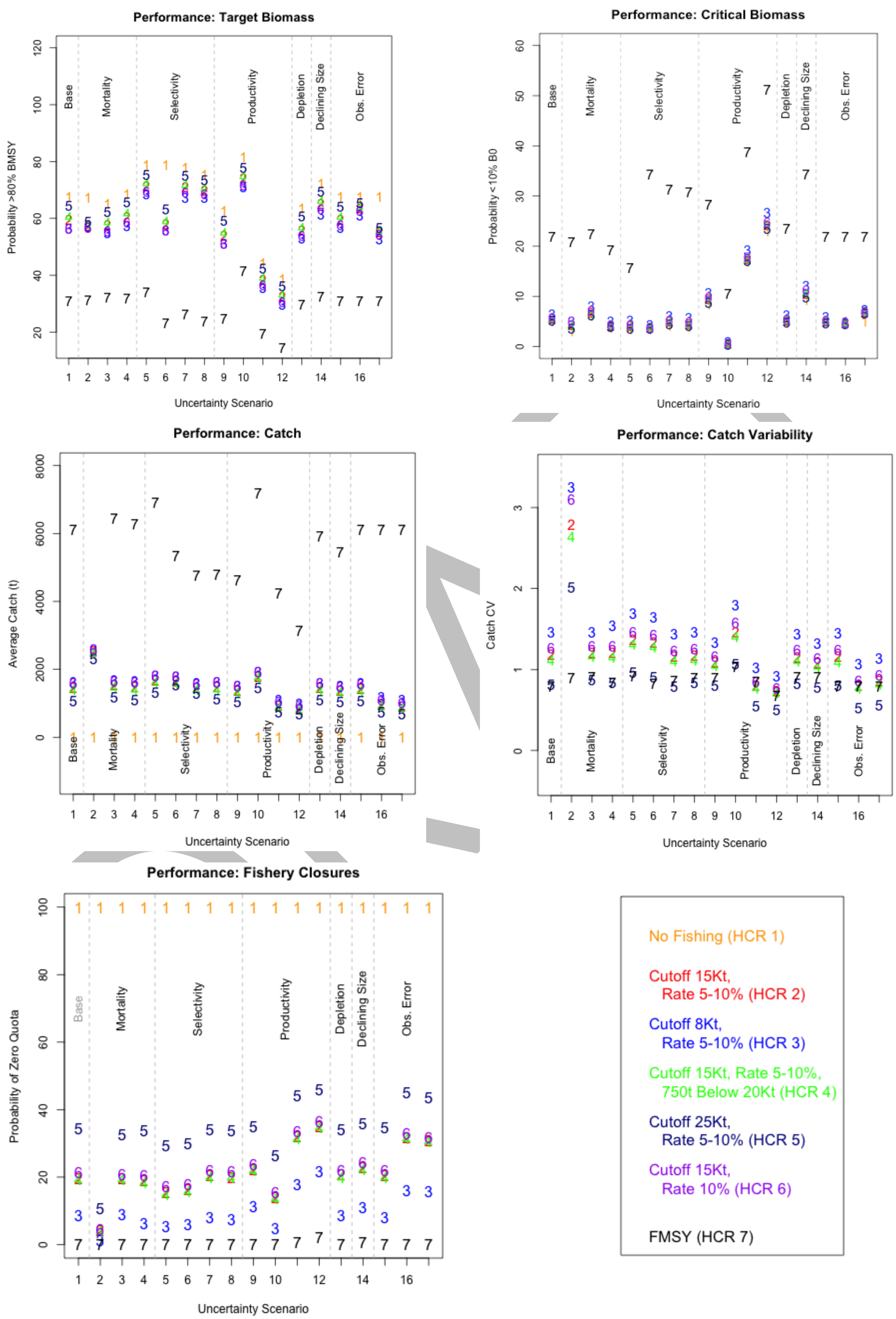


Figure M-8. Performance metrics across all 17 uncertainty scenarios.

Figure M-8 shows the probability of achieving the target biomass across all years and simulations of all 17 uncertainty scenarios. The No Fishing HCR (HCR 1) provides context for the highest possible probability of achieving the biomass target under the assumptions in each uncertainty scenario. The assumptions in each uncertainty scenario change the dynamics of the stock, sometimes in fundamental ways, and so the probability of being above the target (and BMSY itself) is different for each scenario over the 50 yr projection. The exceptions are scenarios 15 through 17, in which only the observation error is different, and so the behavior under HCRs 1 and 7 (which do not depend on the estimate of SSB) are identical to that in scenario 1.

The various mortality scenarios (2 to 4) all increase the natural mortality in different ways. Increasing M with age results in higher catches and lower probabilities of closures across the board, because the higher rate of mortality means that the stock needed to be more productive to achieve the specified depletion at that mortality level. Variable M (scenario 3) resulted in a slightly lower productivity in the stock, and thus the probability of achieving the target biomass was slightly lower across the HCRs considered, as opposed to the slightly higher the probability in this scenario of being under 10% of B0. Increasing M across the years of the scenario had minimal impact on the performance of the HCRs under consideration, though it did increase the variability of that catch.

Lowering the age at maturity while keeping the selectivity curve the same, increases both the probability of being above BMSY under no fishing and average catch at FMSY due to the higher productivity level of the stock that came with increased egg production. Lowering the age at maturity while simultaneously decreasing the selectivity so that all mature fish were vulnerable to the fishing gear means that fishing, even under conservative HCRs, has a higher impact on the stock. However, even with a greater percentage of the spawning stock vulnerable to the fishing gear, the HCRs are able to maintain >50% probability of being above the target. In Scenarios 7 and 8, where the gear selectivity is either domed or uniform above age 3, a smaller percentage of the stock is vulnerable to the fishing gear than in scenario 5.

The assumptions about productivity and variability of the stock have some of the greatest impacts on the performance of the HCRs under consideration. Under the assumption of lower productivity (scenario 9), the stock is less likely overall to be above the target biomass and has a lower probability of being above 10% of B0. However, while the agreed on HCR is able to keep this probability below 10%, HCR 3, with a cutoff of 8 Kt (7 Kmt), surpasses this bench mark under this scenario. In Scenario 10 the variability in the stock is increased and this makes the stock more productive, because of the reduced autocorrelation the stock is more able to bounce back from low stock sizes. Catches are higher and probability of closures are lower under all HCRs in this scenario. Scenarios 11 and 12, in which autocorrelation is increased and, in

Scenario 12, combined with an assumption of low productivity, are very detrimental to the stock. Increased autocorrelation means that periods of lower stock size and a resulting decrease in recruitment reverberate by reducing the productivity of many year classes. Under these scenarios, even the No Fishing Scenario has a greater than 10% probability of being below the 10% of B0. However, the HCRs are able to minimize the impacts of fishing on the stock under those conditions, and keep the probability of the stock falling below this critical biomass threshold to within 2% of the unfished probability. This protection comes at a cost, however, and the probability of closures is very high due to the cutoffs prescribed by the HCRs.

A declining size at age is also detrimental to the long-term productivity of the stock, and results in a 10% probability of the SSB being below 10% B0 even without fishing. This decline in the total length affects the weight of the fish, which affects both the spawning output of the stock and the total biomass. The result is a long-term decline in biomass even without fishing, such that the stock cannot reach its initial "unfished" conditions again. As in the low productivity scenarios, the HCRs tested are able to mitigate biomass impacts under this scenario.

Positive bias in the observation error results in lower probabilities of achieving the target biomass, and higher probabilities of being below 10% of B0. However, we assumed that biases ranged from 30 to 50% above or below the additional survey error, and so a strong directional trend was not always evident in the simulation results. The effects of positive bias was in part lessened by the fact that the vulnerable biomass is only a portion of the total SSB (approximately half). Additionally, the error in this parameter is added to the many other sources of error in these simulations, and so the impacts on the HCR performance generally were not as strong as might otherwise be expected. Given that we generally assume that spawn deposition surveys underestimate the true biomass, the biggest impact of this kind of bias is to the fleet, via reduced catches and increased closures.

Conclusion

These results support the SC's recommendation that the Department use HCR 4 for setting quotas for San Francisco Bay Herring. These simulations were designed to test how robust the agreed upon HCR is to a number of different assumptions about the dynamics of the San Francisco Bay fishery. Many of the uncertainty scenarios were chosen because, under the assumptions within each, the long-term productivity or maximum achievable biomass of the stock decreased, and we wanted to be sure that the HCR would be robust under those conditions. As such, the selection of these scenarios can be thought of as trying to find various "worst case scenarios" that still seem reasonably plausible given what we know about the stock. These scenarios allowed us to understand the likely performance of the HCR should these factors influence the San Francisco Bay Herring stock, either now or at some point during the future.

However, we caution readers from interpreting these results, specifically the average catch or percent closures under these various assumptions, as the actual results that will occur under this HCR. Instead, these results demonstrate that, should the productivity of the San Francisco Bay Herring stock be reduced in these ways, the agreed on HCR can detect the reduction in SSB and adjust harvest rates to safe levels to achieve the two primary stock sustainability objectives, namely, maintaining biomass that has a >50% chance of being above 80% of BMSY, and minimizing the chance of the SSB dropping below 10% of B0 over the next 50 years.

Even with this caution, there may be alarm that closure rates around 20% were common in the scenarios modeled under the agreed on HCR. At first glance there appears to be a strong departure from past dynamics. However, since 1992 the SSB, as estimated from the spawn deposition survey plus the catch (without the hydro-acoustic surveys between 1989 and 2003), has dropped below 15 Kt (14 Kmt) 11 times, and was continuously below this threshold between the 1997-98 and 2002-03 seasons. The simulation results presented here suggest that, had the fishery been closed during that time, the stock may have recovered more quickly.

Like all modeling exercise, this one has a number of limitations. This model does not account for the impact of recreational removals. The magnitude of the recreational catch is unknown, and there is no information with which to parameterize the additional fishing effort, or the effects of a different selectivity for this sector of the fishery. Recreational catch is assumed to be a small fraction of the total removals in most years, because Herring are only available to fishers sporadically, when spawning events occur very near to shore in populated areas. However, there are anecdotal reports suggest that recreational fishing effort has increased in recent year, and recreational removals could have a larger impact on the stock than originally thought.

Another potential source of implementation error that was not considered in this MSE is reduced attainment of the quota in some years. This can be due to a variety of factors, including market conditions, the timing and location of spawns relative to the fishing season and grounds. This analysis assumed that the entire quota was taken in each year, which may be an overestimate of future catches.

Appendix M-A: Operating Model Dynamics

The Operating Model of the DLMtool is a spatial, age-structured operating model that simulates the interaction between a fish population and a fishing fleet.

M-A.1. Conventions

A wide range of parameters and variables are allowed to vary among simulations (e.g., *M*, growth rate, recruitment compensation). All parameters which are random variables that are sampled across simulations are denoted with a tilde (e.g., $\tilde{\sigma}$). Hence, each parameter or variable denoted with a tilde represents a sample from a distribution. For example, the symbol $\tilde{\sigma}$ represents $\tilde{\sigma}_i \sim f(\theta)$ which is the sample of the parameter $\tilde{\sigma}$ corresponding with the i[th] simulation, drawn from a distribution function $f()$, from the operating model parameters θ. By default these are drawn from uniform distributions unless stated otherwise.

In some cases parameters and variables are derived by numerical optimization. The notation *opt* is used to represent optimizing a parameter *p*, to obtain the objective Δ with respect to existing parameters and variables *θ*: *p* = *opt*(Δ | *θ*). For example $q = opt(\tilde{D}|E, \tilde{M}, \tilde{R}_0)$ represents optimization of the catchability *q* in order to obtain depletion $\tilde{D}$ given fishing effort *E*, natural mortality rate $\tilde{M}$ and unfished recruitment $\tilde{R}_0$ (where $\tilde{D}$, $\tilde{M}$ and $\tilde{R}_0$ are all user defined and drawn from distributions).

Management strategy evaluation has two phases: 1) an historical 'spool-up' phase where data are generated and dynamics produced that create current conditions (fishing from 1972 to 2016), and 2) a projection phase where MPs are tested in closed-loop simulation (a 50 yr projection from 2017 to 2066). The last historical year (2016) is referred to as the 'current year' *c*, in this appendix.

M-A.2. Population dynamics

An age-structured model was used to simulate population and fishery dynamics. Numbers of individuals *N* in consecutive years *y* are calculated from those from the previous year and age class *a*, subject to the total instantaneous mortality rate *Z* (there is no 'plus group' and individuals greater than maximum model age n_a are assumed to die):

$$1.\ \mathrm{Ny}+1,\mathrm{a}+1=\sum \mathrm{N}_{\mathrm{y,a,k}}\,\mathrm{e}^{-\mathrm{Z}_{\mathrm{y,a,k}}}$$

Total mortality rate *Z* is the sum of natural mortality (*M*) and fishing mortality (*F*) rates:

$$2.\ Z_{y,a,r}=M_{y,a}+F_{y,a,r}$$

Fishing mortality rate (*F*) calculations are included in section M-A.3. below. Natural mortality rate can vary among ages and years and is calculated:

$$3.\ My,a=\bar{M}\left(1+\frac{\tilde{\theta}_M}{100}\right)^{y-c}+\varepsilon_{M,y}$$

where $\bar{M}$ is the mean natural mortality rate of mature individuals in the current year and ages, $\tilde{\theta}_M$is the percentage annual increase in M over years, n_y is the number of historical years, and $\varepsilon_{M,y}$ is an annual log-normal deviation (Table A.1.).

This parameterization of *M* expressed in Equation 3 is one of the features of the DLMtool. It deliberately allows users the flexibility to include any level of detail in their specification of *M*. Users can only specify mean *M* of mature fish or include any or all of the additional features where appropriate. In uncertainty scenarios where certain parameters are not specified these features are disabled. In addition, it is possible to pass a customized matrix of *M* to the population dynamics model that has dimensions for time and age. Using this feature we also ran a simulation with *M* increasing by linearly from age 3 to age 10, as was recommended by the Cefas review panel:

$$4.\ Ma=\begin{cases}0.2 & 1\le a\ \le 2\\ a*0.1 & 3\le a\le 10\end{cases}$$

By default, DLMtool models growth according to von Bertalanffy model:

$$5.\ Ly,a=L_{y,\infty}\left(1-\exp(-\kappa_y(a-t_0)\right))$$

where κ_y is the growth rate, $L_{y,\infty}$ is the maximum length and t_0 is the theoretical age where length is zero. The growth rate and maximum length parameters have year subscripts because, similarly to *M*, these can vary according to slope parameters.

$$6.\ L_{y,\infty}=\bar{L}\left(1+\frac{\tilde{\theta}_L}{100}\right)^{y-c}+\varepsilon_{L,y}$$

7. $\kappa_y = \bar{\kappa}\left(1 + \frac{\tilde{\theta}_\kappa}{100}\right)^{y-c} + \varepsilon_{\kappa,y}$

Maturity (m_a) was assumed to be age dependent, and was borrowed from values estimated by Hay (1985) in British Columbia. There are no estimates of the age at maturity for any California Herring stocks, but Herring in San Francisco Bay are thought to begin to mature at age 2 and are mature by age 3. Given the latitudinal cline observed in Herring vital rates, San Francisco Bay Herring may mature earlier than Herring in BC, and so an alternate maturity ogive was explored in uncertainty Scenarios 5 and 6.

The numbers of individuals recruited to the first age group $N_{y,a=1}$ in each year y is calculated using a Beverton-Holt stock-recruitment relationship with log-normal recruitment deviations $\varepsilon_{R,y}$:

8. $N_{y+1,a=1} = \varepsilon_{R,y} \frac{4\tilde{h}R_0 S_y}{S_0(1-\tilde{h})+(5\tilde{h}-1)S_y}$

, and numbers at age N:

9. $S_{y,r} = \sum_{a=1}^{n_a} m_a W_a N_{y,a}$

and the density-dependence parameter β is given by:

10. $\beta R = \frac{4\, ln(5\tilde{h})}{5\, S_0}$

The steepness (recruitment compensation) parameter $\tilde{h}$ is sampled from a uniform distribution. Unfished spawning biomass S_0 is calculated from unfished recruitment $\tilde{R}_0$ and survival to age a:

11. $S0 = \sum_{a=1}^{n_a} m_a\, W_a\, \tilde{R}_0\, e^{\sum_{i=1}^{a} M_{1,i}}$

Weight-at-age W_a, is assumed to be related to length by:

where the spawning biomass S in a given year is the summation over ages of the maturity at age m, weight at age W

12. $Wy, a = \beta_W\, {L_{y,a}}^{\alpha_W}$

Log-normal recruitment deviations ε_R include both error and temporal autocorrelation. A series of initial error terms are sampled from a log-normal distribution with mean 1 and standard deviation $\tilde{\sigma}_R$:

13. $\dot{\varepsilon}_{R,y} \sim LN(1, \tilde{\sigma}_R)$

To these initial error terms, temporal autocorrelation θ_{AC} is added:

14. $\hat{\varepsilon}_{R,y} = \tilde{\theta}_{AC}\, \dot{\varepsilon}_{R,y-1} + \dot{\varepsilon}_{R,y}\sqrt{\left(1 - {\tilde{\theta}_{AC}}^2\right)}$

Initial numbers at age (first historical year) were calculated according to unfished recruitment $\tilde{R}_0$, log-normal recruitment deviations ε_R the equilibrium fraction of the stock under unfished conditions.

15. $N_{1,a,r} = \tilde{R}_0 \, e^{\sum_{i=1}^{a} M_{1,i}} \, \varepsilon_{R,y-a}$

Table M-A-1. Sampled parameters controlling variability in stock dynamics

Symbol	Description	Default distribution	Sampled parameter
$\varepsilon_{M,y}$	Inter-annual variability in natural mortality rate	$\varepsilon_{M,y} \sim dlnorm(1, \tilde{\sigma}_M)$	$\tilde{\sigma}_M$
$\varepsilon_{L,y}$	Inter-annual variability in von Bertalanffy growth rate	$\varepsilon_{\kappa,y} \sim dlnorm(1, \tilde{\sigma}_\kappa)$	$\tilde{\sigma}_\kappa$
$\varepsilon_{\kappa,y}$	Inter-annual variability in maximum length	$\varepsilon_{L,y} \sim dlnorm(1, \tilde{\sigma}_L)$	$\tilde{\sigma}_L$
$\varepsilon_{R,y}$	Inter-annual variability in recruitment	$\dot{\varepsilon}_{R,y} \sim LN(1, \tilde{\sigma}_R)$	$\tilde{\sigma}_R$
	Temporal autocorrelation in recruitment	$\hat{\varepsilon}_{R,y} = \tilde{\theta}_{AC} \, \dot{\varepsilon}_{R,y-1} + \dot{\varepsilon}_{R,y} \sqrt{\left(1 - \tilde{\theta}_{AC}^{\,2}\right)}$	$\tilde{\theta}_{AC}$
	Period (wavelength) of cyclical recruitment	$\varepsilon_{R,y} = \hat{\varepsilon}_{R,y} \left(1 + sin\left(\frac{\tilde{U}n_y + 2y\pi}{\tilde{\theta}_{period}}\right) \tilde{\theta}_{amplitude}\right)$	$\tilde{\theta}_{period}$
	Amplitude of cyclical recruitment		$\tilde{\theta}_{amplitude}$

M-A.3. Fishing dynamics

Fishing mortality rate *F* is calculated according to a catchability coefficient, annual effort *E*, age-selectivity *s*, the retention rate (probability of retaining a fish given it is caught) *R*, the discard mortality rate $\tilde{\theta}_{Mdisc}$ (fraction of released fish that die):

16. $F_{y,a,r} = q\, E_y\, s_{y,a}$

The catchability coefficient is calculated by numerical optimization such that stock depletion in the current year matches user-specified depletion $\tilde{D}$ (spawning biomass relative to unfished levels):

17. $q = opt\left(\tilde{D} \mid E_y, s_{y,a}, R_a, \tilde{\theta}_{Mdisc}, M, \tilde{h}, W\right)$

Meeting the condition:

18. $\frac{S_c}{S_0} = \tilde{D}$

Vulnerable biomass *V* in each year is the product of numbers *N*, weight *w* and age selectivity *s*:

19. $Vy = \sum_{a=1}^{n_a} N_{y,a}\, W_{y,a}\, s_{y,a}$

The selectivity at age, $s_{y,a}$, was assumed to be age specific, and was initially based on the Cefas stock assessment outputs of selectivity at age. Historical selectivity at age changed in 1998 to reflect the elimination of round haul gear, which selected smaller, younger fish. The selectivity in the forward projections was assumed to be the current selectivity, and no changes were modeled.

In historical simulations, catch in numbers *C*, are calculated using the Baranov equation:

20. $C_{y,a} = N_{y,a}(1 - e^{-Z_{y,a}})\frac{E_y\, s_{y,a}\, R_a}{Z_{y,a}}$

In projected years when the fishery is controlled via TACs (limits on the weight of landings) the equations are reversed and fishing mortality rates are calculated from prescribed catches. We assumed that TACs are implemented perfectly in this fishery. Fishing mortality rates are then calculated from the TAC subject to the constraint that they do not exceed user-specified F_{max}.

M-A.4. Observation model

The HCRs tested in this analysis rely on an estimate of the absolute SSB each year. Here we simulate two kinds of error that may affect the reliability of this estimate. The estimate can include consistent biases (e.g. underestimates) in addition to error (e.g. lognormal observation error in annual catches).

Annual observed Spawning Stock Biomass (*S*) is calculated by multiplying numbers-at-age *N* by weight-at-age *W* and maturity-at-age *m* and adding observation error and bias through a factor term ω:

21. $S_y^{obs} = \omega_{B,y} \sum_a^{n_a} N_{y+1,a+1} m_a W_a$

The biomass factor ω_B includes both bias $\tilde{b}_B$ and imprecision $\tilde{\sigma}_B$ in observations.

22. $\omega_{B,y} = \tilde{b}_B \, exp\left(\varepsilon_{B,y} - \frac{\tilde{\sigma}_B}{2}\right)$

where bias $\tilde{b}_B$ is an improper fraction (e.g. $\tilde{b}_B$ = 1.2 is equivalent to a 20% positive bias) and the lognormal error term ε, is drawn from a standard normal distribution whose standard deviation $\tilde{\sigma}_B$ is sampled at random in each simulation:

23. $\varepsilon_{B,y} \sim N(0, \tilde{\sigma}_B)$

By default DLMtool samples simulation-specific observation error $\tilde{\sigma}_B$ from a uniform distribution.

24. $\tilde{\sigma}_B \sim U(LB_B, UB_B)$

and bias $\tilde{b}_B$ from a log-normal distribution:

25. $\tilde{b}_B = \ exp\left(\varepsilon_{bB} - \frac{\sigma_{bB}}{2}\right)$

26. $\varepsilon_{bB} \sim N(0, \sigma_{bB})$

This convention means that the user can specify an unbiased (e.g. low σ_{bB} and therefore sampled values of $\tilde{b}_B$ close to 1) or a biased (e.g. high σ_{bB} and therefore sampled values of $\tilde{b}_B$ substantially lower or higher than 1) time series that can be observed with a low degree of error (e.g. low sampled values of $\tilde{\sigma}_B$ specified by lower LB_B and UB_B) or high degree of error (e.g. high sampled values of $\tilde{\sigma}_B$ specified by higher LB_B and UB_B).

Appendix M-B: Additional Figures

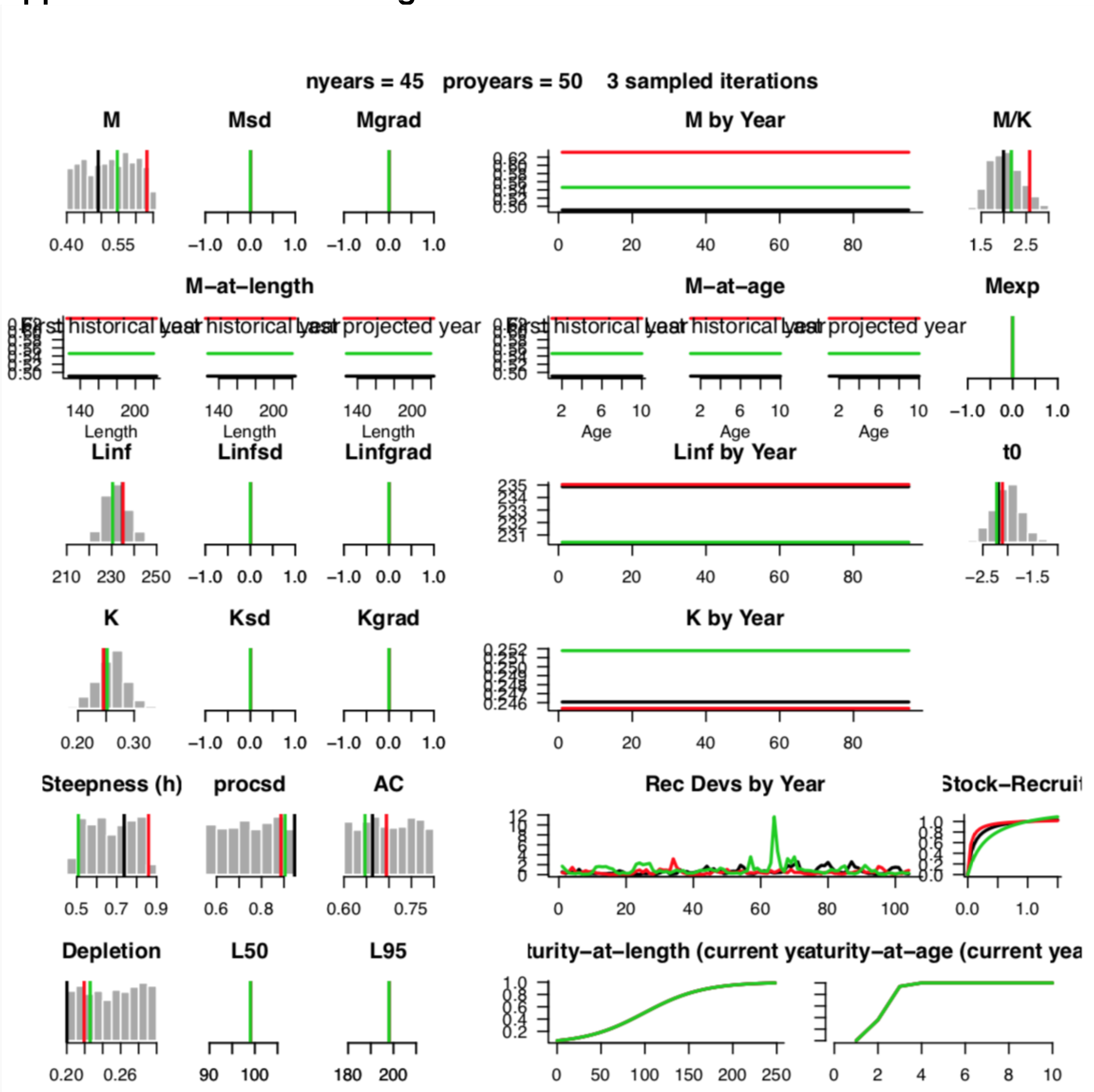


Figure M-B-1. Sampled derived biological parameters for San Francisco Bay Herring under the base model assumptions.

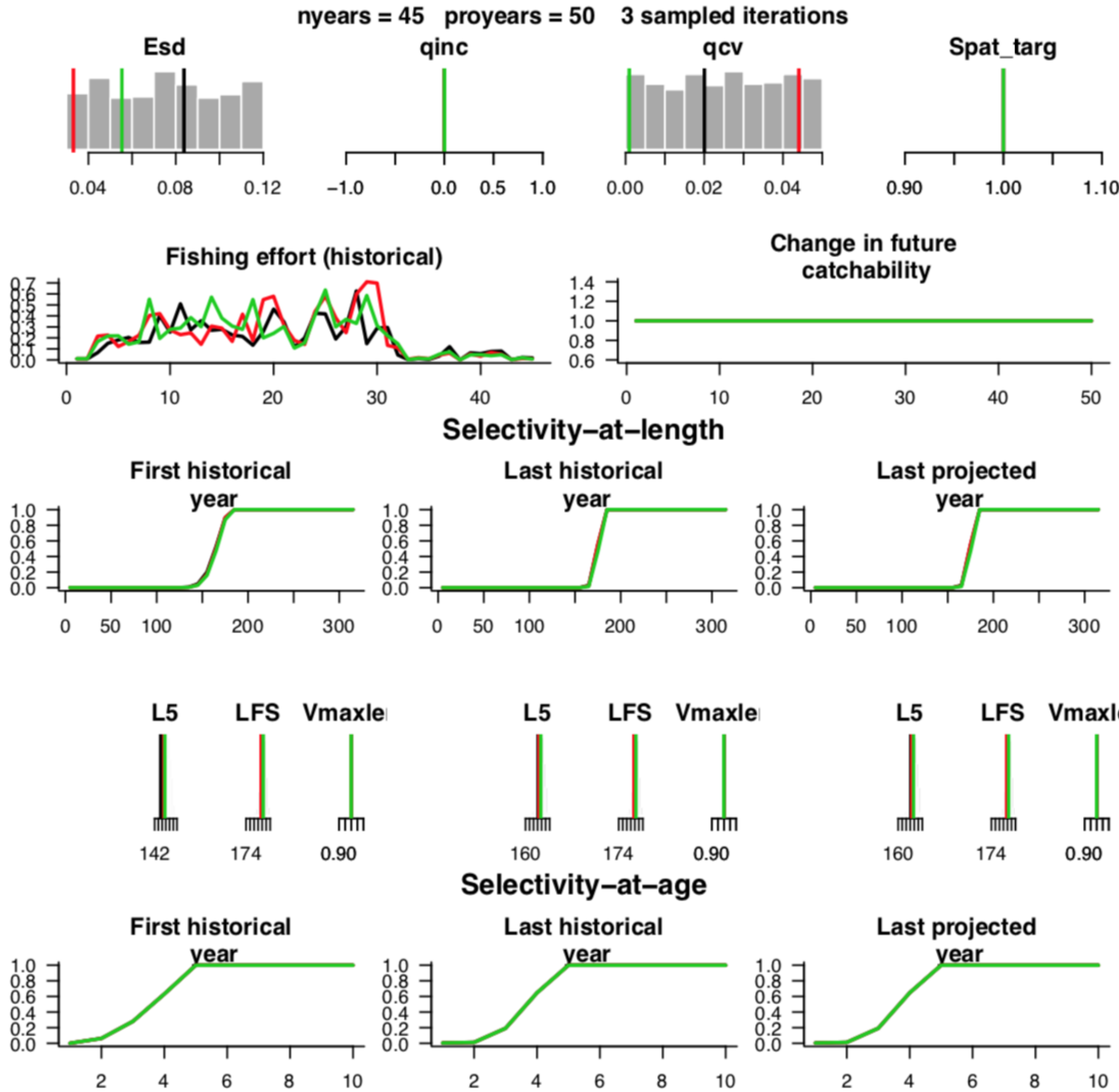


Figure M-B-2. Sampled and derived fleet parameters for San Francisco Bay Herring under the base model assumptions.

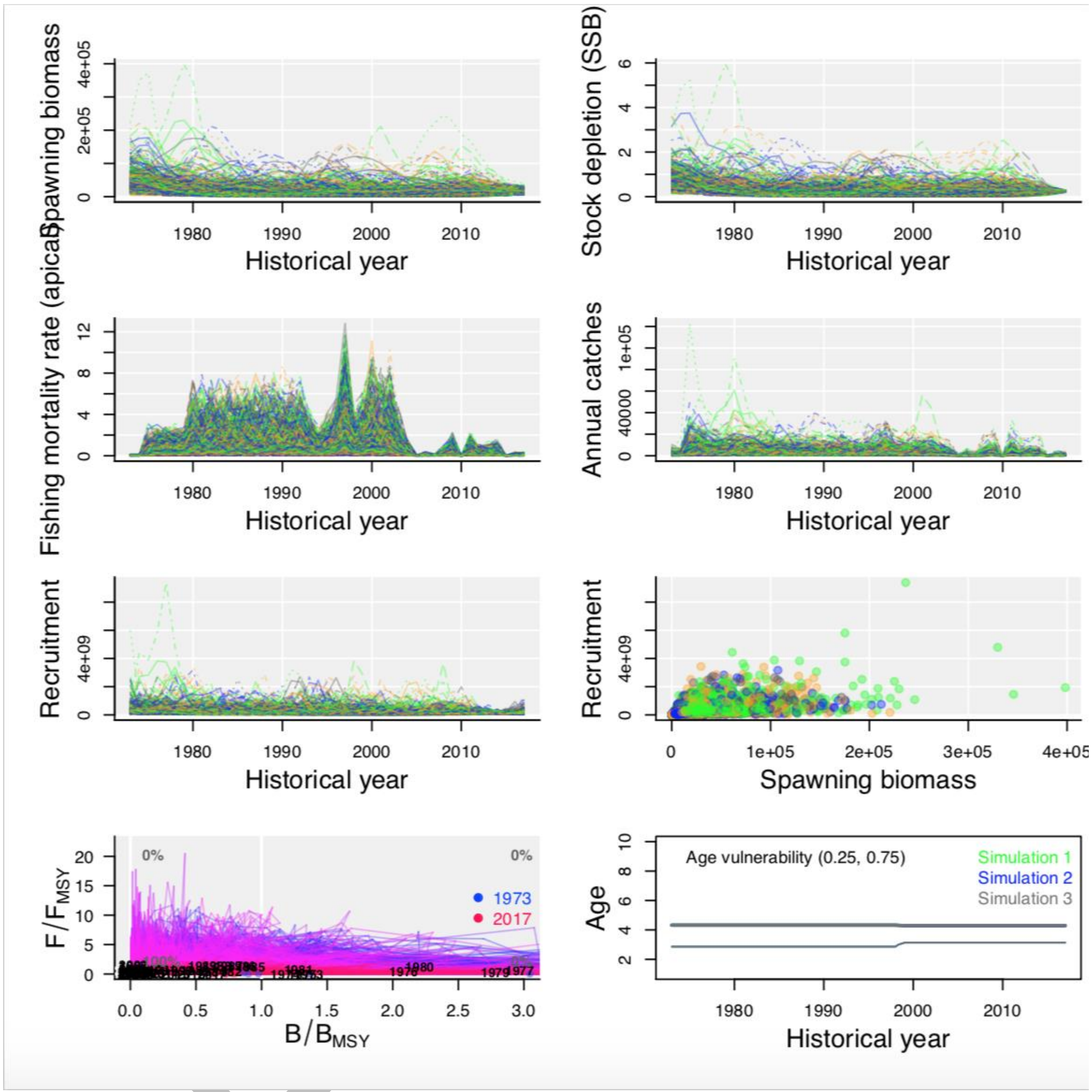


Figure M-B-3. Historical simulations under base model assumptions.

Appendix N HEOK Quota Considerations

This Fishery Management Plan (FMP) establishes a new management procedure for setting the Herring Eggs on Kelp (HEOK) sector quota as part of the commercial Pacific Herring (Herring), *Clupea pallasii,* fishery in the San Francisco Bay management area. Previously, the HEOK sector quota was allocated a proportion of the total San Francisco Bay quota. The HEOK quota was expressed as its 'equivalent' whole fish weight, subtracted from the total San Francisco Bay quota and then converted to the total HEOK product weight quota. The HEOK quota was then assigned to individual permits that elected to fish that sector.

During FMP development a wide range of exploitation rates were evaluated while building the Harvest Control Rule. At that time Department of Fish and Wildlife (Department) staff explored the HEOK relationship to the overall quota and examined potential impacts on the spawning stock through egg removals. Appendix A documents the available information on survival rates of Herring eggs to adult fish, both in the literature and from the available data from San Francisco Bay, which suggests that only a tiny fraction of eggs laid survive to return as spawners. Based on this information, along with the information presented in this document describing the small percentage of total eggs removed by the HEOK sector each year, the impact of HEOK removals on the sustainability of the San Francisco Bay Herring population is likely to be negligible. As a result, this FMP establishes a new method to determine HEOK quotas.

One of the changes that will occur as part of the implementation of this FMP is an update to the permitting system. Originally, HEOK participants were gill net permit holders that elected to convert their permits to a HEOK permit each year. As such, HEOK quotas were originally set by transferring a proportion of the total gill net quota to HEOK quotas. However, the fisheries are very different and the FMP presents an opportunity for the Department to restructure the permitting and quota setting processes such that HEOK permits are completely separate from gill net permits. As part of the implementation of this FMP the HEOK quota will be set at a product weight equal to 1% of the total quantity of eggs produced by the estimated Spawning Stock Biomass (SSB), rather than by converting a percentage of the gill net quota. The remainder of this appendix summarizes the historical relationship between estimated SSB and the quantity of eggs spawned by that stock during spawning season, as well as historical quotas and exploitation rates by the HEOK sector.

Stock Size and Quantity of Eggs Spawned

From the 1989-90 season (when the HEOK fishery began) through the 2017-18 (most recent) season, reported SSB in San Francisco Bay has ranged from a minimum of 4,844 short tons (4,394 metric tons) in 2008-09 to a maximum of 145,053 tons (131,590 metric tons) in 2005-06. The average reported SSB during this period is 44,229 tons (40,124 metric tons). The quantity of eggs spawned by a given season's SSB can be calculated based on a San Francisco Bay Herring fecundity estimate of 113 eggs/gram body weight of combined 50:50 male to female fish (Reilly and Moore, 1986; Spratt, 1986). At this estimated fecundity, 1 ton (0.9 metric tons) of 50:50 male to female sex ratio Herring produce 102 million eggs. First, annual escapement must be calculated by subtracting annual sac-roe sector fishery mortality (landings) from reported SSB (fishery mortality occurs prior to spawning, but landed fish are still considered to be part of the total SSB). During the same 1989-90 through 2017-18 period, the quantities of eggs produced annually by the portions of the spawning stock that escape fishery mortality range from a minimum of 0.5 trillion eggs to a maximum of 14.8 trillion eggs. The average annual egg production during this period is equal to 4.2 trillion eggs.

Quotas and Intended Harvest Percentage

The historical quota for HEOK in San Francisco Bay (1989-90 to 2017-18) has ranged from a minimum of 12.3 tons (11.2 metric tons) of HEOK product (excluding the 2009-10 season, during which commercial Herring fishing was closed) to a maximum of 286 tons (259 metric tons), with an average of 69.1 tons (62.7 metric tons) of product. This equates to a minimum of 5.6 billion eggs and a maximum of 130.4 billion eggs, with an average of 31.5 billion individual eggs taken by the San Francisco Bay HEOK sector annually.

Since quotas are set prior to the season during which they are applicable, it is useful to consider annual HEOK quota as a percentage of the eggs spawned during the prior season. This allows for a consideration of historical HEOK quotas in terms of the 'intended harvest percentage' being provided to the sector. The concept of intended harvest percentage is grounded in the idea that, despite substantial observed year-to-year variability in SSB (and thus the number of eggs produced each year), absent a predictive model, the most recent stock estimate is the best indicator of anticipated stock size available to fishery managers. Using the egg production based on observed SSB and HEOK quota egg number equivalencies above, during the 1989-90 to 2017-18 season period, intended harvest percentages for HEOK have ranged from a minimum of 0.10% to a maximum of 1.38%, with an average of 0.76% (Figure N-1). This suggests that the proposed mechanism of setting quotas at 1% of the SBB estimate would be in line with the quotas that have been set historically.

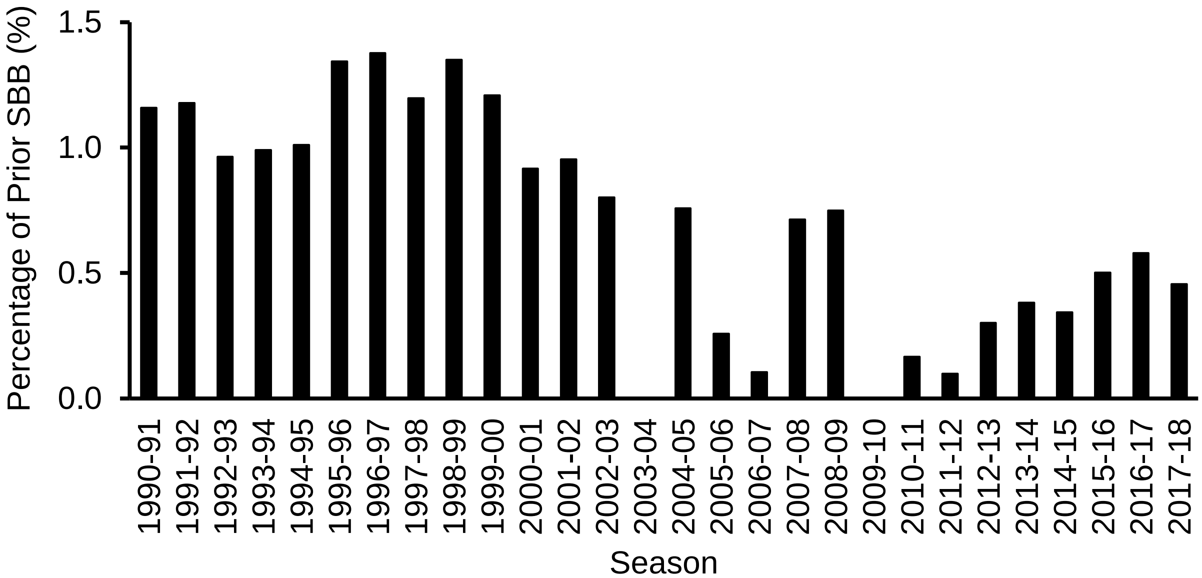


Figure N-1. HEOK quota as a percentage of the previous season SSB estimate from the 1990-91 to 2017-18 season. Note that in the 2003-04 season there was no SSB estimate available, and in the 2009-10 season the fishery was closed.

Landings and Exploitation Rate

Annual landings of HEOK product are reported and historical landing amounts are available in units of short tons of product landed. Considering only years during which landings occurred in this sector of the fishery, these landings range from a minimum of 3.3 tons (3.0 metric tons) to a maximum of 185.7 tons (168.5 metric tons), with an average of 48.3 tons (43.8 metric tons) of product landed annually during years when landings occurred (Figure N-2). Annual landings in tons of HEOK product can also be expressed as number of eggs taken by the HEOK sector of the fishery using the estimated tonnage of Herring required to produce a ton of HEOK product (roughly 4.47 ton (4.06 metric tons) of whole fish) (Spratt, 1992), along with the above fecundity estimate. In numbers of eggs removed, HEOK landings during the 1989-90 to 2017-18 season period have ranged from a minimum of 1.5 billion eggs to a maximum of 85.1 billion eggs, with an average of 22.6 billion eggs (Figure N-1, right axis).

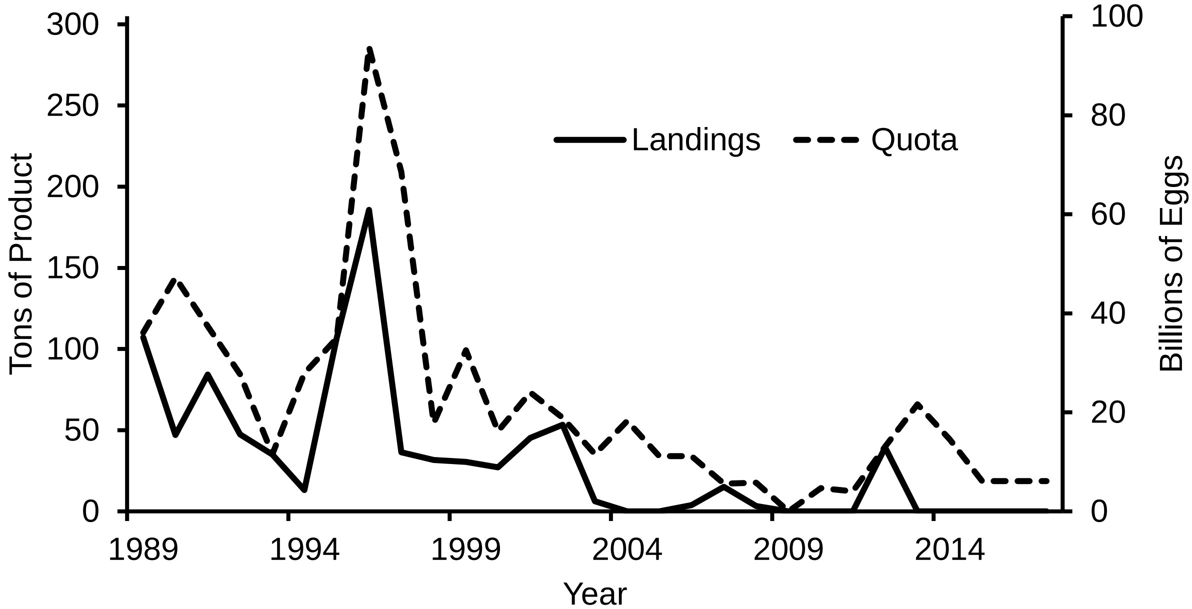


Figure N-2. Historical HEOK landings and quota in tons of product (left axis) and billions of eggs (right axis) between the 1989-90 season and the 2017-18 season. Note there has been no HEOK fishing since the 2012-13 season.

Exploitation rate for the HEOK sector is defined as the amount of product actually landed during a given season relative to the amount of total spawn produced by the SSB during that same season. For years that landings were made by the HEOK sector during the 1989-90 to 2017-18 season period, exploitation rate has ranged from a minimum of 0.16% to a maximum of 1.34%, with an average exploitation rate of 0.56% during that period. This means on average, the HEOK fishery has removed half a percent of the total eggs laid by the Herring stock each season. The fishery has been unable to attain the quota during some of years, in part because it is difficult to induce Herring to spawn on rafts that are tied up in stationary locations. In other years, no fishing occurred due to market reasons.

Appendix O Scientific Review of the Draft Fishery Management Plan for Pacific Herring

Final Report of the Scientific and Technical Review Panel

Scientific review of the draft Fishery Management Plan for Pacific herring (*Clupea pallasii*)

Convened by the California Ocean Science Trust

Supported by the California Ocean Protection Council

October 2018

CALIFORNIA OCEAN SCIENCE TRUST

Review Participants

CALIFORNIA OCEAN SCIENCE TRUST

California Ocean Science Trust is a boundary organization. We work across traditional boundaries, bringing together governments, scientists, and citizens to build trust and understanding in ocean and coastal science. We are an independent non-profit organization established by the California Ocean Resources Stewardship Act (CORSA) of 2000 to support managers and policymakers on the U.S. West Coast with sound science, and empower participation in the decisions that are shaping the future of our oceans. For more information, visit our website at www.oceansciencetrust.org.

Ocean Science Trust served as the independent appointing agency in alignment with the Procedural Guidelines for the California Department of Fish and Wildlife's Ad Hoc Independent Scientific Advisory Committees. Ocean Science Trust convened the review panel and designed and implemented a scientific review process that promoted objectivity, transparency, and scientific rigor (see Appendix A).

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CALIFORNIA DEPARTMENT OF FISH AND WILDLIFE

The mission of the Department of Fish and Wildlife is to manage California's diverse fish, wildlife, and plant resources, and the habitats upon which they depend, for their ecological values and for their use and enjoyment by the public.

California Department of Fish and Wildlife staff were engaged throughout the review process. They delivered presentations to the review panel and supplied additional data, information, and feedback to Ocean Science Trust as necessary throughout the review process.

Ryan Bartling, Environmental Scientist, California Department of Fish and Wildlife, was the primary management contact for this review.

Table of Contents

Recommended citation: Hazen E, Okamoto D, Selden R, and Szuwalski C. Final report of the scientific and technical review panel: Scientific review of the draft Fishery Management Plan for Pacific herring (*Clupea pallasii*). California Ocean Science Trust, Oakland, CA. October, 2018.

Photo credits: CDFW (front cover, p 5, 6, 13, 21, 23); creative commons (p 9, 10, 15); Ryan Meyer (p 18); OST (back cover)

Background

The San Francisco Bay Pacific herring (*Clupea pallasii*) population supports a valuable fishery for herring roe (kazunoko), and a smaller herring-eggs-on-kelp (komochi or kazunoko kombu) fishery. San Francisco Bay also supports a limited commercial fresh fish and recreational fishery. The California Department of Fish and Wildlife (CDFW) developed a draft fishery management plan (FMP) to guide commercial and recreational fisheries for Pacific herring to ensure sustainable fishing levels.

FMPs assemble information, analyses, and management options to guide the management of the fishery by CDFW and the Fish and Game Commission (Commission). The FMP becomes effective upon adoption by the Commission, following their public process for review and revision. Thus, it is important for the scientific underpinnings of the draft FMP to have undergone independent review prior to submission to the Commission. External, independent peer review of the scientific underpinnings of the draft FMP is one way to provide the Commission and stakeholders assurances that FMPs are based upon the best readily available scientific information, as set forth under the Marine Life Management Act (MLMA).

REVIEW SCOPE

Ocean Science Trust worked with CDFW to develop a scope of review focusing on the scientific and technical elements of the proposed management framework that will guide fishery management decisions for the San Francisco Bay Pacific herring stock in the Pacific herring draft FMP and supporting materials. Thus, the review is not intended to be a comprehensive assessment of the entire draft FMP or the proposed approach to management contained therein, but rather focuses on key components identified below. This review focussed on whether the available data and predictive model that underpin the proposed draft FMP management strategy are applied in a manner that is scientifically sound, reasonable, and appropriate. Therefore, the central question of this review was:

Given CDFW's available data streams and analysis techniques, are the applications of the analyses to the integrated management strategy scientifically sound, reasonable, and appropriate?

Specifically, the review focused on evaluation of the following components of the draft FMP:

1. The accuracy and representation of existing literature on the biology of the stock and in the essential fishery information
2. The proposed spawning stock biomass thresholds and associated harvest rates underpinning the catch quota decision making process and signaling when the fishery may warrant management response
3. The decision matrix of ecosystem indicators and the rationale behind the inclusion of these ecosystem indicators in management
4. The science underpinning additional conservation and management measures
5. Identification of research and methods needed to improve assessments and fishery management in the future

For clarity we note that the following are not included in the scope of the current review:

- The data collection protocol, as it has been reviewed previously.
- The new predictive SSB model for spawning stock biomass, as the model underwent separate peer review and was published (Sydeman et al., 2018).

SUMMARY OF THE REVIEW PROCESS

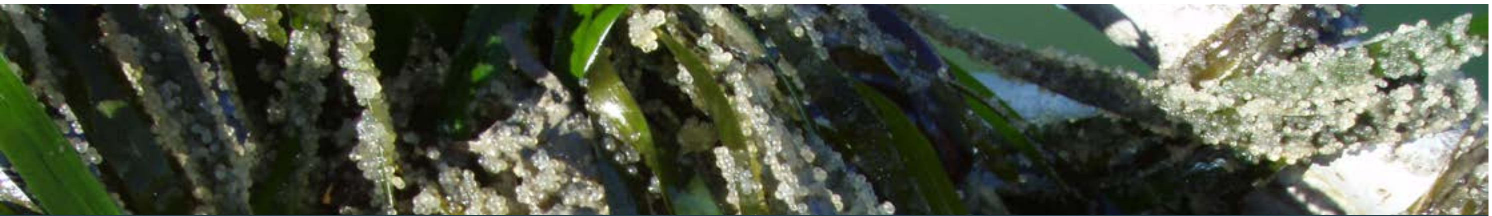
This review took place from February 2018 - October 2018. Ocean Science Trust implemented a scientific review process that sought to promote objectivity, transparency, candor, efficiency, and scientific rigor. Following a broad solicitation for potential reviewers, coordinated via the Ocean Protection Council Science Advisory Team, a multidisciplinary, four-member review panel was assembled, representing expertise in fisheries science and management, marine ecology, stock assessment, and modeling. Ocean Science Trust facilitated constructive interactions between reviewers and CDFW through a series of remote meetings, where CDFW staff provided reviewers with the management context, presented an overview of the science and technical elements under review, and were available to answer reviewers' questions. In addition, Ocean Science Trust convened reviewers independently to allow the review panel to candidly discuss the review materials and conduct their assessment. Ocean Science Trust worked with the review panel to assemble and synthesize their written and verbal responses to guiding questions, as well as discussion from remote meetings into this final report. This report is publicly available on the Ocean Science Trust website.

PROJECT MATERIALS UNDER REVIEW

The following materials were provided by CDFW to the review panel for scientific and technical review:

- Draft Pacific herring Fishery Management Plan, Chapters 2-8.
- Draft Pacific herring Fishery Management Plan Appendices, 200 pages.

Additional data and information were provided by CDFW at the request of the review panel to assist with their assessment throughout the review process.



Review and Recommendations

Foremost, the review panel acknowledges the impressive effort that went into developing the management strategy in the Pacific herring draft fishery management plan (FMP) by the California Department of Fish and Wildlife (CDFW), the Pacific herring Steering Committee, other stakeholders, and outside experts, including the Farallon Institute. The preparers of these documents have thoughtfully considered a diverse amount of information. CDFW produced a management approach for the San Francisco Bay Pacific herring stock that integrates economic, ecological, and population considerations in a simple, flexible, and precautionary framework. The commitment to sustainability is clear, with a focus on minimizing years of a depressed stock, maintenance of a healthy age structure, maintenance of an economically viable fishery, and ensuring Pacific herring remain an important component of the ecosystem. The review panel believes these goals are both appropriate and commendable.

There are, however, details and further considerations that may improve the overall draft FMP and future performance against objectives. Additional scientific guidance and considerations are included that would produce a more scientifically robust FMP, as well as longer-term recommendations, data, and research needs that would strengthen the science contained within the draft FMP and its ability to inform management as new information and analyses become available. These recommendations will be addressed in more detail in the following sections.

This assessment is structured around the key focal areas identified in the scope of review (page 4). These recommendations aim to improve the science supporting the proposed management framework and, where possible, provide insight on the implications of each recommendation.

In addition to the recommendations included in this assessment, reviewers also provided in-text comments to CDFW. These comments did not substantially change the content of the draft FMP, but supported the improvement of the FMP document. Any comment that required additional discussion was pulled out and included in this report. In-texts comments included:

- The addition of citations
- Suggested edits to language for clarity and comprehension

Below are the scientific review panel's recommendations. Recommendations are identified as those that CDFW should address prior to adopting the FMP, and those that are longer-term considerations, which could be addressed following adoption of the FMP.

1. ESSENTIAL FISHERY INFORMATION

In accordance with the Marine Life Management Act (MLMA) sustainability objectives, CDFW is required to collect and maintain the most up-to-date Essential Fishery Information (EFI). The EFI includes information about species biology and life history, habitat requirements, population dynamics, fishing effort, catch level, socio-economic value of the fishery, and other information that would permit the fishery to be managed sustainably. The draft FMP also outlines how to address missing or outdated EFI.

Overall, reviewers found the representation of the existing literature on the biology of the stock was accurate and considered much of the core and relevant information. However, the panel did have recommendations for where clarification would be helpful and additional information gaps could be filled. Section 1.1 contains key recommendations that would allow for greater clarity and a more robust approach and should be considered before adopting the FMP. Section 1.2 includes recommendations that could improve the management of the fishery but are not imminent priorities and/or may require longer-term investment and research.

1.1 Key recommendations

1.1.1 Fecundity

Mass-specific fecundity is a core component of calculating spawning biomass from egg deposition surveys. The current estimates of fecundity and the relationship with weight, as stated within the draft FMP, require further justification. Specifically, it is well known that fecundity per unit mass varies with mass and length, as well as environmental conditions in herring. As a result, applying a single mass specific conversion requires justification. For example, this may be as simple as providing evidence that mass-specific fecundity is reasonably close to consistent regardless of female body mass, and is relatively time-invariant. Moreover, the rationale for monitoring fecundity infrequently, and how that information is used to update estimates, requires discussion. Specifically, Chapter 3 notes that,

> *"Direct fecundity measurements are resource intensive, and so the Department only measures fecundity periodically (approximately once a decade; R. Bartling, Personal Communication). Currently, the Department assumes a fecundity rate of 217eggs/g for females in San Francisco Bay, though a recent estimate suggests that fecundity may have declined during the warm water conditions between 2013 and 2016 (Table 3-5). The fecundity, along with the sex ratio of each observed spawning wave, is used to calculate the total weight of fish that must have laid the number of eggs observed in spawn surveys."*

Collecting higher-resolution information on fecundity should be an important part of EFI and lack of this information should be discussed and justified beyond the fact that they are resource intensive. Moreover, what "approximately once a decade" means should also be described in either in text or in a table with actual information about sampling years, estimates, and plans for continuation of collection of these data. These recommendations are included as a priority, in part, because using outdated or poor estimates of fecundity can impose substantial bias on estimates of spawning biomass.

1.1.2 Spatial and temporal variation

More clarity on the spatial structure of the Pacific herring populations, including maps, graphics and detail to describe how and why populations vary over time is needed.

Additionally, it was not immediately clear in the current draft how spatial information included fit together to inform the management strategy. Questions around whether spatial samples of age structure and sex-ratio are weighted by biomass need to be addressed. If not, skewed sex ratios or age structure from small spot spawns may disproportionately affect overall estimates if they have similar sample sizes for these metrics. It would also be useful to consider if spatial distributions of biomass could be used to inform when and where fisheries occur.

Similar to spatial information, it is currently unclear how temporal information is aggregated to inform the management strategy. Specifically, spawning waves often vary in sex ratios, size-at-age, and age structure. The draft FMP should describe how this information is brought together and whether, during sampling, there is a concerted effort to capture this variation.

1.1.3 Rapid Spawn Assessment Method

The reviewers recognize the potential value of an efficient alternative to the current survey protocols for use in areas outside of San Francisco Bay. However, the current description of the Rapid Spawn Assessment Method lacks sufficient detail. Reviewers would like to see specifics about methods of data collection, data produced, their utility, and a summary of results/products thus far included in the draft FMP. To assess the validity of the method, CDFW should also provide any information on, or plans for, assessment of this approach when applied to data-rich San Francisco Bay. Specifically, are quantitative or qualitative trends comparable between the full spawning protocols and the Rapid Spawning Assessment Method in San Francisco Bay? It would also be useful to provide information on potential costs as compared to current data collection protocols. In sum, if this approach is to be included in the FMP, please provide sufficient detail to evaluate its efficacy and purpose; otherwise, it should be removed.

1.1.4 Monitoring of young-of-year (YOY)

The proposed statistical model used for forecasting spawning stock biomass relies on indices of abundance of YOY. These data are thus a core priority for managing this fishery. The FMP should therefore adequately address the importance of conducting these surveys annually and with sufficient investment to ensure data quality that matches or exceeds recent records used to calibrate the statistical models.

1.2 Longer-term recommendations

While CDFW has an abundance of EFI for the San Francisco Bay Pacific herring stock, they should consider additional data sources and/or research and monitoring in support of acquiring and maintaining the most up-to-date EFI to support a sustainable Pacific herring stock. These data may include higher resolution monitoring of female fecundity, spatial and temporal genetic structure, spatial variation in growth rates, habitat availability and suitability, maturity-at-age, and any information on range shifts within and around the San Francisco Bay. These data would be helpful to test whether assumptions made about the stock dynamics are accurate and to improve forecasts of stock biomass.

Specific longer-term considerations for essential fishery information are listed below:

1.2.1 Population structure

There is a new body of evidence from northern populations of Pacific herring that spawning aggregations separated by several weeks or more in timing exhibit genetic differentiation when using high resolution molecular markers (L. Hauser and E. Petrou, unpublished data). Given that spawn timing in San Francisco Bay spans months, CDFW may consider utilizing these new markers to evaluate if there is genetic structure by spawn timing or geography. These may help inform whether spatial or temporal considerations in management are necessary.

In addition, given this is the southern end of their range, there is a high potential for range shifts in the future. Longer-term objectives assessing trends, poleward shifts, and climate relationships with spawning distribution would provide valuable insight into the future persistence of herring spawn in California (also discussed in Section 5.1). Such data may require detailed spatial records of spawn observations along the California coast. These data may include formal or ad-hoc data collection from spawn flights, anecdotal records, or other sources.

1.2.2 Maturity-at-age and fecundity

CDFW should consider studies that attempt to estimate maturity-at-age and whether that changes over time. Given that fish growth rates have changed dramatically over time (DFO 2015), there is no reason to assume that historical estimates of maturity-at-age reflect their current values. These data will be useful in any attempt to construct a stock-assessment and in translating information about YOY surveys to future spawning biomass forecasts.

Likewise, the reviewers recommend conducting higher frequency of female fecundity monitoring as size/age structure is changing. If data currently being collecting about fecundity are insufficient, CDFW should consider undertaking studies that attempt to estimate current maturity-at-age.

1.2.3 Spawning habitat availability

Herring in the San Francisco Bay utilize eelgrass (*Zostera* spp) and red algae (*Gracillaria* spp) in addition to other physical and biological spawning habitat. Surveys are conducted to assess habitat availability in terms of kilogram per square meter. However, how and if this information is utilized to assess total availability of habitat, what current trends are, and how it compares to other habitat surveys (of eelgrass beds, for example) remains undescribed. The reviewers recommend at least providing some context and background addressing these questions given that these data are on hand.

2. EVALUATION OF SPAWNING STOCK BIOMASS THRESHOLDS AND HARVEST RATES

The draft FMP's aim is to provide an adaptive management strategy for the California Pacific herring fishery that achieves 'sustainability' by implementing a harvest rate of no more than 10% of spawning stock biomass (SSB) each year. However, it is not currently possible to estimate in-season SSB due to management resource constraints. Therefore, quotas for next season are set based on a percentage of the previous season's SSB. This method assumes a relatively stable herring stock size from year to year, but herring SSB has exhibited higher interannual variability since the early 1990s. Consequently, the use of last year's SSB as a proxy for the coming year has become less useful over time. Recently, correlations between indicators of herring stock health and environmental indices have been used to develop a predictive model to estimate the coming year's SSB. This proposed predictive SSB model has been published in a peer-reviewed journal (Sydeman et al., 2018) and at least partially addresses the problem of using last year's SSB as a proxy for this year's SSB by incorporating a

recruitment index and environmental indices. As proposed in the draft FMP, the harvest control rule (HCR) framework is based on this predictive model and the presented management strategy evaluation (MSE) for the San Francisco Bay herring stock. This review did not assess the HCR based on the empirically-based SSB, which would require additional review.

Overall, the review panel is fairly confident that the proposed predictive SSB model as applied in the proposed HCR is appropriate to meet the ecological management objectives of the fishery, given relatively conservative targets for exploitation rates which should be robust to sampling error and population variability (provided the potential problems with fecundity and weight described above are addressed). However, it was more difficult to determine if this HCR as proposed would meet 'economic viability' objectives because no quantitative information was provided on how economic viability was determined, nor were economic objectives directly incorporated into the MSE (catch and variability were included, but these are indirect measures of economic viability).

Below are the review panel's specific evaluations of: the application of the proposed predictive SSB model (Section 2.1), the interpretation and application of MSE results (Section 2.2), and considerations for future investment (Section 2.3). Sections 2.1.1 and 2.2.1 contain recommendations relevant to the proposed predictive SSB model and MSE, respectively, that should especially be considered before adopting the FMP. Sections 2.1.2 and 2.2.2 contain recommendations that could improve management of the fishery but are not imminent priorities and/or may require longer-term investment and research.

2.1 Application of predictive spawning stock biomass (SSB) model

Generally, reviewers view switching from the current empirical method to the proposed predictive SSB model (Sydeman et al., 2018) as appropriate for a number of reasons: 1) the model predicts SSB better than the current methods, 2) recruitment, or YOY, surveys provide valuable information on year-class strength that biomass information does not, 3) assuming the current year will be like the previous year is a poor predictive strategy when temporal auto-correlation is low (recently auto-correlation in SSB has decreased), and 4) more accurate predictions resulting from the proposed predictive SSB model reduce the likelihood of over- or under-exploiting the stock. Although these benefits make the proposed predictive SSB model a clear winner over the empirical method, there were several issues raised and the review panel has concerns that the proposed predictive SSB model may not be the best model to use for the longer-term.

2.1.1 Key Recommendations

Demonstrate the expected efficacy of the predictive SSB model in management

The proposed predictive SSB model was not used in the MSE, consequently it is not clear what the projected performance of this model will be. There would be stronger justification for using this model if it had been used in the MSE (discussed more in Section 2.1.2).

Clarify the reasoning for abandoning the stock assessment model in favor of the predictive SSB model

Reviewers understand that the last assessment was not approved, due in part to difficulty in estimating a stock-recruit curve. However, difficulty in estimating a stock-recruit curve should not be a barrier to building an assessment model and is quite common. For example, herring data in British Columbia has a similar structure (DFO 2015) and has effectively estimated a Bayesian age structured assessment model, as have others (Hulson 2007). Information on the age- and size-structure of the population is lost in the proposed predictive SSB model, but an assessment could present this information in a useful format. Consequently, further discussion about the stock assessment's short-comings and its comparison to the proposed predictive SSB model would be useful to ensure the best model is used in management (explored further in Section 2.2).

Explicitly consider and report uncertainty in management outcomes

Uncertainty enters the management process in many places--e.g. observation error in the survey data, process error in environmental forcing, and implementation error in management. Many of these sources of uncertainty were incorporated into the MSE, yet others were not (like the error surrounding the output and input of the proposed predictive model--arguably one of the most influential sources of error in this management strategy). The reviewers emphasize the need to account for and communicate this uncertainty, and mention other places uncertainty could be important in other recommendations below.

2.1.2 Other Recommendations

While the reviewers believe the proposed predictive SSB model will be an improvement in California Pacific herring management, the panel note potential improvements to the proposed predictive SSB model that should be considered in the model's application to management:

Further explore the phase-space between the variables used in the predictive model

The phase-space between the variables used in the proposed predictive SSB model has not been fully explored (i.e. there are values for environmental variables or the recruitment index that have not been observed, and therefore do not have a corresponding observation of spawning biomass with which to make predictions). Consequently, predictions within unexplored regions of the phase-space cannot be made with any certainty. A sensitivity analysis using simulated data fed to the proposed predictive SSB model (and into the harvest control rule in a full-feedback MSE as noted again in Section 2.2.2) would be useful to further evaluate the performance of the model. An example of a potentially problematic scenario is one in which the YOY survey reports zero recruitment, but environmental conditions are ideal which could lead to SSB estimates that are highly uncertain and uncredible. Exploring and accounting for this uncertainty will be critical to effective management.

Carefully consider assumptions of the model

Assumptions of the model (e.g. additive effects of temperature; assumed Gaussian errors rather than log-normal; errors in variables; jack-knifing vs. k-fold cross-validation) would also be useful to carefully scrutinize and provide justification. Justifying the assumptions of the model would bolster confidence in the output of the proposed predictive SSB model and its use in management.

Directly address and consider uncertainty inherent in predictive SSB modeling and data inputs

Using linear temperature forecasts has the potential to produce conditionally biased results. The existence of such bias can be partially examined using existing data by examining trends in out-of-sample error in the forecast associated with temperature. Consideration of model averaging for the forecasts may be useful in the proposed predictive SSB model. The difference in Akaike Information Criterion (AIC) between the model with-versus-without sea surface temperature (SST) is small (3 AIC units) suggesting model uncertainty is high and the utility of environmental covariates is low. Additionally, the proposed predictive SSB model does not consider the uncertainty in the estimates of SSB and YOY fed to the model. State-space models would offer the ability to do this.

2.2 Management strategy evaluation to inform the harvest control rule

The outcomes of management strategy evaluations depend upon the input parameters. While many of the input parameters for the presented MSE are not well known, the outcomes of the chosen harvest control rule (HCR) configurations were somewhat predictable and the relationship between their outcomes (e.g. rankings of total yields and closures) would likely be preserved for a range of input parameters. In general, while the review panel would not necessarily recommend choosing a different HCR, some concern was expressed related to the scientific backing for the input parameters, performance metrics, model structure, and a relatively high closure rate for the chosen HCR (discussed below).

2.2.1 Key Recommendations

Incorporate the predictive SSB model into the MSE

One of the key purposes of an MSE is to test the performance of "estimation models" (here the predictive SSB model) to be used in management. Per Appendix 11 describing the MSE, this was not done here. Therefore, the reviewers cannot effectively assess how the proposed predictive SSB model performs relative to the empirical model (or other potential assessment methods). In order to strengthen the justification for switching from the current empirical method to the proposed predictive SSB model, the MSE should be run using the proposed SSB model.

Explain the process for selecting final candidate HCRs for the MSE

The review panel understands that the stakeholder engagement process was key in determining the biomass cut-offs and final five candidate HCRs. It would be helpful to include in the draft FMP a description of the full range of cut-offs and HCRs considered and how those were bounded based on stakeholder discussions. The five HCRs run through the MSE seem reasonable given the materials available to reviewers during the review, but it would be useful to know what pitfalls were identified previously and why certain HCRs were eliminated.

2.2.2 Other Recommendations

While the reviewers have a range of additional observations and suggestions related to the MSE, they do not believe these should necessarily impact the overall results or the implementation of the FMP.

Consider different/additional input parameters

Parameters determining the productivity of the stock drive the results of these analyses, but they are not well known. The conditioning of the operating model should be considered more closely--based on the information provided to reviewers, the simulated fishing mortality rates over the historical period exceeded 8.0 (Appendix 11 Figure B3), which is questionable given other information on the fishery. Risks to the fishery other than fishing (e.g. risk of oil spills) should also be considered. Additionally, a sensitivity analysis for out-of-bounds predictions would be useful to understand the performance of the HCR to unexplored portions of the phase-space.

Consider different/additional performance metrics

The key objectives of the draft FMP appear to be economic viability of the fishery and minimizing ecosystem impacts, yet the performance metrics did not reflect these two goals well. For highly variable stocks, like Pacific herring, the metrics currently used in the MSE (B_{MSY} and B_0) are poorly defined and consequently do not provide very useful information for management. The key metric for economic viability presented in the completed MSE was closure rates, yet it would be useful to consider others to understand and communicate the different impacts of management. For example, projecting vessel profits based on projected prices and costs of fishing under different management strategies could provide tangible impacts of alternate strategies.

Additionally, there is no metric for ecosystem impact currently included in the presented MSE. There are many ways of approaching this metric, but a potential method would be estimating the size of predator populations that could be supported by the stock after fishing and use the mean/median predator population and its variance as an indicator. In general, the reviewers would have liked to have seen parameters that influence the outcome of the MSE determined by data, and performance metrics that more closely aligned with the goals of the fishery.

Revisit closure rates and the potential impacts on herring population and the fishery

Based on the MSE, the proposed HCR results in a closure rate of 20%. As the precautionary harvest rate already accounts for stock sustainability and variability due to environmental conditions, reviewers were surprised to see a closure rate this high. An in-depth discussion of what specifically is driving the closure rates (given an apparently conservative HCR), if these conditions appear to mirror reality, and how this impacts the economic viability of the fleet would be useful to build robustness and confidence in the HCR. The reviewers are somewhat concerned with what might happen if there was a closure of the fishery two years in a row (which has a relatively high probability of happening in the not-too-distant future with this closure rate), and if this closure rate actually helps to achieve the stated goals of sustainability and stock rebuilding beyond the precautionary harvest rate. The reviewers acknowledge that the decision about what closure rate is “acceptable” is a management decision, but if moving ahead with the proposed HCR, the draft FMP should more explicitly address the implications and uncertainty contained within this predicted closure rate.

2.3 Longer-term recommendations

Revisit exploring a stock assessment

An impressive amount of biological information exists for the San Francisco Bay herring stock. The development and maintenance of a stock assessment model would benefit CDFW by synthesizing and integrating that information into a format useful in management. A stock assessment would allow a framework for managers to ask more complicated questions about changes in management. For example, changes in selectivity could be useful management levers (e.g. changing mesh sizes), but with the proposed predictive SSB model, it is not clear how changes in selectivity might impact management advice or the sustainability of the fishery.

Stock assessment development is an iterative process, so previous rejections of proposed stock assessments should not discourage future efforts. It may be worth first doing a cost benefit analysis for developing the assessment to the point that it is useful in management. Although it is not immediately clear how much more precise and accurate estimates of SSB from a stock assessment would be compared to the proposed predictive SSB model given the life history and available data streams, the review panel agrees revisiting a stock assessment would be a worthy future investment. An explicit side by side comparison between the developed stock assessment model and proposed predictive SSB model in a management strategy evaluation would be useful to understand the costs and benefits of each model.

Iterate the predictive SSB model and perform regular model validation

If the proposed predictive SSB model will be the tool used for the foreseeable future in management, a routine process to evaluate the performance of the model should be developed. The model should be updated yearly with new data, and model accuracy should be reassessed.

3. EVALUATION OF ECOSYSTEM INDICATORS

Pacific herring play an essential part of the California Current Ecosystem as a forage species. As preliminary quotas in the proposed HCR are developed using a single species model to understand impacts to San Francisco Bay populations of Pacific herring (described and reviewed above), they do not explicitly take into account the current status of alternative forage and predator indicators. In recognition of this, a novel approach to incorporating ecosystem indicators was developed as part of the draft FMP. Indicators include: 1) herring productivity, 2) alternative forage availability, and 3) predator populations. The goal of the indicators described in the decision matrix (Table 7-2) is to signal poor conditions when additional precaution in management may be warranted, or healthy conditions when quota may be increased. As proposed, this matrix would provide qualitative guidance to CDFW to determine if adjustments to the preliminary quota are necessary (Figure 7-2). The decision matrix was developed to be adaptive and updated by CDFW as needed to reflect the best available science. Reviewers focused on rationale behind the interpretation and inclusion of these ecosystem indicators in setting final quotas.

Section 3.1 contains the reviewers overall assessment of the ecosystem indicators decision matrix and key recommendation. Sections 3.2 includes recommendations the review panel feel are critical to improving the robustness of the proposed approach, but may require longer-term work.

3.1 Overall assessment

Develop quantitative thresholds, calculate historical scenarios, and provide additional evidence linking ecosystem indicators to specific ecological responses to support using ecosystem indicators to adjust quota

Ecosystem based management approaches are widely recognized as an important next step in both State and Federal fisheries management approaches. Federally, ecosystem indicators are largely used as information in ecosystem status reports broadly (e.g. Harvey et al., 2017), or to inform fisheries ecosystem plans for a specific stock (e.g. Levin et al., 2018). In these scenarios, the environmental information is not currently used in a decision support tool to adjust quotas, but provide the general context on what to expect in the given year and in upcoming years. In addition, these narratives often can provide context for past years where stock size estimates may have been higher or lower than expected.

The ecosystem indicators section of the draft FMP is quite useful in understanding the broader ecosystem context and the review panel is encouraged that efforts are underway to include this information. Incorporating ecosystem indicators is challenging and few successful implementations of ecosystem based methods exist to guide CDFW in their efforts. Given the novel ecosystem approach developed for the San Francisco Bay herring stock, the draft FMP has the potential to lead the way for future ecosystem-informed FMPs. While admirable and ambitious, the reviewers have reservations regarding the proposed framework as it stands, for incorporating ecosystem indicators into the HCR. The proposed rules are vague and not empirically derived from quantitative analysis or tested with MSE, and appear to lack a transparent process for proposition and adoption of deviations from the HCR from year to year. As a result, the reviewers recommend working to build a more transparent, quantitatively based, and tested ecosystem approach.

Reviewers recommend developing quantitative thresholds, calculating historical scenarios to ensure that the thresholds are adjusting the quota as envisioned by CDFW and stakeholders involved, and providing additional evidence linking ecosystem indicators to specific ecological responses. Generally, ecosystem indicators are useful to pursue, but it is equally important to ensure that effort be spent solidifying the single-species research. As single-species methodologies are the building blocks for ecosystem based approaches, focusing on the single-species details (especially economics) can also answer some of the key questions lingering about the impacts of the ecosystem decision matrix. If CDFW decides to incorporate ecosystem indicators in the interim, the FMP should outline the transparent process by which ecosystems-based deviations from the HCR are considered and justified.

Overall, given that the harvest rate cap implicitly considers some ecosystem conditions, the HCR preliminary quota setting serves as a valid approach. Developing thresholds for incorporating ecosystem indicators and a formal process for adopting them would support their inclusion directly in the HCR. Until then, ecosystem indicators could be used, as in Federal fisheries examples, as general context when setting quotas on what to expect in the given year and in upcoming years (more detail below).

3.2 Recommendations to incoporate ecosystem indicators moving forward

This section includes recommendations that are important for building a more robust approach. Addressing these recommendations would improve the application of the ecosystem indicators and the management of the fishery, and may require longer-term investment and research.

Evaluate performance of HCRs corresponding to the bounds of green, yellow, and red conditions (Figure 7-2) within MSE framework

As a first step, the review panel recommends making it more transparent how ecosystem indicators would link to "green," "yellow," or "red" conditions (Figure 7-2). It would be informative to evaluate performance for HCRs roughly corresponding to these limits to understand how ecosystem conditions and a given increase or decrease in quota to these levels would relate to the current performance metrics. Even without explicit linkages between specific ecosystem indicators and potential quota adjustments, the reviewers recommend that these adjusted quotas be formally run through the MSE.

Consider developing ecosystem status reports to support the FMP

The existing HCR and proposed ecosystem indicators could be used down the line to directly inform ecosystem-level advice. In the meantime, ecosystem status reports, also called fisheries ecosystem summaries, can provide a snapshot and synthesis of the state of fisheries, communities, and the broader ecosystem. These summaries can provide ecosystem considerations to support individual fisheries management plans, and serve as the backbone of broader ecosystem-wide assessments. The summaries can describe environmental, social, and economic states and their potential impacts on commercially important fish species.

Develop statistically- or expert-based thresholds that link indicator level to action to improve reproducibility and transparency in how ecosystem-indicators could lead to adjustments in quotas

The main concern about using the proposed decision matrix is its lack of defined thresholds that link indicator levels to action. The proposed HCR (black line in Figure 7-2) is a conservative approach towards setting herring harvest guidelines that takes into account some of the ecosystem considerations of harvesting forage fish. The explicit ecosystem indicators chosen in the decision matrix make ecological sense, but there was concern raised that the qualitative nature of the decision-making approach as it is proposed is not based on strong enough scientific links between a given indicator, the ecological response, and the proposed quota adjustments and could lead to criticism and unexpected outcomes. In turn, the review panel recommends developing limits to allow reproducibility and transparency in how ecosystem indicators could lead to adjustments in the proposed quotas to accomplish the goal that quotas can be adjusted by the CDFW's Director as needed without regulatory changes.

To then assist in linking ecosystem indicators to management action, the review panel suggests that CDFW could build a decision tree, that highlights at what established ecosystem thresholds HCR adjustments would be made. Other qualitative management indicators used for single species management, such as Productivity Susceptibility Analysis (Patrick et al., 2010), provide semi-quantitative scoring, and developing something analogous for the decision matrix would provide a transparent way to develop a score for the number of indicators that are low/medium/high within each of the broad categories, with a decision tree/table for when or how much quota would be reduced (or increased) given a certain ecosystem score. Table A5 does this for the Alternative Forage Indicators, but the other two components of the decision matrix (Herring Productivity and Predator Indicators) do not have a scoring system developed. Additionally, having a sense of how past conditions would score under any threshold would be useful to make sure that the tool is performing as expected.

An additional approach towards setting thresholds and decision rules could be to incorporate stakeholder involvement while setting the thresholds and potential quota adjustments. For example, such an approach could mirror recent efforts (Draft Risk Assessment and Mitigation Program developed by the California Dungeness

Crab Fishing Gear Working Group) that have developed a framework based on objective criteria, including ecosystem thresholds, to assess whale entanglement risk by Dungeness crab gear. This process brings together a group of scientists, managers, and stakeholders to assess information including ecosystem conditions that can lead to low, medium, or high level of risk to whales. A similar approach for the San Francisco Bay herring fishery could be useful by gathering a diverse set of experts to inform thresholds and build stakeholder engagement and trust in the resulting thresholds.

Regardless of how ecosystem indicators are potentially incorporated into adjusting quotas, more description of the decision-making and stakeholder processes of moving from preliminary HCR to using ecosystem indicators to shift quota, such as a flowchart, would be a critical addition to the draft FMP.

Perform a retrospective analysis to examine how quotas would have been adjusted in past years

The review panel recommends performing retrospective analyses to examine how often quotas would have been adjusted in past years under proposed management scenarios. For example, which years and what overall percentage of time would the quota have been adjusted up or down based on past ecosystem conditions. This would help CDFW and the broader stakeholder community understand what role the ecosystem indicators would likely have in adjusting quota and would increase the transparency of the consequences of choosing an updated quota based on the ecosystem conditions.

Provide additional evidence linking ecosystem indicators to specific ecological responses

While the ecosystem indicators seem logical, the reviewers would like to see additional documentation of studies linking each indicator to ecological impacts, and a discussion of the degree of confidence in that inference. Based on how indicators are related, composite forage indices or decision trees linking conditions of multiple indicators may be appropriate to consider.

Some technical questions about the indicators remain, for example:

- Is it desired to use indicators that are NOT correlated, or would it be desirable that they are reflecting the same phenomenon and therefore several of them would provide greater weight of evidence that that particular phenomenon was occurring?
- The forage indicators for market squid and groundfish appear to reflect poor conditions only if also found in concert with low pelagics. This suggests a composite index might be more appropriate (or a decision tree where only consider squid and groundfish being low IF pelagics are also low).
- Also, given the uncertainty and lack of data on diets from the winter, weighting the forage indices by the number of predators in which the item appeared (as was the originally attempted weighting scheme) appeared to be arbitrary. Do we know if any of the predators actually specialize, or if they are generalist and likely prey switch? If the latter, then some sort of composite forage index might make sense, assuming all predators access it.

Conduct an MSE that more explicitly includes ecosystem indicators

An MSE that includes ecosystem indicators, perhaps in place of those relative to B_0 and B_{MSY} as performance metrics (as discussed in Section 2.2.2) could provide more information and help CDFW understand the impacts of ecosystem conditions on the fishery. For example, combining an MSE including ecosystem indicators with economic analysis could provide insight into whether the most extreme scenarios (i.e. HCR rules under best versus worst ecosystem indicators) are expected to have significant economic impacts.

Set more quantitative goals for the fishery

The review panel recommends setting more quantitative goals, or “targets,” for the fishery. Many of the goals throughout the draft FMP are well stated qualitatively, but lack quantitative targets to measure against. In many cases, management can only react to stock fluctuations, rather than determine them by attempting to maintain biomass around some target. The San Francisco Bay Pacific herring stock seems to follow this sort of pattern—recruitment is largely environmentally driven. The balance to be struck in volatile fisheries like this is one between maintaining a fleet such that booms can be capitalized upon and a fleet small enough to weather periods of poor productivity. Without quantitative targets to measure against, it may be difficult to maintain management objectives.

4. SCIENCE SUPPORTING ADDITIONAL CONSERVATION AND MANAGEMENT MEASURES

The draft FMP describes the history and rationale for the management measures that have been employed in the California Pacific herring fishery. While quotas are the foundation for ensuring sustainability in Pacific herring stocks, the draft FMP describes the additional management measures CDFW employs to provide additional safeguards for the stock. These other management measures include: 1) effort restrictions (which include permit consolidation and fleet capacity limits), 2) gear restrictions, 3) spatial, temporal, and seasonal restrictions, 4) size and sex, 5) prevention of bycatch, and 6) reduction of habitat impacts.

Reviewers concluded that a sloped HCR with a 10% maximum exploitation rate is likely to minimize the impact of the fishery on both the stock and the ecosystem. Thus, using catch restrictions as the main management measure is likely to be effective, and streamlining the temporal regulations, as is proposed, so that all populations have the same start and end date will likely make this management measure more enforceable. The additional conservation measures are likely to further support sustainability of the San Francisco Bay stock and the review panel has only minor recommendations that should be addressed before adoption of the FMP.

4.1 Key recommendations

Provide further rationale for mesh size limits

Mesh limits are often a good idea, but there does not seem to be a quantitative approach for determining what is best included in the analysis. Data on the initial (160-170mm) and fully selected sizes (180-185mm) is given, but the review panel recommends a selectivity ogive, and explicit linkage age (using Figure 3-7) to inform how it relates to age-based selectivity goals.

Expand discussion of implications of targeting age 4+ on stock sustainability

While the recovery of herring age structure shown in Figure 6-2 suggests that the current mesh size is not resulting in major age truncation, targeting age 4+ may still result in evolutionary changes in growth, maturity, fecundity, and reproductive behaviors. Reviewers suggest adding discussion about the implications of this for stock sustainability.

Expand description of effort restrictions and its link to desired tonnage goals

An expanded narrative of the stakeholder process and the rationale for relating the number of permits to maximum quotas was provided to the reviewers by CDFW during the review and should be incorporated into the draft FMP.

Set more quantitative targets for when certain rules will be reconsidered

Some examples of vague, or difficult to evaluate, statements that would benefit from clear, quantitative targets include: “should conditions change in the future,” “some changes to the season dates are warranted,” and “should the recreational sector continue to grow.” CDFW should work to develop thresholds that determine when these rules will be reconsidered.

5. FUTURE RESEARCH AND METHODS

The draft FMP is designed to provide a comprehensive and adaptive management strategy for the California Pacific herring fishery. To support this goal, the draft FMP identifies additional management needs and future research that would assist CDFW in improving assessments and management in the future. Throughout this report, reviewers have identified additional research and data needs that would support more robust management of the fishery, some of which are mirrored in the “Additional Management Needs and Future Research” chapter of the draft FMP. Recommended future research and data needs not already outlined in the draft FMP should be added to the relevant section before adoption.

Overall, as there is a wealth of data for the San Francisco Pacific herring population and the California Current Ecosystem, reviewers recommend prioritizing the synthesis of existing data and information before allocating resources to collecting additional data, except for recruitment data and in the scenario where anomalous conditions require additional data.

5.1 Key recommendations

Prioritize sampling for recruitment

As stated previously, reviewers commend the proposed SSB model and HCR for considering recruitment in setting annual quotas. This is a crucial improvement on the previous method for setting quota and should be prioritized in order for CDFW to successfully reach their management goals (also discussed in Section 1.1.4). If these data become unavailable, SSB estimates are not likely to be as accurate.

Formally analyze predator-prey interactions to inform incorporation of ecosystem indicators

A major component of the draft FMP is the ecosystem considerations, with a focus on predator-prey dynamics. This should likely be a future focus of research, with an aim to identify whether and when prey provide a limiting factor. Questions that should be answered include:

- Is there evidence that predator populations do fluctuate in response to the available forage (or that there is a cutoff below which predator indicators decline)?
- Is there any evidence that, when small pelagics are low in abundance, that abundant herring become a focal prey item or that there is prey overlap? For which predators?
- Are these the same predators that might show occasional prey limitation?
- Does the spatial distribution of predators, prey, and herring play a factor?

Diet analysis, historical analysis, and expert elicitation all might provide fruitful avenues to answer these questions. As noted in the draft FMP, the California Current Integrated Ecosystem Assessment has synthesized a number of indicators of forage, predator status, and ecosystem conditions, and many of these time series are available since the early or late 1990s. Incorporating these data further into the ecosystem decision matrix as well as a formal analysis of the linkage between forage fish and predators could improve the capacity and transparency of including the ecosystem considerations in the setting quotas.

Better characterize spatial variation in response to environmental change

At a minimum, coarse monitoring of stocks in other California locations may help understand whether stocks are responding differentially to environmental change. If it is to be used for this purpose, provide more detail about the Rapid Spawn Assessment Method, and its performance when applied to the relatively data-rich San Francisco Bay stock (as discussed in Section 1.1.3). Because the herring population in San Francisco Bay represents the southern end of their range, there is the possibility that increased temperature stress and/or range shifts may affect this population. As such, explicit monitoring of all California herring populations in response to environmental change should be on the radar for future monitoring or research. This understanding would allow the fishery management system to be more climate-ready.

5.2 Longer-term recommendations

Better characterize interannual spatial dynamics of stocks

Much of the concerns about ecosystem dynamics are complicated by spatial behavior before and after spawning. That is, where do herring go to feed, and what feeds upon them when they are away from spawning areas? Characterizing these dynamics might be a key future research endeavor to identify which ecosystem indicators should actually be considered given the spatial overlap of herring with their prey and predators. CDFW may consider using high resolution, polymorphic SNP markers that are now available (E. Petrou and L. Hauser, in prep) to evaluate spatial structure of the stock (as discussed in Section 1.2.1).

Better track, consider, and integrate recreational take into quota setting

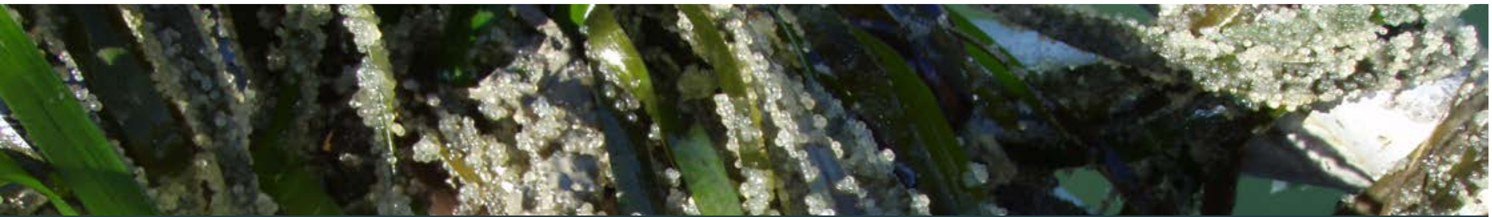
As mentioned in the draft FMP, there is currently no data on the magnitude of catch in the recreational sector of the California Pacific herring fishery. Moving forward, it will be important for CDFW to quantify recreational catch so that it can be considered in setting quota. Currently, it is not clear how recreational take impacts the herring stock under the proposed HCR. Accounting for varying levels of recreational catch in an MSE and integration of this information, when available, will result in a more robust management strategy.

Identify external ecosystem factors that affect herring populations

What are the impacts of cumulative stressors (e.g. temperature together with water quality) on herring stocks? A broader MSE that takes into account external stressors will help identify where the HCR framework may fail.

Develop a sampling program to directly estimate maturity, fecundity, growth, and mortality

These demographic parameters may underlie the changes in size-at-age in San Francisco Bay. Knowing which of these drivers is operating can help identify appropriate management action to counteract these effects.



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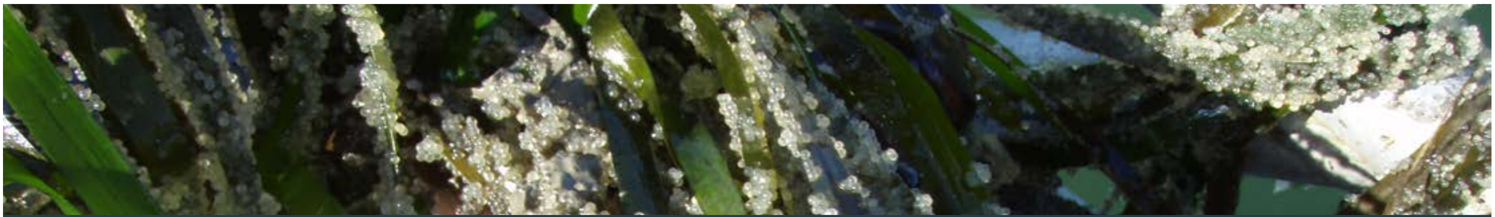

Appendix A: Terms of Reference

1. Introduction

1.1 CDFW Management Context

Pacific herring populations support important commercial and recreational fisheries in California state waters. Herring are a schooling species found throughout California nearshore ecosystems during spring and summer and migrate to bays and estuaries to spawn from November through April. They play an important role in the California marine ecosystem as a forage species for a wide suite of predators, including marine birds and mammals and are among the top forage species in terms of their proportion in predator diets, making them an essential food source for predators on the West Coast. The San Francisco Bay herring population supports a valuable fishery for herring roe (kazunoko), and a smaller herring-eggs-on-kelp (komochi or kazunoko kombu) fishery. San Francisco Bay also supports a limited commercial fresh fish and recreational fishery.

A primary goal of fishery management under the Marine Life Management Act (MLMA) is to ensure that fishing levels are sustainable and do not result in an overfished stock. While the commercial herring fishery is considered well managed, even with a very precautionary management approach, concerns about changing ocean conditions, sea-level rise, loss of spawning habitat, stakeholder interest, and a need to better understand spawning and stock fluctuations and their role as a forage fish have prompted the development of a fishery management plan (FMP). FMPs assemble information, analyses, and management options to guide the management of the fishery by the California Department of Fish and Wildlife (CDFW) and Fish and Game Commission (Commission). The FMP becomes effective upon adoption by the Commission, following their public process for review and revision. Thus, it is important for the scientific underpinnings of the draft FMP to have undergone independent review prior to submission to the Commission. External, independent peer review of the scientific underpinnings of the FMP is one way to provide the Commission and stakeholders assurances that the FMPs are based upon the best readily available scientific information, as set forth under the MLMA. The Ocean Protection Council (OPC) has provided funding to complete the peer review process for the Pacific herring FMP.

1.2. Review Process Goals and Objectives

Ensuring the best use of best available information in fisheries management is an important tenet of the MLMA. The MLMA identifies external scientific review as a key tool to ensure management decisions are based on the best available scientific information. CDFW is committed to incorporating the best available scientific information into fisheries management through a peer review process.

Scientific and technical peer review (review) is widely applied across numerous technical disciplines to assure products are of high quality, reflect solid scholarship, and that the information contained is accurate and based on rigorous, sound scientific methods (OST 2016). In any review, Ocean Science Trust's (OST) intent is to provide an assessment of the work product that is balanced, fairly represents all reviewer evaluations, and provides feedback that is actionable. When building a review process, OST seeks to balance and adhere to six core review principles: scientific rigor, transparency, legitimacy, credibility, salience, and efficiency. These principles ground the review and shape the products that we develop.

As such, the goals and objectives of the FMP review process are to:

1. ensure that the science underpinning the FMP represents the best available scientific information and is appropriately used to inform a harvest control rule;
2. follow a detailed calendar and fulfill explicit responsibilities for all participants to produce required reports and outcomes;
3. provide an independent external scientific and technical review of the agreed upon sections of the herring FMP;
4. use review resources effectively and efficiently.

1.3. Review Coordinating Body: Ocean Science Trust

Ocean Science Trust is an independent non-profit organization working across traditional boundaries to bring together governments, scientists, and citizens to build trust and understanding in ocean and coastal science. We empower participation in the decisions that are shaping the future of our oceans. We were established by the California Ocean Resources Stewardship Act (CORSA) to support managers and policymakers with sound science.

For more information, visit our website at www.oceansciencetrust.org.

Contact information

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2. FMP Peer Review Scope and Process

2.1 Review Request

CDFW's purpose in asking for this review is to ensure the scientific and technical elements presented within the FMP provide a rigorous underpinning for management decisions and regulatory action. Ocean Science Trust is serving as the review coordinating body, and worked with CDFW to develop a scope of review that focuses on key scientific and technical components of the FMP where independent scientific assessment would add value (this document). The review is not intended to be a comprehensive assessment of the entire FMP or the proposed approach to management contained therein, but rather focuses on key components identified below. Components subject to review were determined using criteria from OST 2017 (here).

2.2 Scope of review

CDFW is seeking an independent assessment of the science underpinning the proposed management framework that will guide fishery management decisions for the San Francisco Bay Pacific herring stock. The framework uses a predictive model for determining herring spawning stock biomass mass and data collected by CDFW and others in the California Current Ecosystem. The review will focus on whether the available data and predictive model that underpin the proposed FMP management strategy are applied in a manner that is scientifically sound, reasonable, and appropriate.

The central question of this review is:

Given CDFW's available data streams and analysis techniques, are the applications of the analyses to the integrated management strategy scientifically sound, reasonable and appropriate?

Specifically, the review will focus on evaluation of the following components of the FMP:

- the accuracy of representation of existing literature on the biology of the stock and in the essential fishery information (Sections 3 and 5.2)
- the proposed spawning stock biomass thresholds and associated harvest rates underpinning the catch quota decision making process and signaling when the fishery may warrant management response; (Section 7.7)
- the decision matrix of ecosystem indicators and the rationale behind the inclusion of these ecosystem indicators in management; (Section 7.7)
- the science underpinning additional conservation and management measures (Section 7.8)
- identify research and methods needed to improve assessments and fishery management in the future (Section 8)

For clarity we note that the following are not included in the scope of the current review:

- the data collection protocol (Section 5.1), as it has been reviewed previously
- the new predictive model for spawning stock biomass (Section 7.6), as this is currently undergoing a separate peer review.

2.3 Process

Review Process Overview

- **Select a review mode.** A review process is selected in consultation with CDFW and the Ocean Protection Council by considering complexity, management risk, uncertainty, socioeconomics, level of previous review, and novelty (OST 2016; OST 2017).
- **Assemble review team.** Ocean Science Trust will convene a 3-4 member review panel composed of Ocean Protection Council Science Advisory Team members and other experts (see "Assembling a Review Team," OST 2016 and "assembling a review team" below for additional details).
- **Conduct review via a series of webinars.** Group webinars will allow CDFW to engage directly with reviewers at the outset to present the inputs, model methods, and application of analyses and provide two-way interaction to provide any additional clarity needed to complete the review. There will also be opportunities for independent deliberation and conversation among reviewers.
- **Develop and share final report.** Reviewers will contribute to the development of a final report, which will be made available on the OST and CDFW webpages.

Review Mode: Remote Panel Review

All meetings will take place via remote online meetings (webinars). At the outset of the review, OST will work with CDFW to develop detailed reviewer instructions that encourage focused scientific feedback throughout the process. Instructions will include directed evaluation questions and may delegate tasks for reviewers based on their individual areas of expertise. This document will be used to guide the development of meeting agendas and track progress throughout the course of the review. For each meeting, advance work will be required of participants (e.g. drafting responses to guiding questions) in order for all parties to come prepared for meaningful discussions. OST will notify CDFW of additional requested materials and data immediately following the first webinar.

Webinar 1: Initiation of Review

Ocean Science Trust will host an initial webinar to provide the review committee and CDFW staff an overview of the scope and process, and clarify the roles and responsibilities of each participant. CDFW will also provide a summary of the relevant management context to ensure reviewers understand the role of the review in the larger FMP development process, and how the outputs will be considered. The bulk of the webinar will then focus on a presentation by CDFW and FMP contractor on the scientific and technical components of the draft FMP. This webinar is an opportunity to develop a shared understanding of the tasks and allow reviewers to ask CDFW any clarifying questions about the review materials before they convene independently to conduct their technical assessment.

Webinar 2-3: Reviewers convene with OST to conduct review

Ocean Science Trust will convene approximately two remote one- to two-hour webinars with the review committee to conduct an in-depth evaluation of the components identified in the Scope of Review (above). In advance of each webinar, reviewers will be asked to prepare responses to guiding evaluation criteria questions specified in the review instructions. During each webinar, reviewers will discuss their findings and develop conclusions and recommendations within the context of these questions. Additional follow-up phone conversations may be scheduled as needed to complete the review. Outputs from each webinar, as well as reviewer responses to the questions, will guide the development of the final report.

Webinar 4: Final summary report feedback

Ocean Science Trust will host a final 1-hour webinar to gather final feedback and input from the review panel on the summary report. The review panel will be asked to review the draft summary report in advance of this meeting. This final meeting will provide a space for reviewers to voice any suggested edits or clarifications, and a chance to have a final discussion about results before sharing the final report with CDFW.

Management Preview

Ocean Science Trust will share the final summary report with CDFW for a management preview before the review results are published. There will be an opportunity for CDFW to ask clarifying questions of the review committee and for reviewers to make clarifying edits, as appropriate. This may occur via email, conference call or short webinar as time allows.

Assembling Reviewers

Transparency

Reviewer names will be published on OST's webpage for the review at the outset of the review; however, specific review comments in the final review report will not be attributed to individual reviewers.

Selection of Reviewers

Ocean Science Trust will implement a reviewer selection process to assemble a review committee composed of 3-4 external scientific experts. Ocean Science Trust will consult with and solicit reviewer recommendations from CDFW, the OPC-SAT, as well as OST's own professional network among the academic and research community. Membership may include experts from academia, research institutions, and government agencies as appropriate to deliver balanced feedback and multiple perspectives. Reviewers will be considered based on three key criteria:

Expertise: The reviewer should have demonstrated knowledge, experience, and skills in one or more of the following areas:

- Fisheries biology, stock assessments and modeling, including spawning stock biomass analyses and application
- Herring and/or forage fish biology and ecology, with an understanding of California's coastal ecosystem and how forage fish stocks and linked populations (e.g. predators) respond to fishing pressure and climate change
- Developing and/or testing harvest control rules for fisheries management, including applying ecosystem based management

Objectivity: The reviewer should be independent from the generation of the product under review, free from institutional or ideological bias regarding the issues under review, and able to provide an objective, open-minded, and thoughtful review in the best interest of the review outcome(s). In addition, the reviewer should be comfortable sharing his or her knowledge and perspectives and openly identifying his or her knowledge gaps.

Conflict of Interest: Reviewers will be asked to disclose any potential conflicts of interest to determine if they stand to financially gain from the outcome of the process (i.e. employment and funding). Conflicts will be considered and may exclude a potential reviewer's participation.

Final selections for the review committee will be made by the OPC-SAT Executive Committee. Ocean Science Trust will select one member of the review committee to serve as chair to provide leadership among reviewers, help ensure that all members act in accordance with review principles and policies, and promote a set of review outputs that adequately fulfill the charge and accurately reflect the views of all members.

Transparency in the Review Process

To ensure transparency, reviewers will serve openly. Reviewer names will be published on Ocean Science Trust's review webpage at the outset of the review. However, to encourage unbiased and candid input, specific review comments will not be attributed to individual reviewers. Upon delivery of the final report to CDFW, the report will also be made public on the OST review webpage.

In addition, OST will host a public webinar briefing in which the review committee, led by the chair, will share the draft findings of the review process. The information sharing will be open to the public, and include a Q&A so the reviewers (and CDFW scientists) can answer questions. This meeting will occur after the completion of the final summary report.

2.4 Review Report (reference appendix template)

Ocean Science Trust will work with reviewers to synthesize reviewer assessments (responses to the review instructions and input during webinars) into a cohesive, concise final written summary report. This review summary will be delivered to CDFW by late September 2018, and made publically available on OST's website. Reviewers may also provide individual in-text comments on the draft FMP which will be provided to CDFW for internal use. We acknowledge that reviewers may provide scientific recommendations beyond the given reviewer charge; such scientific recommendations will be honored and represented in the final summary.

2.5 Timeline

The review will commence in February 2018 with the expected delivery of a final summary report to CDFW in October 2018. A timeline is provided below.

Milestone	Feb	Mar	April	May	June	July	Aug	Sept	Oct
Review Preparation									
Develop and Finalize Terms of Reference	X	X							
Establish review panel		X	X						
CDFW delivery of draft FMP to Ocean Science Trust				X					
Conduct Review									
Webinar 1: Initiation of review				X					
Webinar 2: Essential Fishery Information; Spawning stock biomass thresholds; Additional management measures				X					
Webinar 3: Ecosystem indicators matrix; Future research methods						X			
Webinar 4: Final discussion and report feedback							X		
Finalize Summary Report									
Final report available online									X
Public sharing webinar with review panel members									X

3. Roles and Responsibilities of Peer Review Participants

3.1 Shared Responsibilities

All participating parties share the responsibility in assuring adequate technical and scientific review of the Pacific Herring FMP in accordance with the MLMA.

3.2 Reviewer Responsibilities

The role of the review committee is to conduct a detailed evaluation of the scientific underpinnings of aspects of the Pacific Herring FMP where external review will be valuable. The specific responsibilities of the review committee are included in the Review Instructions. The review committee may request additional information, data, and analyses as appropriate to support a comprehensive and useful review.

The review committee chair has, in addition, the responsibility to: 1) provide leadership among reviewers; 2) ensure that review committee participants follow the terms of reference and review instructions and guidelines; and 3) promote review outputs that adequately fulfill the charge and accurately reflect the views of all members.

The review committee is required to make an honest and legitimate attempt to resolve any areas of disagreement during the review process. Occasionally, fundamental differences of opinions may remain between reviewers that cannot be resolved. In such cases, the review committee will document the areas of disagreement in the final summary report.

Selected reviewers should not have financial or personal conflicts of interest with the scientific information, subject matter, or work product under review within the previous year (at minimum), or anticipated. Reviewers should not have contributed or participated in the development of the product or scientific information under review. Review committee members who are federal employees should comply with all applicable federal ethics requirements. Reviewers who are not federal employees will be screened for conflicts of interest.

3.3 CDFW FMP and Management Team Responsibilities

The Mission of the California Department of Fish and Wildlife is to manage California's diverse fish, wildlife, and plant resources, and the habitats upon which they depend, for their ecological values and for their use and enjoyment by the public. CDFW and the management team, including contractors, will participate in the review process as follows:

1. *Provide all relevant project documents, data, and supporting materials.* CDFW will identify and provide all project documents, data, and other information necessary for reviewers to conduct a constructive assessment. CDFW will work to ensure all related materials are clear and accessible to reviewers in a realistic timeframe and respond to additional requests in a timely manner.
2. *Constructively engage with reviewers and OST staff, and respond to data and other information requests in a timely manner.* CDFW staff and contractors most familiar with the draft FMP will engage in the process and be available to answer questions or present materials to the review committee as necessary. The CDFW Environmental Scientist, Ryan Bartling, and contractor, Sarah Valencia, have agreed to serve as the primary contacts during the review process. In order to adhere to review timelines, CDFW will respond to and provide feedback on requested materials from OST in a reasonable, mutually agreed-upon timeframe.
3. *Consider reviewer comments and recommendations.* CDFW intends to consider and incorporate reviewer feedback and recommendations into the FMP and supporting materials as appropriate.

3.4 Ocean Science Trust Responsibilities

California Department of Fish and Wildlife has requested OST to serve as the independent appointed entity to design and coordinate all aspects of this scientific and technical review. Ocean Science Trust will design and implement all aspects of the review process to meet management needs, including assemble and guide a committee of expert reviewers, conduct a review process that is on task and on time, schedule and host remote meetings as appropriate, work with reviewers to produce a written final summary report, and encourage candor among reviewers, among other activities. Upon completion of the review, the final report will be delivered to CDFW and made publicly available on the OST website. Throughout, OST will serve as an honest broker and facilitate constructive interactions between CDFW and reviewers as needed in order to ensure reviewers provide recommendations that are valuable and actionable, while maintaining the independence of the review process and outputs.

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Appendix P Description of Rapid Spawn Assessment

As described in Section 7.5 of the FMP, the Tier 2 management strategy is designed to scale the amount of monitoring required by the Department to the level of fishing effort that occurs in an area. When a management area is assigned to Tier 2, fishing may occur at a precautionary quota level (1.5-3% of historical SSB for that area or 50% of historical average catch for Crescent City Harbor). At a minimum, in Tier 2 management areas catch must be monitored via fishery-dependent monitoring protocols (Section 7.5.1). However, fishery-independent monitoring may also be conducted. Traditionally, fishery-independent monitoring protocols for Pacific Herring (Herring), *Clupea pallasii*, have relied on Spawning Stock Biomass (SSB) estimates derived from spawn deposition and midwater trawl surveys. This provides the most informative indicator of stock status but is costly and labor-intensive (Chapter 6). This level of annual monitoring effort is not necessary for the highly precautionary Tier 2 management areas and likely cannot be achieved at current staffing levels. Instead, the Department of Fish and Wildlife (Department) will apply a less intensive Rapid Spawn Assessment (RSA) approach using information on Herring population spawning characteristics to monitor if Tier 2 management areas remain consistent with sustainable fisheries management. In addition to fishery-independent monitoring provided by the RSA, any quota increase in Tier 2 management areas will require a single-season SSB estimate based on a full spawning deposition survey (Section 6.1.2.1). This reduces the potential risk associated with adjusting quotas and is consistent with the precautionary Tier 2 management approach.

Rapid Spawn Assessment

Department staff have been exploring RSA protocol in Humboldt Bay with the following objectives: 1) identify spawn frequency and timing, 2) identify spawn location and spatial extent, and 3) qualitatively categorize the density of each spawn as high, medium, or low.

The annual frequency (number) and spatial extent (total area) of spawning events within a management area can be used as a course indicator of spawning population condition. Independently, or in association with timing, location, and qualitative spawn density estimates, this data can be compared with historical information and used to track changes in spawn behavior characteristics from year to year. This method can identify potential problems in spawning populations that may warrant more precaution, such as the closure of the fishery, or additional research. For example, significant decreases in the frequency and/or spatial extent of spawning events in a management area may indicate declines in the spawning population. Similarly, sustained shifts in spawn timing, location, or qualitative estimates of spawn density may indicate changes to the spawning population that warrant further research and evaluation. The goal of the RSA is to provide Department staff with a less labor-intensive way to monitor if Herring stocks in Tier 2 management areas can continue to support the precautionary quotas, and to make adaptive management changes as needed.

Identifying Spawning Events (Frequency)

This monitoring procedure requires being able to effectively detect spawning events. Searching for Herring spawn events is time consuming; however, the Department will continue to collaborate with commercial fishermen for assistance with spawn reporting as well as engage other interested stakeholders (see the section on Opportunities for Collaborative Research).

Delineating Spawning Area (Spatial Extent)

Herring spawn in different habitat types, which, in California, can be broadly classified as intertidal shoreline and water-bottom vegetation. The sampling protocols to delineate spawning area for these habitat types are described in the following sections.

Water-bottom Vegetation Spawns

In Humboldt, Tomales, and San Francisco Bays, intertidal and subtidal beds of vegetation (primarily *Zostera marina* and *Gracilaria* spp.) provide significant spawning habitat for Herring. In these areas, the spatial extent of spawn is delineated from a boat. Rake samples of vegetation are systematically taken on a pre-determined regularly spaced grid and visually evaluated for the presence/absence of Herring eggs. The edges of the spawning area can be identified by the consistent absence of eggs on rake samples or topographical features identifying the boundary of the vegetation bed. The boundary of the spawning area is mapped using GPS/GIS to estimate the spatial area of the spawn.

Intertidal Shoreline Spawns

In Crescent City Harbor and San Francisco Bay, Herring commonly spawn on intertidal shorelines. These spawning events can occur on natural shorelines or on manmade structures in the intertidal zone such as riprap and pier pilings. Spawns deposited on natural or riprap intertidal areas are primarily surveyed from land, although in some cases they can be surveyed from a boat. The boundary (length and width) of the spawning area along the shoreline is mapped using GPS/GIS to estimate the spatial area of the spawn. Overall width of the spawn may be estimated by taking the average of several width measurements over the length of the spawn. Surveying spawn deposited on pier pilings is conducted from a boat. The average area of spawn covering each piling is calculated and multiplied by the number of pilings on which spawn was deposited.

Qualitative Assessment of Spawn Density

Qualitative estimates of spawn density can provide useful information to assess spawning population behavior when combined with spatial extent and frequency of spawns. Egg deposition density is observed from multiple spatially balanced points throughout each spawn. Using these observations and historical quantitative observations of spawn density in the management areas, spawns can be visually categorized as low, medium, or high density.

Monitoring Summary

At the end of the spawning season, ahead of the Director's Herring Advisory Committee meeting, the Department will develop a monitoring summary to be included in Chapter 4 of the Pacific Herring Enhanced Status Report for all actively fished Tier 2 management areas. The monitoring summary will include the results of all fishery-dependent and fishery-independent monitoring activities conducted within the Tier 2 management areas during the season. The available information will be used to assess if the precautionary Tier 2 management quotas remain consistent with sustainable fishery management or if additional precautionary action should be taken.

Collaborative Research Workshop

While it is the responsibility of the Department to monitor fish stocks, the Department is limited by staffing and resource constraints, and must allocate sampling efforts to areas where there is the most need. However, there are several opportunities for collaboration with various stakeholders, and these may provide additional information that can help inform management. In May 2018, a workshop was held to discuss opportunities and barriers to expanding collaborative research efforts. There is a history of collaborative research in the Herring fishery, and so permittees and Department staff were invited to share their experiences by describing how various research projects were structured, the types of data collected, management outcomes, research costs, and the administrative process. Some of the key outcomes of this workshop are summarized below, and were used to identify increased opportunities for collaborative research moving forward:

- Successful collaborative research depends on strong relationships between Department staff and stakeholders.
- From the Department's perspective, the most useful information stakeholders can provide is the location and time of an observed spawn, because searching for spawns is very time consuming. Both consumptive and non-consumptive stakeholders could provide this information.
- Other types of gear, such as lampara nets, allow fishermen to take a small but unbiased sample of a Herring school. This can produce useful information on the composition of the stock (age, length, weight, and sex structures).
- Economic incentives or outside funding to offset costs are necessary for collaborative research.

Opportunities for Collaborative Research

The efficacy of the RSA methodology will be greatly aided by collaboration with fishermen. First, Department staff will ask fishermen to notify staff when they observe Herring spawning activity (time and location of spawn) on a voluntary basis, whether they are fishing or not. One of the most time-consuming activities for the Department is searching for Herring spawns in the bays. This will provide more eyes on the water and increase the likelihood that spawns are detected, and their spatial extents assessed. While notifications of spawning events are purely voluntary, there is an incentive for fishermen to report spawns because low numbers of spawns or low total spawning area compared to historical data may indicate problems with the spawning population that could initiate a closure of the fishery. The Department may also be able to work with other stakeholders, such as birders or other non-consumptive users who are routinely out on the water or near shorelines. This will require Department staff to reach out to representatives from these groups and explain the need for spawn reporting and provide contact information to build a network.

Fishermen and other stakeholders may also be able to assist the Department through the collection of additional data on spawn size and density. This type of data collection will require volunteers going into the field to help Department staff map the sizes of spawns and potentially qualitatively assess spawning density. Such voluntary assistance may enable Department staff to more effectively monitor spawning events occurring in different locations at the same time.

Fishermen may be able to assist the Department with taking samples of whole Herring as well. Regulatory language developed in this FMP promotes greater participation. Using letters of authorization, Department staff may issue small individual quotas to permitted fishermen and allow whole Herring to be taken using a specified gear type in specific locations and timeframes. One of the key outcomes of the workshop was a recognition that other gear types such as lampara nets are more appropriate for taking small samples from Herring schools. These nets often have a smaller mesh size, and thus select a greater proportion of the population than variable mesh research gill nets, which can provide a less biased sample of the size or age structure of the stock. Additionally, lampara nets allow for a small sample to be taken quickly and the rest of the netted fish to be returned to the water unharmed.

Appendix Q FMP Scoping Process, Stakeholder Involvement, and Public Outreach

The Marine Life Management Act requires that the California Department of Fish and Wildlife (Department) involve the public in Fishery Management Plan (FMP) preparation. The Department's 2018 Master Plan for Fisheries directs the level of stakeholder engagement to be tailored to the size of the fishery and the complexity of the management changes under consideration. This document describes the ways in which outreach targeted key stakeholder groups to solicit stakeholder involvement in the development of the Pacific Herring (Herring), *Clupea pallasii,* FMP, as well as how this feedback was incorporated to create the proposed management strategy.

Steering Committee

The development of the Herring FMP provided an opportunity to test a new model of FMP development in which a small group of stakeholders representing various interest groups worked with Department scientists and managers to develop a vision for the Herring FMP, provide guidance throughout the FMP process, and communicate the goals and strategies of the plan to their wider communities. The goals of this approach were to solicit stakeholder input early in the process, give an opportunity for stakeholders to understand the results of the various scientific analyses being conducted, and make the overall process more interactive in order to reduce controversy during FMP development and implementation. The Steering Committee (SC) was formed out of an informal discussion group that began meeting in 2012 to discuss the management needs of the Herring fishery. This group, which included Herring fleet leaders, representatives from conservation non-governmental organizations (NGOs), and Department staff developed a "blueprint" outlining the broad scope and goals for the FMP development process, as well as the scientific analyses required to meet those goals.

It was agreed that the desired goal of the FMP development process was to develop a management plan that had the support of all SC members to the extent possible. To facilitate this, regular meetings were held with the SC to provide updates on progress and receive guidance on how to develop key elements of the FMP. Throughout the process the Department retained authority over the final contents of the FMP, and approval of an FMP for submission to the California Fish and Game Commission (Commission).

Public Scoping Process

When FMP development was initiated the first step of the process was to draft a document describing the intended scope of the project to alert stakeholders of the management issues to be addressed. The scope was based on the blueprint developed by the SC. This scoping document was then distributed to the public by various means, including a mailing to current Herring permit holders, posted on the Department's Marine Management News and Pacific Herring Management News websites, via email to the Director's Herring Advisory Committee (DHAC) members and to the interested parties email list.

The Department received 22 comments from the public in response to the release of document describing the intended scope of the project. The majority of the responses (15) were requests to be added to the email list. Of those respondents that listed their affiliation, eight were past or present commercial fishermen and six were from representatives of environmental NGOs or natural resource management agencies.

The comments from environmental interests expressed a desire to see the role of Herring as forage fish and climate change addressed in the FMP. The comments from current and past fishermen expressed concern about the cost of obtaining a Herring permit and the barriers to entry by new fishermen, the cost of a commercial fishing license in years when the respondent elected not to fish, the effects of fishing in Tomales Bay on the Herring population, and a desire to use round-haul (purse-seine) nets to fish for Herring. The SC discussed these concerns, and it agreed that the ecosystem role of Herring, climate readiness, barriers to entry, permit fees and requirements, and management of the Tomales Bay herring population would all be addressed within the FMP development process. However, after much discussion it was decided that due to concerns about the environmental impacts and the increased analytical and stakeholder process required to develop a management procedure that included round haul gear, the Department would not be considering a gear change as part of the FMP process but would provide analysis under Project Alternatives within the FMP.

Pursuant to CEQA § 21080.3.1, as well as the Department's Tribal Communication and Consultation Policy, the Department and Commission provided a joint notification to tribes in California. The letters to the individual tribes were mailed on August 1, 2018. The Commission received a response confirming that the proposed project is outside of the Aboriginal Territory Stewarts Point Rancheria Kashia Band of Pomo Indians. The Indian Canyon Band of Costanoan Ohlone People requested a Native American Monitor and an Archaeologist be present on site at all times if there is to be any earth movement within a quarter of a mile of any culturally sensitives sites. The Department confirmed the project does not involve any earth movement within a quarter mile of any culturally sensitive sites.

The Department initially informed tribes that a FMP for Herring was being developed in a letter dated July 5, 2016. As a follow-up to the initial introduction by mail, Department staff met with Graton Rancheria staff per requested on September 20, 2016 to provide additional details on the FMP process and scope. A subsequent letter soliciting tribal input on the management objectives outlined in the FMP was mailed to tribes on March 28, 2018.

The results of the scoping process were presented to the Commission's Marine Resources Council (MRC) at a public meeting in March 2017 for guidance and support for the intended scope of the FMP. The MRC adopted the intended scope which then guided the remainder of the FMP development process.

Commercial Permit Holder Meetings and Survey

Each year the Department meets with the DHAC, which is a group of industry representatives from various sectors of the fishery. At these meetings, Department scientists provide an overview of catch data (research and commercial) and provide the estimated spawning biomass during the season. It also provides an opportunity to discuss with DHAC members the Department's recommended quota for the next commercial Herring season. During the FMP development process these meetings provided additional opportunities to provide updates on the progress of the FMP. While these meetings focused primarily on changes affecting the San Francisco Bay gill net sector, additional one-on-one meetings were also held with representatives of smaller sectors of the fleet (in particular the Herring Eggs on Kelp (HEOK) sector and the northern gill net permit holders) to ensure that the needs of these sectors were being addressed in the FMP.

Additionally, the Department sought feedback from the Herring fleet on potential regulatory changes via a survey (Appendix Q). The survey was mailed to all permit holders, and could be returned via mail, email, or online. Based on the survey results, the Department worked with the Herring FMP Project Management Consultant Team to develop a draft proposal for regulatory changes that had broad support. A meeting for all permit holders was held in January 2018 (during the Herring season to maximize attendance), and the draft regulatory change proposal and management plan for setting Herring quotas were presented to the fleet. At this meeting permit holders had the opportunity to ask questions and provide comments back to Department staff and the Herring FMP Project Management Consultant Team. The meeting was also broadcasted via webinar to enable remote participation. The feedback from permit holders was recorded and discussed at the next SC meeting and used to refine the regulatory change proposals.

Fish and Game Commission and Marine Resource Committee Meetings

At the April 13, 2016 Commission meeting in Santa Rosa the initiation of the development of the Herring FMP was announced, and the Herring FMP Project Management Consultant Team to assist the Department were introduced. Short presentations were provided at subsequent MRC meetings to inform commissioners about the intended development process and to provide status updates. On July 21, 2016 a presentation was given to describe the overall goals and timeline for FMP development, as well as the public notification process, which was ongoing at that time. The results of the public scoping process were shared at the March 23, 2017 MRC meeting as well as the intended scope of the FMP. To support the development of a management strategy, a presentation providing an overview of the analyses underway was given at the July 21, 2017 MRC meeting. At the March 6, 2018 MRC meeting a more in-depth presentation was given to describe the core pieces of the proposed management strategy, including development of a Harvest Control Rule (HCR) framework, which accounts for ecosystem needs and a collaborative research protocol. At the July 17, 2018 MRC meeting, a presentation was given to provide updates on FMP development, including conducting an external peer review coordinated by California Ocean Science Trust, and updates on the HCR framework, collaborative research, regulations and permitting, and timeline. At each of these meetings members of the public were given the opportunity to ask questions and/or provide comments. All comments were recorded and discussed with the SC. Lastly, the Commission requested a presentation at the March 20, 2019 MRC to provide an update on the commercial Herring fishery catch and participation over time, and FMP updates including peer review recommendations, and the agreed HCR framework.

Public Meetings and Opportunities for Public Comment

Throughout the FMP development process, the public has been able to submit questions or comments to the Department staff via email or phone. In addition, public meetings were held in Sausalito, California, a number of times to share information with the public and provide an opportunity for interested parties to ask questions or provide comment. A public meeting was held in Sausalito in April 2016 to announce the initiation of the Herring FMP and to allow the public to ask questions. Once a management strategy was developed and agreed upon by the SC, that strategy was presented at a public meeting in Sausalito in January 2018. The meeting was filmed and posted online so people who were unable to attend could learn about the proposed management changes. The meeting had broad attendance and included commercial permit holders, recreational fishers, agencies and NGOs. One hour was allocated for comments and discussion. The feedback received, particularly from the recreational sector, was considered when developing the final regulatory proposal.

Notice of Preparation and Scoping Meeting for CEQA Process

On August 17, 2017, the Commission filed a Notice of Preparation (NOP) with the State Clearinghouse pursuant to the California Environmental Quality Act (CEQA). The NOP included a copy of the Initial Study pursuant to CEQA. On August 25, 2018, the Department held a scoping meeting to alert the public that the Initial Study, detailed project description, and a preliminary analysis of the environmental impacts was available for review. The meeting was publicized using the Herring FMP email list, on the Herring Management News and Marine Management News websites. The meeting provided an opportunity for interested stakeholders to ask questions and provide feedback on what environmental impacts they were most concerned about. The public was also encouraged to submit comments by email or mail between August 17, 2018 and September 21, 2018 (CEQA public comment period). Richardson Bay Regional Agency staff attended the meeting, and asked questions about impacts on eelgrass habitat in Richardson's Bay from non-fishing activities and to better understand the scope of the FMP. Environmental Action Committee of West Marin submitted a comment by email requesting that the Department consider direct and indirect environmental impacts to the Herring fishery and other fisheries, to wildlife including bird species, marine mammals and changing climate conditions.

Print Form

Appendix C

Notice of Completion & Environmental Document Transmittal

Mail to: State Clearinghouse, P.O. Box 3044, Sacramento, CA 95812-3044 (916) 445-0613
For Hand Delivery/Street Address: 1400 Tenth Street, Sacramento, CA 95814

SCH #

Project Title: Pacific Herring Fishery Management Plan (FMP) and Regulatory Amendments

Lead Agency: California Fish and Game Commission
Contact Person: Ryan Bartling (CDFW)
Mailing Address: P.O. Box 944209
Phone: (707) 576-2877
City: Sacramento
Zip: CA
County: Sonoma

Project Location: County: Multiple (see attachment) City/Nearest Community: Various
Cross Streets: n/a Zip Code:
Longitude/Latitude (degrees, minutes and seconds): ___° ___′ ___″ N / ___° ___′ ___″ W Total Acres:
Assessor's Parcel No.: n/a Section: Various Twp.: Range: Base:
Within 2 Miles: State Hwy #: Multiple Waterways: Multiple
Airports: Multiple Railways: Schools: Multiple

Document Type:

CEQA: ☒ NOP ☐ Early Cons ☐ Neg Dec ☐ Mit Neg Dec ☐ Draft EIR ☐ Supplement/Subsequent EIR (Prior SCH No.) Other:

NEPA: ☐ NOI ☐ EA ☐ Draft EIS ☐ FONSI

Other: ☐ Joint Document ☐ Final Document ☐ Other:

Governor's Office of Planning & Research
AUG 17 2018
STATE CLEARINGHOUSE

Local Action Type:

☐ General Plan Update
☐ General Plan Amendment
☐ General Plan Element
☐ Community Plan
☐ Specific Plan
☐ Master Plan
☐ Planned Unit Development
☐ Site Plan
☐ Rezone
☐ Prezone
☐ Use Permit
☐ Land Division (Subdivision, etc.)
☐ Annexation
☐ Redevelopment
☐ Coastal Permit
☒ Other: FMP

Development Type:

☐ Residential: Units ___ Acres ___
☐ Office: Sq.ft. ___ Acres ___ Employees ___
☐ Commercial: Sq.ft. ___ Acres ___ Employees ___
☐ Industrial: Sq.ft. ___ Acres ___ Employees ___
☐ Educational:
☐ Recreational:
☐ Water Facilities: Type ___ MGD ___
☐ Transportation: Type
☐ Mining: Mineral
☐ Power: Type ___ MW ___
☐ Waste Treatment: Type ___ MGD ___
☐ Hazardous Waste: Type
☐ Other:

Project Issues Discussed in Document:

☒ Aesthetic/Visual
☒ Agricultural Land
☒ Air Quality
☒ Archeological/Historical
☒ Biological Resources
☒ Coastal Zone
☒ Drainage/Absorption
☐ Economic/Jobs
☐ Fiscal
☒ Flood Plain/Flooding
☒ Forest Land/Fire Hazard
☒ Geologic/Seismic
☒ Minerals
☒ Noise
☒ Population/Housing Balance
☒ Public Services/Facilities
☒ Recreation/Parks
☒ Schools/Universities
☒ Septic Systems
☒ Sewer Capacity
☒ Soil Erosion/Compaction/Grading
☒ Solid Waste
☒ Toxic/Hazardous
☒ Traffic/Circulation
☒ Vegetation
☒ Water Quality
☒ Water Supply/Groundwater
☒ Wetland/Riparian
☒ Growth Inducement
☒ Land Use
☒ Cumulative Effects
☐ Other:

Present Land Use/Zoning/General Plan Designation:

Commercial and recreational fishing in state waters, excluding marine protected areas that prohibit take

Project Description: *(please use a separate page if necessary)*
See attachment.

Note: The State Clearinghouse will assign identification numbers for all new projects. If a SCH number already exists for a project (e.g. Notice of Preparation or previous draft document) please fill in.

Revised 2010

Reviewing Agencies Checklist

Lead Agencies may recommend State Clearinghouse distribution by marking agencies below with and "**X**".
If you have already sent your document to the agency please denote that with an "**S**".

X	Air Resources Board
X	Boating & Waterways, Department of
	California Emergency Management Agency
	California Highway Patrol
	Caltrans District # ____
	Caltrans Division of Aeronautics
	Caltrans Planning
	Central Valley Flood Protection Board
	Coachella Valley Mtns. Conservancy
X	Coastal Commission
	Colorado River Board
X	Conservation, Department of
	Corrections, Department of
	Delta Protection Commission
	Education, Department of
	Energy Commission
S	Fish & Game Region # 7
	Food & Agriculture, Department of
	Forestry and Fire Protection, Department of
	General Services, Department of
	Health Services, Department of
	Housing & Community Development
	Native American Heritage Commission
	Office of Historic Preservation
	Office of Public School Construction
X	Parks & Recreation, Department of
	Pesticide Regulation, Department of
	Public Utilities Commission
X	Regional WQCB # 1,2,3
X	Resources Agency
	Resources Recycling and Recovery, Department of
X	S.F. Bay Conservation & Development Comm.
	San Gabriel & Lower L.A. Rivers & Mtns. Conservancy
	San Joaquin River Conservancy
	Santa Monica Mtns. Conservancy
X	State Lands Commission
	SWRCB: Clean Water Grants
	SWRCB: Water Quality
	SWRCB: Water Rights
	Tahoe Regional Planning Agency
	Toxic Substances Control, Department of
	Water Resources, Department of
X	Other: National Park Service
X	Other: United States Coast Guard

Local Public Review Period (to be filled in by lead agency)

Starting Date August 17, 2018 Ending Date September 21, 2018

Lead Agency (Complete if applicable):

Consulting Firm: ____________________ Applicant: ____________________
Address: ____________________ Address: ____________________
City/State/Zip: ____________________ City/State/Zip: ____________________
Contact: ____________________ Phone: ____________________
Phone: ____________________

Signature of Lead Agency Representative: Melissa A. Miller-Henson **Date:** 8/17/18

Authority cited: Section 21083, Public Resources Code. Reference: Section 21161, Public Resources Code.

Revised 2010

Project Description:

The proposed project is the adoption of a Fishery Management Plan (FMP) for Pacific Herring fishing under the State's jurisdiction. The project includes both commercial and recreational fishing as an element of the Department of Fish and Wildlife's (Department) Pacific Herring management program. Herring are primarily harvested commercially for their roe (eggs) during the months of January through March (spawning season) using small-mesh, set gill nets to take whole fish.

Minor fisheries are also conducted for roe on kelp, human consumption and bait purposes. Once the FMP is adopted, regulations implementing the FMP and the State's policies for managing the commercial and recreational take of Pacific Herring will be considered for inclusion in the California Code of Regulations (CCR). The proposed project includes recommendations for continuation, amendment, or change to an existing body of regulations (Sections 27.6,163, 163.5, and 164, Title 14, CCR). The recommendations are based on fishery modeling, biological assessments of existing stock conditions and comments received from the FMP Steering Committee, interested individuals, commercial fishermen, and from the Director's Herring Advisory Committee.

The Pacific Herring FMP would further refine and implement the long-term management objectives as well as meet requirements for fisheries management under the Marine Life Management Act. The FMP would serve as the framework to manage the commercial and recreational fishery for Pacific Herring in accordance with Fish and Game Code (§§ 8550-8559, 7078. Amendments to existing regulations, if adopted, will implement the FMP pursuant to Fish and Game Code sections 7072, 7075, and 7080-7088.

Project Location:

The project is located within state waters in coastal northern and central California, including San Francisco Bay, Tomales Bay, Humboldt Bay and Crescent City Harbor, encompassing the following counties: San Mateo, San Francisco, Alameda, Contra Costa, Marin, Humboldt, and Del Norte.

Notice of Preparation

To: State Clearinghouse, OPR
P.O. Box 3044
Sacramento, CA 95812-3044

From: California Dept. of Fish and Wildlife
Marine Region
5355 Skylane Blvd Suite B
Santa Rosa, CA 95403

Subject: Notice of Preparation of a Certified Regulatory Program Draft Environmental Document

The California Fish and Game Commission, with assistance from the California Department of Fish and Wildlife, will be the Lead Agency and will prepare a certified regulatory program environmental analysis for the project identified below. We need to know the views of your agency as to the scope and content of the environmental information which is germane to your agency's statutory responsibilities in connection with the proposed project. Your agency may need to use functional equivalent environmental analysis prepared by our agency when considering your permit or other approval for the project.

The project description, location, and the potential environmental effects are contained in the attached materials. A copy of the Initial Study (☒ is ☐ is not) attached.

Due to the time limits mandated by State law, your response must be sent at the earliest possible date but not later than 30 days after receipt of this notice.

Please send your response to Ryan Bartling at the address shown above. We will need the name for a contact person in your agency.

Project Title: Pacific Herring Fishery Management Plan and Regulatory Amendments

Project Applicant, if any: __________

Date 8/17/18

Signature Melissa A. Miller-Henson

Title Deputy Executive Director

Telephone 916-653-4899

State of California – Natural Resources Agency
DEPARTMENT OF FISH AND WILDLIFE
Marine Region
1933 Cliff Drive, Suite 9
Santa Barbara, CA 93109
www.wildlife.ca.gov

EDMUND G. BROWN JR., Governor
CHARLTON H. BONHAM, Director

August 17, 2018

NOTICE OF PREPARATION OF AN ENVIRONMENTAL DOCUMENT AND PUBLIC SCOPING MEETING NOTICE FOR THE PACIFIC HERRING FISHERY MANAGEMENT PLAN AND REGULATORY AMENDMENTS PROJECT

The California Department of Fish and Wildlife (CDFW) is preparing a Fishery Management Plan (FMP) for Pacific Herring (*Clupea pallasii*). The California Fish and Game Commission (Commission), with assistance from CDFW, is providing this formal notice as the project lead agency pursuant to the California Environmental Quality Act (CEQA). CDFW, assisting the Commission under its certified regulatory program, has prepared the attached Initial Study (IS), detailed project description, and a preliminary analysis of the impacts identified in the IS. (See Cal. Code Regs., tit. 14, § 781.5.) The public comment period for this Notice of Preparation (NOP) is from August 17, 2018 to September 21, 2018. Comments may be provided by email to Ryan Bartling at Ryan.Bartling@wildlife.ca.gov or by letter to the following address:

Attn: Ryan Bartling
California Department of Fish and Wildlife
5355 Skylane Blvd, Suite B
Santa Rosa, CA 95403

Pacific Herring is a natural resource managed currently by CDFW under the Commission's annual rulemaking process. The existing herring fishery is closely regulated through a catch quota system, limited entry permits, seasons, gear restrictions, closed fishing areas, and landing and monitoring restrictions. The Pacific Herring FMP, if adopted by the Commission, would further refine and implement the long-term management objectives as well as meet requirements for fisheries management under the Marine Life Management Act. The FMP, if adopted, will serve as the framework to manage the commercial and recreational fishery for Pacific Herring in accordance with Fish and Game Code (FGC) §§ 8550-8559, 7078. Amendments to existing regulations, if adopted, will implement the FMP pursuant to Fish and Game Code sections 7072, 7075, and 7080-7088.

The project to be described is commercial and recreational fishing as an element of the Department's Pacific Herring management program. The locations of the project are San Francisco Bay, Tomales Bay, Humboldt Bay and Crescent City Harbor. Herring are primarily harvested for their roe (eggs) during the months of January through March (spawning season) using small mesh gill nets to take whole fish. Minor fisheries are also conducted for roe on kelp, human consumption and bait purposes.

A public hearing as part of the scoping effort will be held August 25, 2018 at the Bay Model Visitor's Center, 2100 Bridgeway, Sausalito, CA from 10:00am to 12:00pm. The meeting is being held to solicit comments on the environmental impacts of the proposed project and answer questions related to FMP development.

CEQA APPENDIX G:
ENVIRONMENTAL CHECKLIST FORM

1. **Project Title:** Pacific Herring Fishery Management Plan and Proposed Regulatory Amendments

2. **Lead Agency:**
   California Fish and Game Commission
   P.O. Box 944209
   Sacramento, CA 94244-2090

3. **Lead Agency Contact Persons:**
   Valerie Termini
   California Fish and Game Commission
   P.O. Box 944209
   Sacramento, CA 94244-2090

   Ryan Bartling
   California Department of Fish and Wildlife
   5355 Skylane Blvd, Suite B
   San Rosa, CA 95403

4. **Project Location:**
   The project is located within state waters in coastal northern and central California, including San Francisco Bay, Tomales Bay, Humboldt Bay and Crescent City Harbor, encompassing the following counties: San Mateo, San Francisco, Alameda, Contra Costa, Marin, Humboldt, and Del Norte (Figure 1).

5. **General Plan Designation:** NA

6. **Zoning:** NA

7. **Description of project:**
   The proposed project is the adoption of a Fishery Management Plan (FMP) for Pacific Herring fishing under the State's jurisdiction. The project includes both commercial and recreational fishing as an element of the Department of Fish and Wildlife's (Department) Pacific Herring management program. Herring are primarily harvested commercially for their roe (eggs) during the months of January through March (spawning season) using small-mesh, set gill nets to take whole fish.

   Minor fisheries are also conducted for roe on kelp, human consumption and bait purposes. Once the FMP is adopted, regulations implementing the FMP and the State's policies for managing the commercial and recreational take of Pacific Herring will be considered for inclusion in the California Code of Regulations (CCR). The proposed project includes recommendations for continuation, amendment, or change to an existing body of regulations (Sections 27.6,163, 163.5, and 164, Title 14, CCR). The recommendations are based on fishery modeling, biological assessments of existing stock conditions and comments received from the FMP Steering Committee, interested individuals, commercial fishermen, and from the Director's Herring Advisory Committee.

The Pacific Herring FMP would further refine and implement the long-term management objectives as well as meet requirements for fisheries management under the Marine Life Management Act. The FMP would serve as the framework to manage the commercial and recreational fishery for Pacific Herring in accordance with Fish and Game Code (§§ 8550-8559, 7078). Amendments to existing regulations, if adopted, will implement the FMP pursuant to Fish and Game Code sections 7072, 7075, and 7080-7088.

8. **Surrounding land uses and setting: Briefly describe the project's surroundings:**
The project occurs in the marine environment within state waters that are open for take of fish and marine invertebrate resources. The project area includes San Francisco Bay, Tomales Bay, Humboldt Bay and Crescent City Harbor (Figure 1).

San Francisco Bay is an estuary which is separated from the Pacific Ocean by an approximately one-mile wide natural opening called the Golden Gate. San Francisco Bay is situated on the central California coast and surrounded by several large cities including San Francisco, San Jose, and Oakland. The area ranges from highly urbanized cities to large areas of open parkland. The bay is characterized by broad shallows carved by narrow channels whose depths are maintained by swiftly moving currents. The Bay encompasses an area of approximately 550 square miles with an average depth of 20 feet, the maximum depth is 360 feet near the Golden Gate Bridge.

Tomales Bay is located approximately 40 miles north of San Francisco. The bay occupies the northern end of the San Andreas Rift between the Point Reyes Peninsula and the rest of the coast. The west side of the Bay is bordered by Point Reyes National Seashore and the east shore is a mix of agricultural (grazing and dairy) and open space. The bay encompasses an area of 11 square miles, is 13 miles long and slightly over 1 mile wide at its widest with an average depth of less than 20 feet. Tomales Bay has several aquaculture lease operations, small coastal villages and is used for many watersport activities such as kayaking, fishing and sailing.

Humboldt Bay is located approximately 200 miles north of San Francisco. The bay is about 25 square miles in size and is 14 miles long and 4.5 miles wide at its widest point. The bay consists of three regions: North (Arcata) Bay, Entrance Bay, and South Bay. Entrance Bay has one deep connecting channel that leads to the ocean through two concrete and rock jetties. The bay is separated from the ocean by two long sand spits. Tidal channels average 25 feet in depth near the bay mouth and decrease in depth in the bay's upper reaches. The largest coastal communities surrounding the shores of the North and Entrance Bays are Arcata and Eureka, respectively, with Eureka being the largest. Land and water bottom uses include aquaculture, timber harvesting and tourism.

Crescent City Harbor is approximately 20 miles south of the Oregon - California Border and approximately 350 miles north of San Francisco. The area is primarily rocky open coast with a small harbor protected by a southwest facing rock jetty. The area is home to commercial fishing and the small community of Crescent City.

9. **Other public agencies whose approval is required (e.g., permits, financing approval, or participation agreement):** NA

10. **<u>Have California Native American tribes traditionally and culturally affiliated with the project area requested consultation pursuant to Public Resources Code Section 21080.3.1? If so, has consultation begun?</u>** See “Discussion of Checklist,” section XVII.

ENVIRONMENTAL FACTORS POTENTIALLY AFFECTED:
The environmental factors checked below would be potentially affected by this project, involving at least one impact that is a "Potentially Significant Impact" as indicated by the checklist on the following pages.

☐	Aesthetics	☐	Agriculture and Forestry Resources	☐	Air Quality
☒	Biological Resources	☐	Cultural Resources	☐	Geology /Soils
☐	Greenhouse Gas Emissions	☐	Hazards & Hazardous Materials	☐	Hydrology / Water Quality
☐	Land Use / Planning	☐	Mineral Resources	☐	Noise
☐	Population / Housing	☐	Public Services	☐	Recreation
☐	Transportation/Traffic	☐	Tribal Cultural Resources	☐	Utilities/Service Systems

☐ Mandatory Findings of Significance

DETERMINATION: (To be completed by the Lead Agency)
On the basis of this initial evaluation:

☐ I find that the proposed project COULD NOT have a significant effect on the environment, and a NEGATIVE DECLARATION will be prepared.

☐ I find that although the proposed project could have a significant effect on the environment, there will not be a significant effect in this case because revisions in the project have been made by or agreed to by the project proponent. A MITIGATED NEGATIVE DECLARATION will be prepared.

☒ I find that the proposed project MAY have a significant effect or potentially significant effect on the environment, and a functional equivalent environmental analysis should be prepared under the Fish and Game Commission's certified regulatory program. (Cal. Code Regs., tit. 14, § 781.5.)

☐ I find that the proposed project MAY have a "potentially significant impact" or "potentially significant unless mitigated" impact on the environment, but at least one effect 1) has been adequately analyzed in an earlier document pursuant to applicable legal standards, and 2) has been addressed by mitigation measures based on the earlier analysis as described on attached sheets. An ENVIRONMENTAL IMPACT REPORT is required, but it must analyze only the effects that remain to be addressed.

☐ I find that although the proposed project could have a significant effect on the environment, because all potentially significant effects (a) have been analyzed adequately in an earlier EIR or NEGATIVE DECLARATION pursuant to applicable standards, and (b) have been avoided or mitigated pursuant to that earlier EIR or NEGATIVE DECLARATION, including revisions or mitigation measures that are imposed upon the proposed project, nothing further is required.

____ ________________________

Valerie Termini, Executive Director — Date
California Fish and Game Commission

EVALUATION OF ENVIRONMENTAL IMPACTS

1) A brief explanation is required for all answers except "No Impact" answers that are adequately supported by the information sources a lead agency cites in the parentheses following each question. A "No Impact" answer is adequately supported if the referenced information sources show that the impact simply does not apply to projects like the one involved (e.g., the project falls outside a fault rupture zone). A "No Impact" answer should be explained where it is based on project-specific factors as well as general standards (e.g., the project will not expose sensitive receptors to pollutants, based on a project-specific screening analysis).

2) All answers must take account of the whole action involved, including off-site as well as on-site, cumulative as well as project-level, indirect as well as direct, and construction as well as operational impacts.
3) Once the lead agency has determined that a particular physical impact may occur, then the checklist answers must indicate whether the impact is potentially significant, less than significant with mitigation, or less than significant. "Potentially Significant Impact" is appropriate if there is substantial evidence that an effect may be significant. If there are one or more "Potentially Significant Impact" entries when the determination is made, an EIR is required.
4) "Negative Declaration: Less Than Significant With Mitigation Incorporated" applies where the incorporation of mitigation measures has reduced an effect from "Potentially Significant Impact" to a "Less Than Significant Impact." The lead agency must describe the mitigation measures, and briefly explain how they reduce the effect to a less than significant level (mitigation measures from "Earlier Analyses," as described in (5) below, may be cross-referenced).
5) Earlier analyses may be used where, pursuant to the tiering, program EIR, or other CEQA process, an effect has been adequately analyzed in an earlier EIR or negative declaration. Section 15063(c)(3)(D). In this case, a brief discussion should identify the following:
   a) Earlier Analysis Used. Identify and state where they are available for review.
   b) Impacts Adequately Addressed. Identify which effects from the above checklist were within the scope of and adequately analyzed in an earlier document pursuant to applicable legal standards, and state whether such effects were addressed by mitigation measures based on the earlier analysis.
   c) Mitigation Measures. For effects that are "Less than Significant with Mitigation Measures Incorporated," describe the mitigation measures which were incorporated or refined from the earlier document and the extent to which they address site-specific conditions for the project.
6) Lead agencies are encouraged to incorporate into the checklist references to information sources for potential impacts (e.g., general plans, zoning ordinances). Reference to a previously prepared or outside document should, where appropriate, include a reference to the page or pages where the statement is substantiated.
7) Supporting Information Sources: A source list should be attached, and other sources used or individuals contacted should be cited in the discussion.
8) This is only a suggested form, and lead agencies are free to use different formats; however, lead agencies should normally address the questions from this checklist that are relevant to a project's environmental effects in whatever format is selected.
9) The explanation of each issue should identify:
   a) the significance criteria or threshold, if any, used to evaluate each question; and
   b) the mitigation measure identified, if any, to reduce the impact to less than significance

ISSUES:

	Potentially Significant Impact	Less Than Significant with Mitigation Incorporated	Less Than Significant Impact	No Impact
I. AESTHETICS. Would the project:				
a) Have a substantial adverse effect on a scenic vista?	☐	☐	☒	☐
b) Substantially damage scenic resources, including, but not limited to, trees, rock outcroppings, and historic buildings within a state scenic highway?	☐	☐	☐	☒
c) Substantially degrade the existing visual character or quality of the site and its surroundings?	☐	☐	☐	☒
d) Create a new source of substantial light or glare which would adversely affect day or nighttime views in the area?	☐	☐	☐	☒
II. AGRICULTURE AND FORESTRY RESOURCES. In determining whether impacts to agricultural resources are significant environmental effects, lead agencies may refer to the California Agricultural Land Evaluation and Site Assessment Model (1997) prepared by the California Dept. of Conservation as an optional model to use in assessing impacts on agriculture and farmland. In determining whether impacts to forest resources, including timberland, are significant environmental effects, lead agencies may refer to information compiled by the California Department of Forestry and Fire Protection regarding the state's inventory of forest land, including the Forest and Range Assessment Project and the Forest Legacy Assessment project; and forest carbon measurement methodology provided in Forest Protocols adopted by the California Air Resources Board. Would the project:				

	Potentially Significant Impact	Less Than Significant with Mitigation Incorporated	Less Than Significant Impact	No Impact
a) Convert Prime Farmland, Unique Farmland, or Farmland of Statewide Importance (Farmland), as shown on the maps prepared pursuant to the Farmland Mapping and Monitoring Program of the California Resources Agency, to non-agricultural use?	☐	☐	☐	☒
b) Conflict with existing zoning for agricultural use, or a Williamson Act contract?	☐	☐	☐	☒
c) Conflict with existing zoning for, or cause rezoning of, forest land (as defined in Public Resources Code section 12220(g)), timberland (as defined by Public Resources Code section 4526), or timberland zoned Timberland Production (as defined by Government Code section 51104(g))?	☐	☐	☐	☒
d) Result in the loss of forest land or conversion of forest land to non-forest use?	☐	☐	☐	☒
e) Involve other changes in the existing environment which, due to their location or nature, could result in conversion of Farmland, to non-agricultural use or conversion of forest land to non-forest use?	☐	☐	☐	☒
III. AIR QUALITY. Where available, the significance criteria established by the applicable air quality management or air pollution control district may be relied upon to make the following determinations. Would the project:				
a) Conflict with or obstruct implementation of the applicable air quality plan?	☐	☐	☐	☒
b) Violate any air quality standard or contribute substantially to an existing or projected air quality violation?	☐	☐	☐	☒
c) Result in a cumulatively considerable net increase of any criteria pollutant for which the project region is non-attainment under an applicable federal or state ambient air quality standard (including releasing emissions which exceed quantitative thresholds for ozone precursors)?	☐	☐	☒	☐
d) Expose sensitive receptors to substantial pollutant concentrations?	☐	☐	☐	☒
e) Create objectionable odors affecting a substantial number of people?	☐	☐	☐	☒
IV. BIOLOGICAL RESOURCES: Would the project:				
a) Have a substantial adverse effect, either directly or through habitat modifications, on any species identified as a candidate, sensitive, or special status species in local or regional plans, policies, or	☐	☐	☒	☐

	Potentially Significant Impact	Less Than Significant with Mitigation Incorporated	Less Than Significant Impact	No Impact
regulations, or by the California Department of Fish and Game or U.S. Fish and Wildlife Service?				
b) Have a substantial adverse effect on any riparian habitat or other sensitive natural community identified in local or regional plans, policies, regulations or by the California Department of Fish and Game or US Fish and Wildlife Service?	☐	☐	☒	☐
c) Have a substantial adverse effect on federally protected wetlands as defined by Section 404 of the Clean Water Act (including, but not limited to, marsh, vernal pool, coastal, etc.) through direct removal, filling, hydrological interruption, or other means?	☐	☐	☐	☒
d) Interfere substantially with the movement of any native resident or migratory fish or wildlife species or with established native resident or migratory wildlife corridors, or impede the use of native wildlife nursery sites?	☐	☐	☐	☒
e) Conflict with any local policies or ordinances protecting biological resources, such as a tree preservation policy or ordinance?	☐	☐	☐	☒
f) Conflict with the provisions of an adopted Habitat Conservation Plan, Natural Community Conservation Plan, or other approved local, regional, or state habitat conservation plan?	☐	☐	☐	☒
(g) Impact a native fish or wildlife species through authorized take in a commercial or recreational fishing or hunting program?	☒	☐	☐	☐

	Potentially Significant Impact	Less Than Significant with Mitigation Incorporated	Less Than Significant Impact	No Impact
V. CULTURAL RESOURCES. Would the project:				
a) Cause a substantial adverse change in the significance of a historical resource as defined in § 15064.5?	☐	☐	☐	☒
b) Cause a substantial adverse change in the significance of an archaeological resource pursuant to § 15064.5?	☐	☐	☐	☒
c) Directly or indirectly destroy a unique paleontological resource or site or unique geologic feature?	☐	☐	☐	☒
d) Disturb any human remains, including those interred outside of dedicated cemeteries?	☐	☐	☐	☒
VI. GEOLOGY AND SOILS. Would the project:				
a) Expose people or structures to potential substantial adverse effects, including the risk of loss, injury, or death involving:				
i) Rupture of a known earthquake fault, as delineated on the most recent Alquist-Priolo Earthquake Fault Zoning Map issued by the State Geologist for the area or based on other substantial evidence of a known fault? Refer to Division of Mines and Geology Special Publication 42.	☐	☐	☐	☒
ii) Strong seismic ground shaking?	☐	☐	☐	☒
iii) Seismic-related ground failure, including liquefaction?	☐	☐	☐	☒
iv) Landslides?	☐	☐	☐	☒
b) Result in substantial soil erosion or the loss of topsoil?	☐	☐	☐	☒
c) Be located on a geologic unit or soil that is unstable, or that would become unstable as a result of the project, and potentially result in on- or off-site landslide, lateral spreading, subsidence, liquefaction or collapse?	☐	☐	☐	☒

	Potentially Significant Impact	Less Than Significant with Mitigation Incorporated	Less Than Significant Impact	No Impact
d) Be located on expansive soil, as defined in Table 18-1-B of the Uniform Building Code (1994), creating substantial risks to life or property?	☐	☐	☐	☒
e) Have soils incapable of adequately supporting the use of septic tanks or alternative waste water disposal systems where sewers are not available for the disposal of waste water?	☐	☐	☐	☒
VII. GREENHOUSE GAS EMISSIONS. Would the project:				
a) Generate greenhouse gas emissions, either directly or indirectly, that may have a significant impact on the environment?	☐	☐	☐	☒
b) Conflict with an applicable plan, policy or regulation adopted for the purpose of reducing the emissions of greenhouse gases?	☐	☐	☐	☒
VIII. HAZARDS AND HAZARDOUS MATERIALS. Would the project:				
a) Create a significant hazard to the public or the environment through the routine transport, use, or disposal of hazardous materials?	☐	☐	☐	☒
b) Create a significant hazard to the public or the environment through reasonably foreseeable upset and accident conditions involving the release of hazardous materials into the environment?	☐	☐	☐	☒
c) Emit hazardous emissions or handle hazardous or acutely hazardous materials, substances, or waste within one-quarter mile of an existing or proposed school?	☐	☐	☐	☒
d) Be located on a site which is included on a list of hazardous materials sites compiled pursuant to Government Code Section 65962.5 and, as a result, would it create a significant hazard to the public or the environment?	☐	☐	☐	☒

	Potentially Significant Impact	Less Than Significant with Mitigation Incorporated	Less Than Significant Impact	No Impact
e) For a project located within an airport land use plan or, where such a plan has not been adopted, within two miles of a public airport or public use airport, would the project result in a safety hazard for people residing or working in the project area?	☐	☐	☐	☒
f) For a project within the vicinity of a private airstrip, would the project result in a safety hazard for people residing or working in the project area?	☐	☐	☐	☒
g) Impair implementation of or physically interfere with an adopted emergency response plan or emergency evacuation plan?	☐	☐	☐	☒
h) Expose people or structures to a significant risk of loss, injury or death involving wildland fires, including where wildlands are adjacent to urbanized areas or where residences are intermixed with wildlands?	☐	☐	☐	☒
IX. HYDROLOGY AND WATER QUALITY. Would the project:				
a) Violate any water quality standards or waste discharge requirements?	☐	☐	☐	☒
b) Substantially deplete groundwater supplies or interfere substantially with groundwater recharge such that there would be a net deficit in aquifer volume or a lowering of the local groundwater table level (e.g., the production rate of pre-existing nearby wells would drop to a level which would not support existing land uses or planned uses for which permits have been granted)?	☐	☐	☐	☒
c) Substantially alter the existing drainage pattern of the site or area, including through the alteration of the course of a stream or river, in a manner which would result in substantial erosion or siltation on- or off-site?	☐	☐	☐	☒

	Potentially Significant Impact	Less Than Significant with Mitigation Incorporated	Less Than Significant Impact	No Impact
d) Substantially alter the existing drainage pattern of the site or area, including through the alteration of the course of a stream or river, or substantially increase the rate or amount of surface runoff in a manner which would result in flooding on- or off-site?	☐	☐	☐	☒
e) Create or contribute runoff water which would exceed the capacity of existing or planned stormwater drainage systems or provide substantial additional sources of polluted runoff?	☐	☐	☐	☒
f) Otherwise substantially degrade water quality?	☐	☐	☐	☒
g) Place housing within a 100-year flood hazard area as mapped on a federal Flood Hazard Boundary or Flood Insurance Rate Map or other flood hazard delineation map?	☐	☐	☐	☒
h) Place within a 100-year flood hazard area structures which would impede or redirect flood flows?	☐	☐	☐	☒
i) Expose people or structures to a significant risk of loss, injury or death involving flooding, including flooding as a result of the failure of a levee or dam?	☐	☐	☐	☒
j) Inundation by seiche, tsunami, or mudflow?	☐	☐	☐	☒
X. LAND USE AND PLANNING. Would the project:				
a) Physically divide an established community?	☐	☐	☐	☒
b) Conflict with any applicable land use plan, policy, or regulation of an agency with jurisdiction over the project (including, but not limited to the general plan, specific plan, local coastal program, or zoning ordinance) adopted for the purpose of avoiding or mitigating an environmental effect?	☐	☐	☐	☒

	Potentially Significant Impact	Less Than Significant with Mitigation Incorporated	Less Than Significant Impact	No Impact
c) Conflict with any applicable habitat conservation plan or natural community conservation plan?	☐	☐	☐	☒
XI. MINERAL RESOURCES. Would the project:				
a) Result in the loss of availability of a known mineral resource that would be of value to the region and the residents of the state?	☐	☐	☐	☒
b) Result in the loss of availability of a locally-important mineral resource recovery site delineated on a local general plan, specific plan or other land use plan?	☐	☐	☐	☒
XII. NOISE -- Would the project result in:				
a) Exposure of persons to or generation of noise levels in excess of standards established in the local general plan or noise ordinance, or applicable standards of other agencies?	☐	☐	☐	☒
b) Exposure of persons to or generation of excessive groundborne vibration or groundborne noise levels?	☐	☐	☐	☒
c) A substantial permanent increase in ambient noise levels in the project vicinity above levels existing without the project?	☐	☐	☐	☒
d) A substantial temporary or periodic increase in ambient noise levels in the project vicinity above levels existing without the project?	☐	☐	☐	☒
e) For a project located within an airport land use plan or, where such a plan has not been adopted, within two miles of a public airport or public use airport, would the project expose people residing or working in the project area to excessive noise levels?	☐	☐	☐	☒
f) For a project within the vicinity of a private airstrip, would the project expose people residing or working in the project area to excessive noise levels?	☐	☐	☐	☒

	Potentially Significant Impact	Less Than Significant with Mitigation Incorporated	Less Than Significant Impact	No Impact
<u>XIII. POPULATION AND HOUSING.</u> Would the project:				
a) Induce substantial population growth in an area, either directly (for example, by proposing new homes and businesses) or indirectly (for example, through extension of roads or other infrastructure)?	☐	☐	☐	☒
b) Displace substantial numbers of existing housing, necessitating the construction of replacement housing elsewhere?	☐	☐	☐	☒
c) Displace substantial numbers of people, necessitating the construction of replacement housing elsewhere?	☐	☐	☐	☒
<u>XIV. PUBLIC SERVICES.</u>				
a) Would the project result in substantial adverse physical impacts associated with the provision of new or physically altered governmental facilities, need for new or physically altered governmental facilities, the construction of which could cause significant environmental impacts, in order to maintain acceptable service ratios, response times or other performance objectives for any of the public services:				
Fire protection?	☐	☐	☐	☒
Police protection?	☐	☐	☐	☒
Schools?	☐	☐	☐	☒
Parks?	☐	☐	☐	☒
Other public facilities?	☐	☐	☐	☒
<u>XV. RECREATION.</u>				
a) Would the project increase the use of existing neighborhood and regional parks or other recreational facilities such that substantial physical deterioration of the facility would occur or be accelerated?	☐	☐	☐	☒

	Potentially Significant Impact	Less Than Significant with Mitigation Incorporated	Less Than Significant Impact	No Impact
b) Does the project include recreational facilities or require the construction or expansion of recreational facilities which might have an adverse physical effect on the environment?	☐	☐	☐	☒
<u>XVI. TRANSPORTATION/TRAFFIC.</u> Would the project:				
a) Conflict with an applicable plan, ordinance or policy establishing measures of effectiveness for the performance of the circulation system, taking into account all modes of transportation including mass transit and non-motorized travel and relevant components of the circulation system, including but not limited to intersections, streets, highways and freeways, pedestrian and bicycle paths, and mass transit?	☐	☐	☐	☒
b) Conflict with an applicable congestion management program, including, but not limited to level of service standards and travel demand measures, or other standards established by the county congestion management agency for designated roads or highways?	☐	☐	☐	☒
c) Result in a change in air traffic patterns, including either an increase in traffic levels or a change in location that results in substantial safety risks?	☐	☐	☐	☒
d) Substantially increase hazards due to a design feature (e.g., sharp curves or dangerous intersections) or incompatible uses (e.g., farm equipment)?	☐	☐	☐	☒
e) Result in inadequate emergency access?	☐	☐	☐	☒
f) Conflict with adopted policies, plans, or programs regarding public transit, bicycle, or pedestrian facilities, or otherwise decrease the performance or safety of such facilities?	☐	☐	☐	☒

	Potentially Significant Impact	Less Than Significant with Mitigation Incorporated	Less Than Significant Impact	No Impact
XVII. TRIBAL CULTURAL RESOURCES				
a) Would the project cause a substantial adverse change in the significance of a tribal cultural resource, defined in Public Resources Code section 21074 as either a site, feature, place, cultural landscape that is geographically defined in terms of the size and scope of the landscape, sacred place, or object with cultural value to a California Native American tribe, and that is:				
i) Listed or eligible for listing in the California Register of Historical Resources, or in a local register of historical resources as defined in Public Resources Code section 5020.1(k), or	☐	☐	☒	☐
ii) A resource determined by the lead agency, in its discretion and supported by substantial evidence, to be significant pursuant to criteria set forth in subdivision (c) of Public Resources Code Section 5024.1. In applying the criteria set forth in subdivision (c) of Public Resource Code Section 5024.1, the lead agency shall consider the significance of the resource to a California Native American tribe.	☐	☐	☒	☐
XVIII. UTILITIES AND SERVICE SYSTEMS. Would the project:				
a) Exceed wastewater treatment requirements of the applicable Regional Water Quality Control Board?	☐	☐	☐	☒
b) Require or result in the construction of new water or wastewater treatment facilities or expansion of existing facilities, the construction of which could cause significant environmental effects?	☐	☐	☐	☒
c) Require or result in the construction of new storm water drainage facilities or expansion of existing facilities, the construction of which could cause significant environmental effects?	☐	☐	☐	☒
d) Have sufficient water supplies available to serve the project from existing entitlements and resources, or are new or expanded entitlements needed?	☐	☐	☐	☒
e) Result in a determination by the wastewater treatment provider which serves or may serve the project that it has adequate capacity to serve the project’s projected demand in addition to the provider’s existing commitments?	☐	☐	☐	☒

	Potentially Significant Impact	Less Than Significant with Mitigation Incorporated	Less Than Significant Impact	No Impact
f) Be served by a landfill with sufficient permitted capacity to accommodate the project's solid waste disposal needs?	☐	☐	☐	☒
g) Comply with federal, state, and local statutes and regulations related to solid waste?	☐	☐	☐	☒
XIX. MANDATORY FINDINGS OF SIGNIFICANCE				
a) Does the project have the potential to degrade the quality of the environment, substantially reduce the habitat of a fish or wildlife species, cause a fish or wildlife population to drop below self-sustaining levels, threaten to eliminate a plant or animal community, reduce the number or restrict the range of a rare or endangered plant or animal or eliminate important examples of the major periods of California history or prehistory?	☐	☐	☒	☐
b) Does the project have impacts that are individually limited, but cumulatively considerable? ("Cumulatively considerable" means that the incremental effects of a project are considerable when viewed in connection with the effects of past projects, the effects of other current projects, and the effects of probable future projects)?	☐	☐	☒	☐
c) Does the project have environmental effects which will cause substantial adverse effects on human beings, either directly or indirectly?	☐	☐	☐	☒

Note: Authority cited: Sections 21083 and 21083.05, 21083.09 Public Resources Code. Reference: Section 65088.4, Gov. Code; Sections 21073, 21074 21080(c), 21080.1, 21080.3, 21083, 21083.05, 21083.3, 21080.3.1, 21080.3.2,21082.3, 21084.2, 21084.3, 21093, 21094, 21095, and 21151, Public Resources Code; *Sundstrom v. County of Mendocino,*(1988) 202 Cal.App.3d 296; *Leonoff v. Monterey Board of Supervisors,* (1990) 222 Cal.App.3d 1337; *Eureka Citizens for Responsible Govt. v. City of Eureka* (2007) 147 Cal.App.4th 357; *Protect the Historic Amador Waterways v. Amador Water Agency* (2004) 116 Cal.App.4th at 1109; *San Franciscans Upholding the Downtown Plan v. City and County of San Francisco* (2002) 102 Cal.App.4th 656.

DISCUSSION OF CHECKLIST

I. Aesthetics. Would the project:

a) Have a substantial adverse effect on a scenic vista?

Less Than Significant. The project area may be visible from scenic vistas, depending on the fishing location and fish behavior, in a way consistent with current, baseline conditions within the project area. During the open season, fishing activities may concentrate along shoreline areas, near roads and public piers. The scenic quality of herring fisheries will be viewed as aesthetically pleasing by some and not by others. All of these activities are seasonal and do not leave behind permanent structures. In addition, implementation of the FMP and regulatory amendments would not substantially increase or decrease the level of fishing activity within the project area such that views from a scenic vista would be degraded. Therefore, the FMP and regulatory amendments would not have a substantial adverse effect on scenic vistas.

b) Substantially damage scenic resources, including, but not limited to, trees, rock outcroppings, and historic buildings within a scenic highway?

No Impact. The project area is within marine and estuarine environments, there are no trees or historic buildings within a scenic highway located within the project area. The FMP and regulatory amendments would not substantially change the type or level of fishing activities such that views within the project area would change substantially. Therefore, no impact would occur.

c) Substantially degrade the existing visual character or quality of the site and its surroundings?

No Impact. The herring fishery is not currently known to substantially degrade the existing scenery of the coastline, and the FMP and regulatory amendments would not result in substantial changes in the type or level of fishing activities that would degrade the existing visual character or quality of the project site and its surroundings. Therefore, no impact would occur.

d) Create a new source of substantial light or glare which would adversely affect day or nighttime views in the area?

No Impact. The commercial herring fishery occurs from vessels that must adhere to regulations set forth by the United States Coast Guard under Rule 26. Fishing vessels also must adhere to California Code of Regulations Title 14 § 163 (f)(2)(F) which describe net marking requirements. Implementation of the FMP and regulatory amendments would not alter these requirements, and no increase or decrease in the amount of light or glare from fishing operations would occur. The project would not create or produce new light sources or glare. Therefore, no impact would occur.

II. Agriculture. Would the project:

a) Convert Prime Farmland, Unique Farmland, or Farmland of Statewide Importance (Farmland), as shown on the maps prepared pursuant to the Farmland Mapping and Monitoring Program (FMMP) of the California Resources Agency, to non-agricultural use?
b) Conflict with existing zoning for agricultural use, or a Williamson Act contract?

No Impact. The project is within marine and estuarine environments, it does not contain any Prime Farmland, Unique Farmland, or Farmland of Statewide Importance, as mapped by the FMMP. The herring fishery has no effect on terrestrial agriculture, and the project would not cause changes that would result in direct or indirect conversion of these types of farmland. In addition, there is no potential for conflict with zoning for agricultural use or a Williamson Act contract due to the project's location. Therefore, no impact would occur.

c) Conflict with existing zoning for, or cause rezoning of, forest land (as defined in Public Resources Code [PRC] section 12220(g)), timberland (as defined by PRC section 4526), or timberland zoned Timberland Production (as defined by Government Code section 51104(g))?
d) Result in the loss of forest land or conversion of forest land to non-forest use?

No Impact. The project area is within marine and estuarine environments and does not contain any forestland as defined by PRC, nor does it contain timberland, or zoned Timberland Production as defined by the Government Code. The herring fishery has no effect on forestland or other related resources, and the project would not cause changes that would result in direct or indirect conversion of or conflict with zoning related to forestland types of land uses. Therefore, there is no impact.

e) Involve other changes in the existing environment which, due to their location or nature, could result in conversion of Farmland to non-agricultural use or conversion of forest land to non-forest use?

No Impact. The herring FMP and regulatory amendments would only involve changes to the existing management of the herring fishery, which is located in the marine and estuarine environment. No change to the land uses in the surrounding terrestrial areas is anticipated; therefore, the FMP and regulatory amendments would not result in any changes or conversion to either Important Farmland or forest land uses to other land uses. Therefore, no impact would occur.

III. Air Quality. Would the project:

a) Conflict with or obstruct implementation of the applicable air quality plan?

No Impact. The proposed project occurs includes bays and coastal areas that are encompassed by San Francisco, San Mateo, Alameda, Contra Costa, Marin, Humboldt, and Del Norte Counties, which are under the San Francisco Bay Area and North Coast air basins.

The purpose of any air quality plan is to reduce criteria and toxic air pollutants in a particular region. These plans can be established by jurisdictional agencies such as air districts or through a general plan document. Typical air quality plans in given air districts address the feasibility and actions that air districts should take to meet or maintain state and federal clean air standards. As shown in Table 1, air districts within the project area are at non-attainment status in the southern portion and at unclassified/attainment in the northern portion with respect to state and national standards, except for the PM_{10}.

Table 1. National and State Air Quality Attainment Statuses at Affected Counties

County	Ozone[a]	PM_{10}	$PM_{2.5}$[b]
National Standard			
Del Norte	Unclassified/Attainment	Unclassified/Attainment	Unclassified/Attainment
Humboldt	Unclassified/Attainment	Unclassified/Attainment	Unclassified/Attainment
Marin	Nonattainment	Unclassified/Attainment	Nonattainment
San Mateo	Nonattainment	Unclassified/Attainment	Nonattainment
San Francisco	Nonattainment	Unclassified/Attainment	Nonattainment
Alameda	Nonattainment	Unclassified/Attainment	Nonattainment
Contra Costa	Nonattainment	Unclassified/Attainment	Nonattainment
State Standard			
Del Norte	Attainment	Attainment	Attainment

Humboldt	Attainment	Attainment	Nonattainment
Marin	Nonattainment	Nonattainment	Nonattainment
San Mateo	Nonattainment	Nonattainment	Nonattainment
San Francisco	Nonattainment	Nonattainment	Nonattainment
Alameda	Nonattainment	Nonattainment	Nonattainment
Contra Costa	Nonattainment	Nonattainment	Nonattainment

a. Reflects the national 8-hour standard. The 1-hour standard was revoked on June 15, 2005.
b. Reflects the latest 2012 $PM_{2.5}$ standard.

Source: CARB 2017; USEPA 2018

Air quality plans within general plan documents are usually written as goals, actions, and policies that prohibit or limit land use development actions that would worsen air quality. Any project or plan that would result in short-term or long-term increases in air pollutants would be at risk of conflicting with or obstructing applicable air quality plans. Whether or not an actual conflict would occur depends on the specific limitations presented in the air quality plans and would vary by region.

The proposed FMP and regulatory amendments would result in establishing an updated management framework for the recreational and commercial Pacific Herring fishery and would not directly conflict with or obstruct with the implementation of any applicable air quality plans. Therefore, no impact would occur.

b) Violate any air quality standard or contribute substantially to an existing or projected air quality violation?

No Impact. The proposed project would not result in increased emissions of air pollutants or contaminants over existing conditions. Movement, concentration, or location of fishing activities would remain similar to baseline conditions under the FMP; therefore, the FMP is not anticipated to impact air quality for air districts within the project area (see district thresholds of significance listed in Table 2). The proposed project would not violate any air quality standard or contribute substantially to an existing or projected air quality violation. Therefore, no impact would occur.

Table 2. Threshold of Significance for Each Affected Air District for Operational Impacts Only

Air District	NOx	ROG	PM_{10}	$PM_{2.5}$
North Coast Unified AQMD[a]	50 lb/day	50 lb/day[b]	80 lb/day	50 lb/day
Bay Area AQMD	54 lb/day	54 lb/day	82 lb/day (exhaust)	54 lb/day (exhaust)

a. North Coast Unified AQMD has not adopted CEQA thresholds of significance. These thresholds reflect published screening level thresholds for air quality impact analyses for new sources.
b. Threshold for reactive organic compounds.

Source: North Coast Unified AQMD 2015, Bay Area AQMD 2017

c) Result in a cumulatively considerable net increase of any criteria pollutant for which the project region is non-attainment under an applicable federal or state ambient air quality standard (including releasing emissions which exceed quantitative thresholds for ozone precursors)?

Less Than Significant. Air quality is affected by emissions generated from the operation of gas and diesel engines in commercial fishing vessels, and from the operation of gas and diesel engines in support vehicles. Pollutant emissions released when vessels are underway are influenced by a variety of factors including power source, engine size, fuel used, operating speed, and load. The implementation of the FMP and proposed regulatory amendments would not anticipate an increase in vessel capacity and would establish a long-term capacity limit on the number of vessels in the fleet. No long-term adverse impacts to air quality are anticipated since no increased vessel activity is expected as a result of adopting the proposed FMP or implementing regulations. The project would not result in a cumulative net increase of any criteria pollutant for which the plan region is in non-attainment under an applicable federal or state ambient air quality standard.

d) Expose sensitive receptors to substantial pollutant concentrations?

No Impact. Sensitive receptors are typically defined as schools, hospitals, residential care facilities, daycare facilities, or other facilities that may house individuals with health conditions that would be adversely impacted by changes in air quality. The proposed project is the preparation and implementation of the Pacific Herring FMP and proposed regulatory amendments. The project does not propose uses or activities that would result in exposure of these identified sensitive receptors to significant pollutants. Therefore, no impact would occur.

e) Create objectionable odors affecting a substantial number of people?

No Impact. The proposed project involves the adoption of a Pacific Herring FMP and regulatory amendments to sustainably manage the herring resource and improve the long-term sustainability of the fishery. The project does not proposed any construction or operational impacts that would significantly create objectionable odors affecting a substantial number. Therefore, no impact would occur.

IV. Biological Resources. Would the project:

a) Have a substantial adverse effect, either directly or through habitat modifications, on any species identified as a candidate, sensitive, or special-status species in local or regional plans, policies, or regulations, or by the California Department of Fish and Wildlife or the U.S. Fish and Wildlife Service?
b) Have a substantial adverse effect on any riparian habitat or other sensitive natural community identified in local or regional plans, policies, or regulations or by the California Department of Fish and Wildlife or the U.S. Fish and Wildlife Service?

Less Than Significant. There are a number of special status or otherwise protected species that are known to occur or may occur in the project area. The potential exists for any fish or invertebrate in the area of fishing to be taken; however, the species most likely to be taken are relatively small in size and vulnerable to the mesh size used in the commercial fishery. The method of take employed by the commercial Pacific Herring fishery is limited to set gill nets of a mesh size that selects adult herring. Therefore, the existing selective fishing practices ensure a low risk of impact to non-target organisms and surrounding habitats. A midwater trawl and research gill nets with mesh sizes that overlap the commercially legal mesh size are used to independently sample the herring population. There is potential to incidentally capture special status or otherwise protected species during research activities; however, the FMP does not anticipate an increase in research activity above the current, baseline conditions within the project area. The FMP will maintain the existing fishing season, commercial gear restrictions, and closure areas, which limits incidental take of non-target species by the commercial fishery. Cast net fishing in the recreational fishery targets spawning herring in shallow habitat at a time of year when protected species are not likely to occur. The FMP focuses on the commercial and recreational herring fisheries, and continues to implement the long-term management objectives that have been developed by the herring management project. Preventing or limiting bycatch of all types has been a long standing objective of CDFW's management program for herring.

The development of the Pacific Herring FMP is also based on the principles adopted as part of the MLMA. To this end, the project minimizes potential effects to sensitive natural communities and habitats identified through state regulations, most of which are administered by CDFW. Although fishing practices may have some minor effects on the marine environment, the FMP and regulatory amendments would continue to prevent negative effects to the marine environment and ecosystem through its management and proposed regulatory changes. Therefore, this impact would be less than significant.

c) Have a substantial adverse effect on federally protected wetlands as defined by Section 404 of the Clean Water Act (including, but not limited to, marsh, vernal pool, coastal, etc.) through direct removal, filling, hydrological interruption, or other means?

No Impact. The proposed project involves the adoption of a Pacific Herring FMP and regulatory amendments to sustainably manage the herring resource and improve the long-term sustainability of the fishery. The project would not result in removal, fill, hydrologic interruption, or other activities that would result in a direct substantial adverse effect on federally protected wetlands. Therefore, no impact would occur.

d) Interfere substantially with the movement of any native resident or migratory fish or wildlife species or with established native resident or migratory wildlife corridors, or impede the use of native wildlife nursery sites?

No Impact. The proposed project involves the adoption of a Pacific Herring FMP and regulatory amendments to sustainably manage the herring resource and improve the long-term sustainability of the fishery. As discussed under questions IV (a-c), substantial impacts to habitats and substrates would not occur as a result of the FMP and regulatory amendments. As such, no substantial interference with movement or effect to native wildlife nursery sites would occur. Therefore, no impact would occur.

e) Conflict with any local policies or ordinances protecting biological resources, such as a tree preservation policy or ordinance?
f) Conflict with the provisions of an adopted Habitat Conservation Plan, Natural Community Conservation Plan, or other approved local, regional, or state habitat conservation plan?

No Impact. There are no Habitat Conservation Plans or Natural Community Conservation Plans within the project area. The guiding regulation regarding conservation in the project area is the MLMA. The Pacific Herring FMP and proposed regulatory changes have been developed in conjunction with the goals of the MLMA and do not conflict with its provisions. Specifically, the MLMA calls for "conservation, sustainable use, and restoration of California's marine living resources." This includes the conservation of healthy and diverse marine ecosystems and marine living resource," including the development of FMPs. Because the FMP and regulatory amendments have been developed as a result of and in accordance with the MLMA, there would be no conflict with these or other local policies; thus, there is no impact.

(g) Impact a native fish or wildlife species through authorized take in a commercial or recreational fishing or hunting program?

Potentially Significant Impact. The Commission recognizes that any FMP, under appropriate circumstances, would allow for take of a fish species (Pacific Herring in this proposed project). Any take through fishing effort increases mortality rates to the spawning stock beyond what would naturally occur in the absence of fishing. Out of an abundance of caution, the Commission plans to further evaluate whether the proposed FMP may have significant effects on the Pacific Herring population. However, the goal of the FMP is to improve the long-term sustainability of the fishery in accordance with the MLMA, and ensure appropriate management tools are used to protect the resource. The proposed FMP provides management guidance and thresholds that are consistent with existing conditions in the project area and prevent over exploitation, helping to ensure a sustainable fishery based on accepted fishery management principles. The Commission anticipates the potentially significant beneficial impacts to the spawning stock due to the inclusion of a peer reviewed Harvest Control Rule in the FMP, specifically for the only active herring fishery in California (San Francisco Bay).

V. Cultural Resources. Would the project:

a) Cause a substantial adverse change in the significance of a historical resource as defined in Section 15064.5?

No Impact. The proposed project would not directly or indirectly disturb any historical resources or alter activity around any known historical resources beyond baseline conditions. The herring fishery occurs in estuaries and harbors where natural conditions are typically mud bottom subjected to high levels of natural disturbance due to tides and currents. Therefore, there would be no impact.

b) Cause a substantial adverse change in the significance of an archaeological resource pursuant to Section 15064.5?

No Impact. CA State law (PRC §§ 6313, 6314) prohibits all unauthorized salvage and removal of artifacts from submerged archaeological sites in state waters, which are under the jurisdiction of SLC. The proposed project would not modify this existing state law. Furthermore, the proposed project would not result in construction or significant disturbance to the bottoms of bays or estuaries. Therefore, the proposed project would have no to impact submerged archaeological resources.

c) Directly or indirectly destroy a unique paleontological resource or site or unique geologic feature?

No Impact. The proposed project would not result in an increase in activities that would directly or indirectly destroy paleontological or geologic features. The proposed project will have minimal effect on the sea floor, which is where paleontological and geological features have the potential to occur. Therefore, no impact would occur.

d) Disturb any human remains, including those interred outside of formal cemeteries?

No Impact. The proposed project would not result in excavation or other activities onshore or offshore that have the potential to directly or indirectly disturb any known cemeteries or burial grounds. Therefore, no impact would occur.

<u>VI. Geology and Soils.</u> Would the project:

a) Expose people or structures to potential substantial adverse effects, including the risk of loss, injury, or death involving:
i) Rupture of a known earthquake fault, as delineated on the most recent Alquist-Priolo Earthquake Fault Zoning Map issued by the State Geologist for the area or based on other substantial evidence of a known fault? Refer to California Geological Survey Special Publication 42.

No Impact. Portions of the project area are within the Alquist-Priolo Earthquake Fault Zones and several faults are located within the area. However, the project area is within a marine/estuarine environment, and implementation of the FMP and regulatory amendments would not include construction of any structures that would directly expose people or structures to rupture of an earthquake fault. Therefore, no impact would occur.

ii) Strong seismic ground shaking?

No Impact. The FMP and regulatory amendments pertain to the marine/estuarine environment and would not directly expose or increase existing exposure of people or structures to seismic ground shaking that could occur on land. Therefore, no impact would occur.

iii) Seismic-related ground failure, including liquefaction?

No Impact. The FMP and regulatory amendments pertain to the marine/estuarine environment and would not directly expose people or structures to seismic-related ground failure or liquefaction that could occur on land nor increase existing exposure. This impact would be less than significant.

iv) Landslides?

No Impact. The FMP and regulatory amendments pertain to the marine/estuarine environment and would not directly expose people or structures to landslides that could occur on land or increase existing exposure. This impact would be less than significant.

b) Result in substantial soil erosion or the loss of topsoil?

No Impact. The project area is within a marine/estuarine environment, and soil erosion and loss of topsoil are land-based occurrences. Therefore, the FMP and regulatory amendments would have no impact on soil erosion or loss of topsoil.

c) Be located on a geologic unit or soil that is unstable, or that would become unstable as a result of the project, and potentially result in on- or offsite landslide, lateral spreading, subsidence, liquefaction, or collapse?

No Impact. The project area is within a marine/estuarine environment, and unstable soils is a land-based occurrence. Therefore, the FMP and regulatory amendments would have no impact on unstable soils.

d) Be located on expansive soil, as defined in Table 18-1-B of the Uniform Building Code (1994), creating substantial risks to life or property?

No Impact. The project does not involve the construction of buildings or structures that would create substantial risks to life or property. Therefore, the FMP and regulatory amendments would have no impact on expansive soils.

e) Have soils incapable of adequately supporting the use of septic tanks or alternative waste water disposal systems where sewers are not available for the disposal of waste water?

No Impact. The project does not involve the construction of buildings or structures, nor propose the use of septic tanks as part of the FMP or regulatory amendments. Therefore, the FMP and regulatory amendments would have no impact on soils incapable of supporting septic tanks.

VII. Greenhouse Gas Emissions. Would the project:

a) Generate greenhouse gas (GHG) emissions, either directly or indirectly, that may have a significant impact on the environment?

No Impact. The implementation of the FMP and proposed regulatory amendments would not result in an overall increase of GHG emissions over existing conditions. Commercial and recreational fishing activity for Pacific Herring is seasonal and spatially distributed primarily in San Francisco Bay. Thus, it would not substantially affect associated fuel combustion above existing conditions. Therefore, no impact is anticipated.

b) Conflict with an applicable plan, policy or regulation adopted for the purpose of reducing the emissions of greenhouse gases?

No Impact. The proposed project involves the adoption of a Pacific Herring FMP and regulatory amendments to sustainably manage the herring resource and improve the long-term sustainability of the fishery. The FMP would not conflict with any adopted plans, policies, or regulations for the purpose of reducing GHG emissions. Therefore, no impact would occur.

<u>VIII. Hazards and Hazardous Materials.</u> Would the project:

a) Create a significant hazard to the public or the environment through the routine transport, use, or disposal of hazardous materials?

No Impact. The proposed project involves the adoption of a Pacific Herring FMP and regulatory amendments to sustainably manage the herring resource and improve the long-term sustainability of the fishery. Commercial and recreational fishing for herring does not generate any hazardous wastes that would create a significant hazard to the public or the environment. Therefore, no impact would occur.

b) Create a significant hazard to the public or the environment through reasonably foreseeable upset and/or accident conditions involving the release of hazardous materials into the environment?

No Impact. The proposed project involves the adoption of Pacific Herring FMP and regulatory amendments to sustainably manage the herring resource and improve the long-term sustainability of the fishery. Commercial and recreational fishing for herring does not involve the use of hazardous materials. As such, no impact is anticipated for accidents related to the release hazardous materials into the environment.

c) Emit hazardous emissions or handle hazardous or acutely hazardous materials, substances, or waste within one-quarter mile of an existing or proposed school?

No Impact. The proposed project involves the adoption of a Pacific Herring FMP and regulatory amendments to sustainably manage the herring resource and improve the long-term sustainability of the fishery. Commercial and recreational fishing for herring does not involve the use of hazardous materials. Therefore, no impact is anticipated relating to the emission or handling of hazardous materials, substances, or waste within one-quarter mile of any existing or proposed schools within the project area.

d) Be located on a site which is included on a list of hazardous materials sites compiled pursuant to Government Code Section 65962.5 and, as a result, would it create a significant hazard to the public or the environment?

No Impact. Based on a regulatory database search, listed sites currently undergoing cleanup within the project study area are shown in Appendix B. None of the sites listed would be impacted by fishing activities from the herring fishery. The proposed project would not interfere with cleanup efforts, nor would it exacerbate hazardous conditions at the sites. Therefore, no impact would occur.

Source: California Department of Toxic Substances 2018
https://www.dtsc.ca.gov/SiteCleanup/Cortese_List.cfm

e) For a project located within an airport land use plan or, where such a plan has not been adopted, within two miles of a public airport or public use airport, would the project result in a safety hazard for people residing or working in the project area?

No Impact. There are airports within the vicinity of the project area. However, commercial and recreational herring fishing does not currently interfere with airport operations or air traffic that would result in the exposure of people to a safety hazard. Therefore, no impact would occur.

f) For a project within the vicinity of a private airstrip, would the project result in a safety hazard for people residing or working in the project area?

No Impact. The proposed project involves the adoption of a Pacific Herring FMP and regulatory amendments to sustainably manage the herring resource and improve the long-term sustainability of the fishery. The proposed project would not interfere with airport operations or result in any changes to the air traffic patterns that would expose people to a safety hazard. Therefore, no impact would occur.

g) Impair implementation of or physically interfere with an adopted emergency response plan or emergency evacuation plan?

No Impact. The proposed project involves the adoption of a Pacific Herring FMP and regulatory amendments to sustainably manage the herring resource and improve the long-term sustainability of the fishery. The FMP and regulatory amendments would not substantially change the fishing that is currently occurring within the project area. As such, the proposed project would not modify or interfere with any existing emergency response plan or emergency evacuation plan. Therefore, this impact would no impact.

h) Expose people or structures to a significant risk of loss, injury or death involving wildland fires, including where wildlands are adjacent to urbanized areas or where residences are intermixed with wildlands?

No Impact. The project area is within the marine and estuarine environment and is not subject to wildfires. Therefore, no impact would occur.

IX. Hydrology and Water Quality. Would the project:

a) Violate any water quality standards or waste discharge requirements?

No Impact. The proposed project involves the adoption of a Pacific Herring FMP and regulatory amendments to sustainably manage the herring resource and improve the long-term sustainability of the fishery. There is no known contribution to the degradation of water quality nor is there known discharge of pollutants to the environment associated with current commercial and recreational fishing operations for herring. Therefore, no impact would occur.

b) Substantially deplete groundwater supplies or interfere substantially with groundwater recharge such that there would be a net deficit in aquifer volume or a lowering of the local groundwater table level (e.g., the production rate of pre-existing nearby wells would drop to a level that would not support existing land uses or planned uses for which permits have been granted)?

No Impact. The proposed project involves the adoption of a Pacific Herring FMP and regulatory amendments to sustainably manage the herring resource and improve the long-term sustainability of the fishery. The project occurs within the marine and estuarine environment and would not affect groundwater supplies or recharge. Furthermore, no facilities constructed with impervious surfaces that could affect groundwater are proposed as part of this project. Therefore, no impact would occur.

c) Substantially alter the existing drainage pattern of the site or area, including through the alteration of the course of a stream or river, in a manner which would result in substantial on- or offsite erosion or siltation?

No Impact. The proposed project involves the adoption of a Pacific Herring FMP and regulatory amendments to sustainably manage the herring resource and improve the long-term sustainability of the fishery. The project occurs within the marine and estuarine environment. No changes to land use are proposed as part of this project that would modify, either directly or indirectly, existing drainage patterns of any built structures, facilities, or hydrologic features that may exist in the project area in a manner which would result in substantial on- or offsite erosion or siltation. Therefore, no impact would occur.

d) Substantially alter the existing drainage pattern of the site or area, including through the alteration of the course of a stream or river, or substantially increase the rate or amount of surface runoff in a manner which would result in on- or offsite flooding?

No Impact. As discussed under question IX (c), the project occurs within the marine and estuarine environment and no changes to land use are proposed as part of this project that would affect structures, alter existing drainage patterns or other hydrologic features that could affect existing patterns of surface runoff or result in on- or off-site flooding from surface runoff. Therefore, no impact would occur.

e) Create or contribute runoff water which would exceed the capacity of existing or planned stormwater drainage systems or provide substantial additional sources of polluted runoff?

No Impact. As discussed under questions IX (c) and (d), the project is within the marine and estuarine environment and no land use changes are proposed; as such, there would be no contribution to runoff water that would exceed the capacity of existing or planned stormwater drainage systems. In addition, the project would not result in changes to facilities, impervious surfaces, or other structures or stormwater drainage systems such that runoff volumes, flows, or quality of polluted runoff into stormwater drainage systems would be affected. Therefore, no impact would occur.

f) Otherwise substantially degrade water quality?

No Impact. As discussed under questions IX (a) and (c-d), the project does not propose land use changes nor would it create or contribute to discharge of pollutants into the environment that substantially degrade water quality. Therefore, no impact would occur.

g) Place housing within a 100-year flood hazard area as mapped on a federal Flood Hazard Boundary or Flood Insurance Rate Map or other flood hazard delineation map?

No Impact. No housing is proposed as part of the project. Therefore, would be no impact to housing within a Flood Hazard Boundary or other flood hazard delineation map.

h) Place within a 100-year flood hazard area structures that would impede or redirect flood flows?

No Impact. No structures are proposed as part of the project. Therefore, there would be no impact to the 100-year flood hazard area or flood flows.

i) Expose people or structures to a significant risk of loss, injury, or death involving flooding, including flooding as a result of the failure of a levee or dam?

No Impact. The proposed project is located within the marine and estuarine environment. There would be no effect related to or from flooding as a result of a levee or dam, as those types of events do not occur in the project area. Therefore, no impact would occur.

j) Inundation by seiche, tsunami, or mudflow?

No Impact. Seiche and mudflow are hazards generated primarily in terrestrial environments that could affect structures and people on land nearby to inland bodies of water and other inland hydrologic features. Although rare, the potential exists for tsunamis to occur in the project area. However, the proposed project would not increase the risk or vulnerability to hazards from inundation by seiche, tsunami, or mudflow beyond baseline conditions. Therefore, no impact would occur.

X. Land Use and Planning. Would the project:

a) Physically divide an established community?

No Impact. The proposed project involves the adoption of a Pacific Herring FMP and regulatory amendments to sustainably manage the herring resource and improve the long-term sustainability of the fishery. There are coastal communities adjacent to the project area; however, no communities would be divided, either directly or indirectly, from implementation of the FMP and regulatory amendments. Therefore, no impact would occur.

b) Conflict with any applicable land use plan, policy, or regulation of an agency with jurisdiction over the project (including, but not limited to a general plan, specific plan, local coastal program, or zoning ordinance) adopted for the purpose of avoiding or mitigating an environmental effect?

No Impact. The FMP and regulatory amendments would not conflict with any existing land use plan, policy, or regulation because these regulatory changes are focused on management of the commercial and recreational fishery which the Department has authority. Therefore, no impact would occur.

c) Conflict with any applicable habitat conservation plan or natural community conservation plan?

No Impact. The project area is not subject to a habitat conservation plan or natural community conservation plan. The proposed project involves the preparation of a Pacific Herring FMP and regulatory amendments to sustainably manage the herring resource and improve the long-term sustainability of the fishery. Therefore, no impact would occur.

XI. Mineral Resources. Would the project:

a) Result in the loss of availability of a known mineral resource that would be of value to the region and the residents of the state?

No Impact. Since no oil and gas extraction sites are located within the project area, implementation of the FMP and regulatory amendments would not affect the production or extraction of those resources. Thus, there would be no loss of any known mineral resources, or preclusion of future access to any mineral resources. Therefore, no impact would occur.

b) Result in the loss of availability of a locally important mineral resource recovery site delineated on a local general plan, specific plan, or other land use plan?

No Impact. Since no oil and gas extraction sites are located within the project area, the FMP and regulatory amendments would not affect the production or extraction of those resources. Thus, there would be no loss of or preclusion of future access to any mineral resources. Therefore, no impact would occur.

XII. Noise. Would the project:

a) Exposure of persons to or generation of noise levels in excess of standards established in the local general plan or noise ordinance, or applicable standards of other agencies?

No Impact. The proposed project involves the adoption of a Pacific Herring FMP and regulatory amendments to sustainably manage the herring resource and improve the long-term sustainability of the fishery. The project would not result in any construction activity that would generate noise disturbances nor would it increase noise levels compared to baseline conditions. Therefore, no impact would occur.

b) Exposure of persons to or generation of excessive groundborne vibration or groundborne noise levels?

No Impact. As discussed in question XII (a), the adoption project would not result in any construction or other activities that would generate groundborne vibration or groundborne noise levels. Therefore, no impact would occur.

c) A substantial permanent increase in ambient noise levels in the project vicinity above levels existing without the project?

No Impact. The proposed project involves the adoption of a Pacific Herring FMP and regulatory amendments to sustainably manage the herring resource and improve the long-term sustainability of the fishery. The project would not result in any permanent, fixed noise sources nor would it result in a substantial increase in ambient noise levels in the project vicinity above baseline conditions. Therefore, no impact would occur.

d) A substantial temporary or periodic increase in ambient noise levels in the project vicinity above levels existing without the project?

No Impact. The proposed project involves the adoption of a Pacific herring FMP and regulatory amendments to sustainably manage the herring resource and improve the long-term sustainability of the fishery. No construction is proposed a part of the project that would result in temporary or periodic noise disturbances. Therefore, no impact would occur.

e) For a project located within an airport land use plan or, where such a plan has not been adopted, within two miles of a public airport or public use airport, would the project expose people residing or working in the project area to excessive noise levels?

No Impact. There are three public airports (San Francisco Airport, Oakland Airport, California Redwood Coast-Humboldt County Airport) located within a 2-mile radius of the project site. However, the proposed project involves the preparation of a Pacific Herring FMP and regulatory amendments to sustainably manage the herring resource and improve the long-term sustainability of the fishery. There would be no substantial effect on the existing noise conditions from implementation of the proposed project. In addition, the project would not locate sensitive receptors near the vicinity of a public or public use airport. Therefore, no impact would occur.

f) For a project within the vicinity of a private airstrip, would the project expose people residing or working in the project area to excessive noise levels?

No Impact. Similar to question XII (e), there would be no substantial effect on the existing noise conditions from implementation of the proposed project and no sensitive receptors would be located near the vicinity of a private airstrip. Therefore, no impact would occur.

XIII. Population and Housing. Would the project:

a) Induce substantial population growth in an area, either directly (for example, by proposing new homes and businesses) or indirectly (for example, through extension of roads or other infrastructure)?

No Impact. The FMP and regulatory amendments would not include construction of new housing or commercial businesses. Therefore, no direct population growth would result from implementation of the FMP or regulatory amendments. In addition, the proposed changes would not require or indirectly cause any new construction or any infrastructure modification, and no additional temporary or permanent staff would be needed for operations and maintenance of the fishery. Therefore, no impact would occur.

b) Displace substantial numbers of existing homes, necessitating the construction of replacement housing elsewhere?

No Impact. The FMP and regulatory amendments would not remove any homes or require construction of replacement housing. Therefore, no impact would occur.

c) Displace substantial numbers of people, necessitating the construction of replacement housing elsewhere?

No Impact. The FMP and regulatory amendments would not displace any people or require construction of replacement housing. Therefore, no impact would occur.

XIV. Population and Housing. Would the project:

a) Result in substantial adverse physical impacts associated with the provision of new or physically altered governmental facilities, need for new or physically altered governmental facilities, the construction of which could cause significant environmental impacts, in order to maintain acceptable service ratios, response times or other performance objectives for any of the public services:

Fire protection?

No Impact. No construction of any new government facilities or the alteration of any existing government facilities that would increase the demand for fire protection services is proposed as part of the project. In addition, the project area is within the marine environment and the potential for fires would be limited to those on board of fishing vessels. The FMP and regulatory amendment would not substantially increase the amount of vessels in the project area or the demand for fire services. Therefore, no impact would occur.

Police protection?

No Impact. The FMP and regulatory amendments would not involve the construction of any new government facilities or the alteration of any existing government facilities that would increase the demand for police protection services. In addition, the FMP and regulatory amendment would not substantially increase the amount of vessels in the project area or the demand for police or other law enforcement services. Therefore, no impact would occur.

Schools?

No Impact. The FMP and regulatory amendments would not involve the construction or alternation facilities that would increase the demand for schools. Therefore, no impact would occur.

Parks?

No Impact. The FMP and regulatory amendments would not involve the construction or alteration of any facilities that would increase the demand for parks. Therefore, no impact would occur.

Other public facilities?

No Impact. The FMP and regulatory amendments would not involve the construction or alteration of any facilities that would increase the demand for other public facilities. Therefore, no impact would occur.

XV. Recreation. Would the project:

a) Increase the use of existing neighborhood and regional parks or other recreational facilities such that substantial physical deterioration of the facility would occur or be accelerated?
b) Include recreational facilities or require the construction or expansion of recreational facilities which might have an adverse physical effect on the environment?

No Impact. The proposed project would not result in increased use of recreational facilities in neighborhood or regional parks above existing conditions. As a result no new construction or expansion would be required. Therefore, no impact would occur.

XVI. Transportation/Traffic. Would the project:

a) Conflict with an applicable plan, ordinance or policy establishing measures of effectiveness for the performance of the circulation system, taking into account all modes of transportation including mass transit and non-motorized travel and relevant components of the circulation system, including but not limited to intersections, streets, highways and freeways, pedestrian and bicycle paths, and mass transit?

No impact. The proposed project would not conflict with any plans or policies related to circulation. The FMP and regulatory amendments would not conflict with the performance of existing circulation systems for traffic. Therefore, no impact would occur.

b) Conflict with an applicable congestion management program, including, but not limited to level of service standards and travel demand measures, or other standards established by the county congestion management agency for designated roads or highways?

No Impact. The proposed project is located within the marine environment and is not subject to any congestion management program for roads or highways. Therefore, no impact would occur.

c) Result in a change in air traffic patterns, including either an increase in traffic levels or a change in location that results in substantial safety risks?

No Impact. The proposed project is within the marine environment and implementation of the project would not affect any air traffic patterns. Therefore, no impact would occur.

d) Substantially increase hazards due to a design feature (e.g., sharp curves or dangerous intersections) or incompatible uses (e.g., farm equipment)?

No Impact. No new facilities would be constructed under the FMP or regulatory amendments, and implementation of these changes would not involve any design feature related to any transportation of traffic-related infrastructure. Therefore, no impact would occur.

e) Result in inadequate emergency access?

No Impact. The proposed project would not change emergency access within the project area. Therefore, no impact would occur.

f) Conflict with adopted policies, plans, or programs regarding public transit, bicycle, or pedestrian facilities, or otherwise decrease the performance or safety of such facilities?

No Impact. The proposed project is located within the marine environment. Implementation of the FMP and regulatory amendments would not affect adopted policies, plans, or programs regarding public transit, bicycle, or pedestrian facilities, or otherwise decrease the performance or safety of such facilities. Therefore, no impact would occur.

XVII. Tribal Cultural Resources. Would the project:

a) Cause a substantial adverse change in the significance of a tribal cultural resource, defined in Public Resources Code section 21074 as either a site, feature, place, cultural landscape that is geographically defined in terms of the size and scope of the landscape, sacred place, or object with cultural value to a California Native American tribe, and that is:

   i) Listed or eligible for listing in the California Register of Historical Resources, or in a local register of historical resources as defined in Public Resources Code section 5020.1(k), or
   ii) A resource determined by the lead agency, in its discretion and supported by substantial evidence, to be significant pursuant to criteria set forth in subdivision (c) of Public Resources Code Section 5024.1. In applying the criteria set forth in subdivision (c) of Public Resource Code Section 5024.1, the lead agency shall consider the significance of the resource to a California Native American tribe?

Less Than Significant. Both the Commission and CDFW are committed to open communication with Tribes under their respective consultation policies (CDFW's Tribal Communication and Consultation Policy, which is available through the CDFW's Tribal Affairs webpage at https://www.wildlife.ca.gov/General-Counsel/Tribal-Affairs; Commission's Tribal Consultation Policy, which is available through the Commission's Policies webpage at http://www.fgc.ca.gov/policy/p4misc.aspx#tribal). Early tribal consultation with the Graton Rancheria Federation of Coast Miwok and Southern Pomo groups in September 2016. CDFW initiated communication with the tribe on issues concerning Pacific Herring management and the development of the FMP.

In addition, in July 2018, CDFW contacted NAHC to identify registered, Native American sacred sites in or within the vicinity of the project area and to obtain a list of tribes affiliated with the geographic area of the project. The results of the NAHC Sacred Lands File search indicate that Native American cultural sites are present within the project area. NAHC provided a list of Native American tribes who may have knowledge of cultural resources in the project area. On August 1, 2018, the Commission and CDFW sent a joint letter pursuant to PRC 21080.3.1 describing the project to Tribal representatives on the NAHC Tribal Consultation List requesting any input or concerns they might have regarding the project. The goal of the Commission and CDFW is to understand Tribal interests and concerns early in the project and to work collaboratively to resolve any concerns. No request for consultation has been submitted to CDFW to date. Correspondences related to tribal cultural resources are included in Appendix A.

Pacific Herring are a culturally important resource to many coastal tribes within the project area. The proposed project seeks to sustainably manage the herring resource and improve the long-term sustainability of the fishery. Any changes to the fishery that may affect tribal use will be addressed directly with the tribes through the consultation process.

XVIII. Utilities. Would the project:

a) Exceed wastewater treatment requirements of the applicable Regional Water Quality Control Board?

No Impact. The proposed project involves the adoption of a Pacific Herring FMP and regulatory amendments to sustainably manage the herring resource and improve the long-term sustainability of the fishery. No land use changes or development are proposed as part of the project which would generate wastewater requiring treatment. Therefore, no impact would occur.

b) Require or result in the construction of new water or wastewater treatment facilities or expansion of existing facilities, the construction of which could cause significant environmental effects?

No Impact. Implementation of the FMP and regulatory amendments would not include any facilities that would require water and would not increase the demand for water. In addition, the proposed project would not result in impact related to construction of new or expanded wastewater treatment facilities. Therefore, no impact would occur.

c) Require or result in the construction of new storm water drainage facilities or expansion of existing facilities, the construction of which could cause significant environmental effects?

No Impact. The proposed project involves the adoption of a Pacific Herring FMP and regulatory amendments to sustainably manage the herring resource and improve the long-term sustainability of the fishery. Implementation of the project would not result in land use change or development that would generate stormwater that would require the construction of new storm water drainage facilities or the expansion of existing facilities within the project area. Therefore, no impact would occur.

d) Have sufficient water supplies available to serve the project from existing entitlements and resources, or are new or expanded entitlements needed?

No Impact. Implementation of the FMP and regulatory amendments would not include any facilities that would require water and would not increase the demand for water. Therefore, no impact would occur.

e) Result in a determination by the wastewater treatment provider that serves or may serve the project that it has adequate capacity to serve the project's projected demand, in addition to the provider's existing commitments?

No Impact. See discussion under XVIII (a). There would be no impact related to wastewater treatment capacity.

f) Be served by a landfill with sufficient permitted capacity to accommodate the project's solid waste disposal needs?

No Impact. Although some solid waste is generated with fishing activities, implementation of the FMP and regulatory amendments would not result in an overall increase in solid waste generated by the fishery. Therefore, there would be no impact on landfill capacity.

g) Comply with federal, state, and local statutes and regulations related to solid waste?

No Impact. The proposed FMP and regulatory amendments would not result in a change in compliance with solid waste regulations. Therefore, no impact would occur.

h) Interfere with utilities?

No Impact. Fishing activities are not known to interfere with underwater cable or other submerged utilities. Therefore, no impact would occur.

<u>XIX. Mandatory Findings of Significance.</u>

a) Does the project have the potential to substantially degrade the quality of the environment, substantially reduce the habitat of a fish or wildlife species, cause a fish or wildlife population to drop below self-sustaining levels, threaten to eliminate a plant or animal community, reduce the number or restrict the range of an endangered, rare, or threatened species, or eliminate important examples of the major periods of California history or prehistory?

Less Than Significant. As evaluated in this Initial Study, the proposed project would not substantially degrade the quality of the environment, substantially reduce the habitat of a fish or wildlife species, cause a fish or wildlife population to drop below self-sustaining levels, threaten to eliminate a plant or animal community, reduce the number or restrict the range of an endangered, rare, or threatened species, or eliminate important examples of the major periods of California history or prehistory. The proposed FMP and regulatory amendments would benefit the Pacific Herring fishery by adaptively managing it to ensure the long-term health of the resource. Pacific Herring would be removed from the project area by the commercial and recreational fisheries which could have impacts to the ecosystem. However, harvest of herring is strictly regulated and managed to minimize impacts to the ecosystem and other species. Therefore, this impact would be less than significant.

b) Does the project have impacts that are individually limited, but cumulatively considerable? ("Cumulatively considerable" means that the incremental effects of a project are considerable when viewed in connection with the effects of past projects, the effects of other current projects, and the effects of probable future projects.)

Less Than Significant. The potential for adverse cumulative effects were considered in the response to each question in sections I through XIX of this Initial Study. As a result of this evaluation, there is no substantial evidence that there are adverse cumulative effects associated with the proposed project that would have significant impacts or require mitigation. Pursuant to the MLMA, this project in combination with past, present, and probable future projects would contribute to the conservation of marine ecosystems and marine living resources. Therefore, the proposed project would not add considerably to any cumulative impacts in the region. Therefore, cumulative impacts would be less than significant.

c) Does the project have environmental effects that will cause substantial adverse effects on human beings, either directly or indirectly?

No Impact. The potential for adverse direct or indirect impacts to human beings were considered in the evaluation of environmental impacts for certain questions in sections I, III, VI, VIII, IX, XII, XIII, and XVI of this Initial Study. As a result of this evaluation, the proposed project would not have environmental effects that would cause substantial adverse direct or indirect effects on human beings. Therefore, no impact would occur.

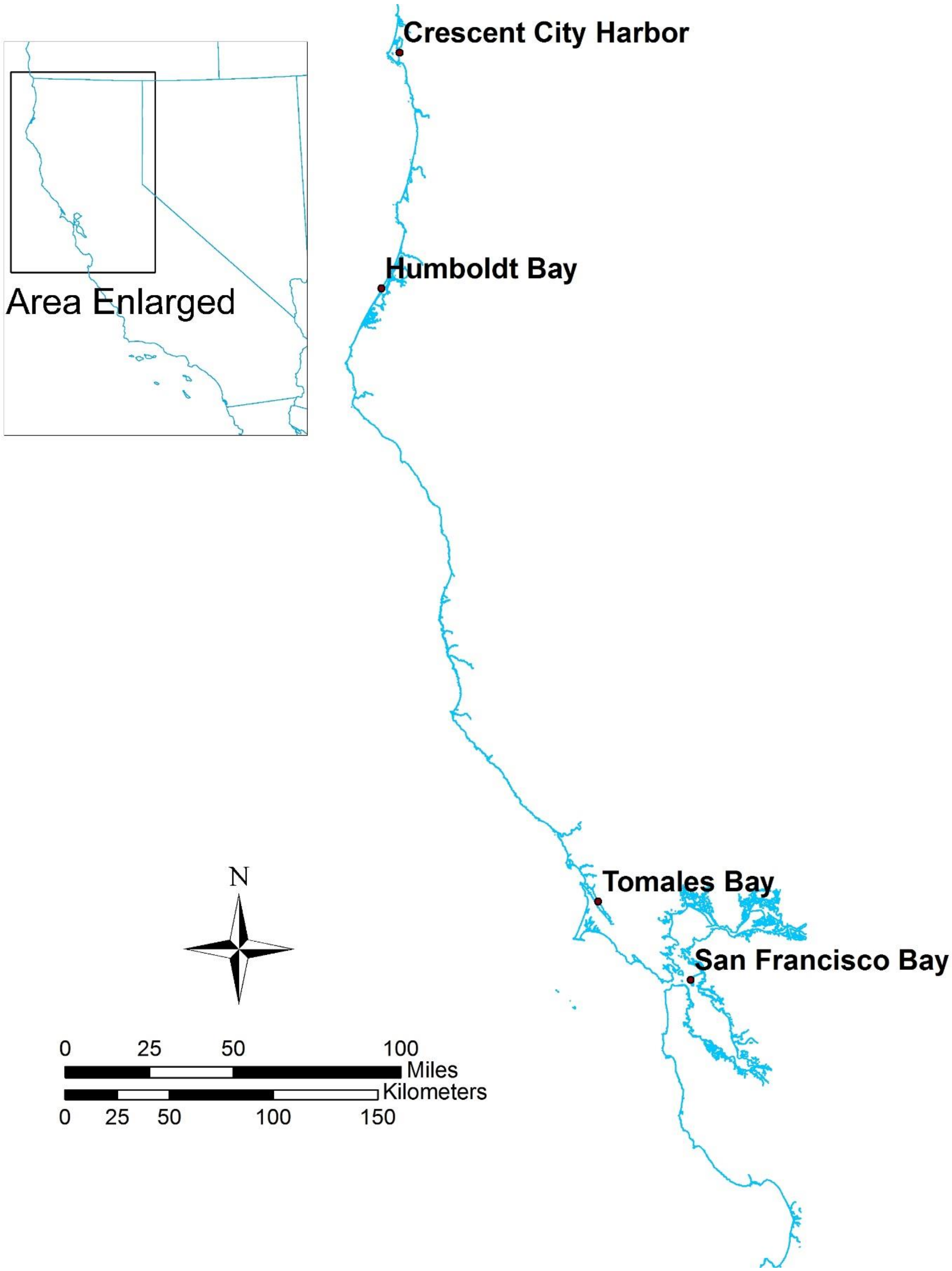

Figure 1. Map of the project area in California.

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APPENDIX A

Correspondence Related to Tribal Cultural Resources

STATE OF CALIFORNIA
EDMUND G. BROWN JR., GOVERNOR

NATURAL RESOURCES AGENCY

California Fish and Game Commission
P.O. Box 944209
Sacramento, CA 94244-2090

California Department of Fish and Wildlife
Santa Barbara Field Office
1933 Cliff Drive, Suite 9
Santa Barbara, CA 93109

August 1, 2018

Honorable [Name, Title]
[Tribe name]
[Address]
[City, State Zip]

Subject: Notification Pursuant to California Environmental Quality Act Section 21080.3.1 of California Pacific Herring Fishery Management Plan

Dear Honorable Tribal Representative:

The California Fish and Game Commission (Commission) and the California Department of Fish and Wildlife (Department) would like to inform you as a tribal representative that the Commission is proposing development of a California Pacific Herring Fishery Management Plan (Project), including changes to regulations in Title 14 of the California Code of Regulations. The Commission is providing this formal notice as the Project lead agency pursuant to the California Environmental Quality Act (CEQA, Public Resources Code Section 21080.3.1).

Your input on the proposed Project can be provided to the Commission through consultation pursuant to CEQA sections 21080.3.1 and 21080.3.2 or during the public comment period planned to begin in August 2018. The Commission and the Department welcome direct communication and consultation prior to the public process on this proposed Project and any anticipated impacts on tribal interests or cultural resources.

The proposed Project would develop a comprehensive management strategy for Pacific herring (*Clupea pallasi*) through a fishery management plan (FMP), which may be of interest to your tribe. The proposed Project area is located within San Francisco Bay, Tomales Bay, Humboldt Bay, and Crescent City Harbor.

FMP development will include proposed changes to the California Code of Regulations, Title 14, sections 27.60, 28.60, 163, 163.5 and 164; these sections regulate the harvest of Pacific herring for the recreational and commercial fisheries in California. The Department previously reached out to your tribe on this same project with letters sent on July 18, 2016, and March 28, 2018. The FMP will be responsive to environmental and socioeconomic changes using a decision-making process that preserves the sustainability of the fishery while considering the entire ecosystem. The Department has outlined a number of management objectives for the FMP, which include:

- Consider the role of herring as a forage fish within the wider ecosystem
- Modernize the limited entry permit system

- Develop a harvest control rule for the San Francisco Bay fishery
- Create a framework for collaborative research in the northern fishing areas
- Update and streamline existing commercial regulations
- Develop recreational fishing regulations

The goal of the Commission and the Department is to understand tribal interests and concerns early in the proposed Project and to work collaboratively to resolve any concerns. The Commission's Tribal Consultation Policy can be viewed at http://www.fgc.ca.gov/policy/p4misc.aspx. The Department is committed to open communication with your tribe under its Tribal Communication and Consultation Policy, which is available through the Department's Tribal Affairs webpage at https://www.wildlife.ca.gov/General-Counsel/Tribal-Affairs.

If you would like more information on the proposed Project, please contact Kirsten Ramey at Kirsten.Ramey@wildlife.ca.gov or 707-445-5365. To request formal consultation with the Commission on the Project pursuant to CEQA section 21080.3.1, please respond in writing within 30 days to Executive Director Valerie Termini at Valerie.Termini@fgc.ca.gov or California Fish and Game Commission, P.O. Box 944209, Sacramento, CA 94244. To request consultation with the Department, please contact Tribal Liaison Nathan Voegeli at Tribal.Liaison@wildlife.ca.gov or Department of Fish and Wildlife, P.O. Box 944209, Sacramento, CA 94244. Please be sure to designate and provide contact information for the appropriate lead contact person.

We look forward to your response and input into the proposed Project.

Sincerely,

Valerie Termini
Executive Director
California Fish and Game Commission

Craig Shuman, D. Env.
Marine Regional Manager
California Department of Fish and Wildlife

ec: California Department of Fish and Wildlife

Nathan Voegeli, Tribal Liaison
Office of General Counsel
Tribal.Liaison@wildlife.ca.gov

Kirsten Ramey, Program Manager
Marine Region
Kirsten.Ramey@wildlife.ca.gov

Tribal Distribution List

STATE OF CALIFORNIA Edmund G. Brown, Jr., *Governor*

NATIVE AMERICAN HERITAGE COMMISSION
Environmental and Cultural Department
1550 Harbor Blvd., ROOM 100
West SACRAMENTO, CA 95691
(916) 373-3710
Fax (916) 373-5471

July 25, 2018

Kirsten Ramey
California Department of Fish & Wildlife

Sent by Email: Kirsten.Ramey@wildlife.ca.gov

Re : California Pacific Herring Fishery Management Plan, Monterey, Santa Cruz, San Mateo, San Francisco, Marin, Sonoma, Mendocino, Humboldt, Del Norte, Alameda and Contra Costa Counties

Dear Ms. Ramey,

A record search of the Native American Heritage Commission (NAHC) Sacred Lands File (SLF) was completed for the information you have submitted for the above referenced project. The results indicate Native American cultural sites are present. Please contact the tribes and individuals lists on the "Sacred Lands File Results Contact List". Other sources for cultural resources should also be contacted for information regarding known and/or recorded sites.

Enclosed is a list of Native American tribes who may also have knowledge of cultural resources in the project area. I suggest you contact all of those indicated, if they cannot supply information, they might recommend others with specific knowledge. By contacting all those listed, your organization will be better able to respond to claims of failure to consult with the appropriate tribe. If a response has not been received within two weeks of notification, the Commission requests that you follow-up with a telephone call to ensure that the project information has been received.

If you receive notification of change of addresses and phone numbers from any of these tribes, please notify me. With your assistance we are able to assure that our lists contain current information. If you have any questions or need additional information, please contact me at frank.lienert@nahc.ca.gov.

Sincerely,

Frank Lienert
Associate Governmental Program Analyst

Sacred Lands File Results Contact List

Tolowa Dee Ni' (Smith River Rancheria)

(see tribal contact list)

Amelia Brown

PO BOX 1

Smith River, CA 95567

Sam Lopez

PO Box 10

Smith River, CA 95567

Ed Lopez

PO Box 1

Smith River, CA 95567;

Dorothy Habeman

Old Arcata Road,

Eurkea, CA 95501

Florence Shaughnessy

PO Box 478

Klamath, CA 95548

Carrie Hodge Gilbert

PO Box 13

Requa, Crescent City, CA

Francis White

PO Box 236

Orick, CA 95555

Walt Lara Sr.

PO Box 516

Trinidad, CA 95570

707-488-3754

Margaret Lara

PO Box 405

Orick, CA 95555

707-488-5531

NICPA

PO Box 876

Trinidad, CA 95570

707-677-0122

Cher-Ae Heights Indian Community of the Trinidad Rancheria

(See tribal contact list)

Wiyot Tribe

(See tribal contact list)

Sacred Lands File Results Contact List

Cahto Tribe

(See tribal contact list)

Manchester Band of Pomo Indians

(See tribal contact list)

Kashia Band of Pomo Indians

(See tribal contact list)

Amah Mutsun Tribal band

(See tribal contact list)

The Ohlone Indian Tribe

(See tribal contact list)

Costanoan Rumsen Carmel Tribe

(see tribal contact list)

Ohlone Costanoan-Esselen Nation

(See tribal contact list)

Linda G. Yamane

1585 Mira Mar Ave.

Seaside, CA 93955

831-394-5915

Native American Heritage Commission
Native American Contacts
July 25, 2018

Big Lagoon Rancheria
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vmoorehead@earthlink.net
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(707) 826-1737 - Fax

Blue Lake Rancheria
Claudia Brundin, Chairperson
P.O. Box 428 — Wiyot
Blue Lake, CA 95525 — Yurok
bmobbs@bluelakerancheria-nsn.gov — Tolowa
(707) 668-5101
(707) 668-4272 Fax

Cloverdale Rancheria of Pomo Indians
Patricia Hermosillo, Chairperson
555 S. Cloverdale Blvd., Suite A — Pomo
Cloverdale, CA 95425
(707) 894-5775
(707) 894-5727

Dry Creek Rancheria Band of Pomo Indians
Chris Wright, Chairperson
P.O. Box 607 — Pomo
Geyserville, CA 95441
(707) 522-4233
(707) 522-4286

Elk Valley Rancheria
Dale Miller, Chairperson
2332 Howland Hill Road — Tolowa
Crescent City, CA 95531
dmiller@elk-valley.com
(707) 464-4680
(707) 464-4519

Guidiville Rancheria
Merlene Sanchez, Chairperson
P.O. Box 339 — Pomo
Talmage, CA 95481
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(707) 462-3682
(707) 462-9183 Fax

Hoopa Valley Tribe
Ryan P. Jackson, Chairperson
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Hoopa, CA 95546
(530) 625-4211
(530) 625-4594 Fax

Hopland Band of Pomo Indians
Ivesha Miller Chairperson
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Hopland, CA 95449 — Sokow
selliott@hoplandtribe.com — Shanel
(707) 472-2100 — Pomo
(707) 744-1506

Karuk Tribe
Russell Attebery, Chairperson
P.O. Box 1016 — Karuk / Karok
Happy Camp, CA 96039
(530) 493-1600
(530) 493-5322 - Fax

Jakki Kehl
720 North 2nd Street — Ohlone/Costanoan
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jakkikehl@gmail.com
510-701-3975

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Native American Heritage Commission
Native American Contacts
July 25, 2018

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Sonnv Elliot. EPA Director
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Environmental@cahto.ora — Pomo
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(707) 984-6201 Fax

Lvtton Rancheria
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(707) 882-3417 Fax

Middletown Rancheria
Jose Simon III. Chairperson
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Middletown, CA 95461 — Lake Miwok
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(707) 987-9091 Fax

Pinoleville Pomo Nation
Leona Willams. Chairperson
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Ukiah, CA 95482
(707) 463-1454
(707) 463-6601 Fax

Potter Vallev Tribe
Salvador Rosales. Chairperson
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Ukiah, CA 95482
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(707) 462-1240 - Fax

Redwood Vallev or Little River Band of Pomo Indiai
Debra Ramirez. Chairperson
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Redwood Vallev, CA 95470
rvrsecretarv@comcast.net
(707) 485-0361
(707) 485-5726 Fax

Resiahini Rancheria
Rick Dowd. Chairperson
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(707) 482-2431
(707) 482-3425 Fax

Bear River Band of the Rohnerville Rancheria
Barrv Brenard. Chairperson
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Loleta, CA 95551 — Mattole
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(707) 733-1727 Fax

Round Valley Indian Tribes of the Round Valley Reservation
James Russ. President
77826 Covelo Road — Yuki ; Nomlaki
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tribalcouncil@rvit.ora — Pomo
(707) 983-6126 — Concow
Wailaki: Wintun
(707) 983-6128 Fax

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Native American Heritage Commission
Native American Contacts
July 25, 2018

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TribalChair@EsselenTribe.com
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Native American Heritage Commission
Native American Contacts
July 25, 2018

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Coast Yuki

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Ohlone/Costanoar
Northern Valley Yoki

Coastanoan Rumsen Carmel Tribe
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Salinan

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Ohlone/Costanoan

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Salinan

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Ramona Garibay, Representative
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Ohlone/Costanoan
Bay Miwok
Plains Miwok
Patwin

North Valley Yokuts Tribe
Katherine Erolinda Perez, Chairperson
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Bay Miwok

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Native American Heritage Commission
Native American Contacts
July 25, 2018

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Blue Lake Rancheria
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Yurok Tribe
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(707) 954-5355
(707) 482-1377

Muwekma Ohlone Indian Tribe of the SF Bay Area
Rosemary Cambra, Chairperson
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Indian Canyon Mutsun Band of Costanoan
Ann Marie Sayers, Chairperson
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(831) 637-4238

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Native American Heritage Commission
Native American Contacts
July 25, 2018

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916-683-6015

Federated Indians of Graton Rancheria
Gene Buvelot
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Xolon-Salinan Tribe
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(925) 470-5019

Salinan Tribe of Monterey, San Luis Obispo Counties
Fredrick Segobia
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Muwekma Ohlone Indian Tribe of the SF Bay Area
Rosemary Cambra, Chairperson
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(510) 581-5194

Coyote Valley Band of Pomo Indians
Michael Hunter, Chairperson
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(707) 485-8723

(707) 485-1247 Fax

Federated Indians of Graton Rancheria
Greg Sarris, Chairperson
6400 Redwood Drive, Ste 300 — Coast Miwok
Rohnert Park , CA 94928 — Southern Pomo
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(707) 566-2291 Fax

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APPENDIX B

Hazardous Material Sites

Site/Facility Name	Envirostor ID	Address Description	City	Zip	County
1450 MARIN ST. LLC PROJECT / FEDERATED FRY METALS	38330005	1901 CESAR CHAVEZ	SAN FRANCISCO	94124	SAN FRANCISCO
ACTION PLATING (2W)	1340116	10132 EDES AVENUE	OAKLAND	94603	ALAMEDA
AMCO CHEMICAL	1390001	1414 THIRD STREET	OAKLAND	94607	ALAMEDA
ARLENE'S CLEANERS	60001242	2017 CHESTNUT STREET	SAN FRANCISCO	94123	SAN FRANCISCO
BAYVIEW PLUME STUDY AREA	70000015	NEAR INTERSECTION OF SHAFTER AVENUE AND HAWES STREET	SAN FRANCISCO	94124	SAN FRANCISCO
BLAIR SOUTHERN PACIFIC LANDFILL	7490012	AT THE FOOT OF SOUTH 51ST STREET	RICHMOND	94804	CONTRA COSTA
CAL TECH METALS	1340118	825, 829, 841 31ST STREET	OAKLAND	94608	ALAMEDA
CALTRANS/SSF MAINTENANCE STATION	41280108	166 HARBOR WAY	S SAN FRANCISCO	94080	SAN MATEO
CATERPILLAR INC	1350119	800 DAVIS STREET	SAN LEANDRO	94577	ALAMEDA
CINTAS/DEDOMENICO SITE	1890017	777 139TH AVENUE	SAN LEANDRO	94578	ALAMEDA
COMMERCIAL BUILDINGS	1720110	1250-1276, 1284 W. GRAND & 2232 POPLAR	OAKLAND	94607	ALAMEDA
COOPER CHEMICAL	7280154	2801 GIANT ROAD	RICHMOND	94806	CONTRA COSTA
DEL NORTE PESTICIDE STORAGE	8420001	2650 W WASHINGTON BLVD	CRESCENT CITY	95531	DEL NORTE
DREW SALES	7500035	1156 CASTRO STREET	RICHMOND	94804	CONTRA COSTA
DUTCH BOY #3	1390006	4825 SAN LEANDRO STREET	OAKLAND	94601	ALAMEDA
DWA PLUME	1990002	SAN LEANDRO (GROUNDWATER CONTAMINATION)	SAN LEANDRO	94578	ALAMEDA
E-D COAT INC	60002501	715 4TH STREET	OAKLAND	94607	ALAMEDA
ELECTRO FORMING CO. - RICHMOND	1330044	130 NEVIN AVENUE	RICHMOND	94801	CONTRA COSTA
FASS METALS	7330030	818 W. GERTRUDE AVENUE	RICHMOND	94801	CONTRA COSTA
FMC CORPORATION - RICHMOND	7280011	855 PARR BLVD	RICHMOND	94801	CONTRA COSTA
FORMER J. H. BAXTER FACILITY, ALAMEDA	1240036	2189, 2199, 2201, 2229 CLEMENT AVENUE	ALAMEDA	94501	ALAMEDA
GENERAL ELECTRIC - OAKLAND	1360059	5441 EAST 14TH STREET	OAKLAND	94601	ALAMEDA
HARBORFRONT TRACT	70000178	MEADE SOUTH 49TH EAST MONTGOMERY	RICHMOND	94804	CONTRA COSTA
HARBOUR WAY SOUTH	7340024	738 HARBOUR WAY SOUTH	RICHMOND	94804	CONTRA COSTA
HARD CHROME ENGINEERING	1870003	750 107TH AVENUE	OAKLAND	94603	ALAMEDA

HARRIS DRY CLEANERS	1720109	2801 MARTIN LUTHER KING JR. WAY	OAKLAND	94609	ALAMEDA
HOWARD MARINE TERMINAL SITE	1440006	EMBARCADERO WEST AND MARKET STREETS	OAKLAND	94604	ALAMEDA
IKEA (FORMER BARBARY COAST)	1440005	4300 EASTSHORE HIGHWAY	EMERYVILLE	94608	ALAMEDA
JENKINS AUTO WRECKERS	1750025	1778 10TH STREET	OAKLAND	94607	ALAMEDA
KAISER AEROSPACE & ELECTRONICS COMPANY	1990015	880 DOOLITTLE DRIVE	SAN LEANDRO	94577	ALAMEDA
LANE METAL FINISHERS	60000594	2942 SAN PABLO AVENUE	OAKLAND	94608	ALAMEDA
LIQUID GOLD OIL CORP	7290039	HOFFMAN BLVD & S 47TH ST	RICHMOND	94804	CONTRA COSTA
MACDONALD SAN PABLO WALL 45TH PLUME	60000506	SAN PABLO WALL 45TH PLUME	EL CERRITO AND RICHMOND	94804	CONTRA COSTA
MARCHANT/WHITNEY	60001628	5679 HORTON STREET	EMERYVILLE	94608	ALAMEDA
MCNAMARA AND PEEPE LUMBER MILL	12240115	1619 GLENDALE DRIVE	ARCATA	95521	HUMBOLDT
MYERS DRUM - EMERYVILLE	1340110	4500 SHELLMOUND STREET	EMERYVILLE	94608	ALAMEDA
NORTHWESTERN VENETIAN SUPPLY CORP. SITE	1340123	1218 24TH STREET	OAKLAND	94607	ALAMEDA
PORT OF OAKLAND - EMBARCADERO COVE	1510021	DENNISON AND EMBARCADERO STREETS	OAKLAND	94606	ALAMEDA
PORT OF OAKLAND, BERTH 25 AND 26	1280092	2500 7TH STREET	OAKLAND	94607	ALAMEDA
PORT OF RICHMOND (SHIPYARD #3)	7370030	1312 CANAL BLVD	RICHMOND	94804	CONTRA COSTA
REACTION PRODUCTS	7280013	840 MORTON AVENUE	RICHMOND	94806	CONTRA COSTA
RICHMOND TOWNHOUSE APARTMENTS	7990005	2887 AND 2989 PULLMAN AVENUE	RICHMOND	94804	CONTRA COSTA
SCHLAGE LOCK COMPANY	38340157	BAYSHORE BLVD AND SUNNYDALE AVE.	SAN FRANCISCO	94134	SAN FRANCISCO
SHERWIN WILLIAMS	60000189	1450 SHERWIN AVENUE	EMERYVILLE	94608	ALAMEDA
SINGER FRIDEN	1360094	2350 AND 2450 WASHINGTON AVENUE	SAN LEANDRO	94577	ALAMEDA
SOUTHERN PACIFIC - BRISBANE (NORTH AREA)	41490037	GENEVA AVENUE AND BAYSHORE BOULEVARD	BRISBANE	94005	SAN MATEO
SOUTHERN PACIFIC -WEST OAKLAND RAIL YARD	1400010	CYPRESS CORRIDOR	OAKLAND	94607	ALAMEDA
UNION PACIFIC OAKLAND COLISEUM SITE	1400015	700 73RD AVENUE	OAKLAND	94621	ALAMEDA
UNITED HECKATHORN	7280015	8TH & WRIGHT	RICHMOND	94804	CONTRA COSTA
UNIVERSITY OF CALIFORNIA, RICHMOND SE	7730003	1301 SOUTH 46TH STREET	RICHMOND	94804	CONTRA COSTA
ZENECA RICHMOND AG PRODUCTS	7280002	1415 SOUTH 47TH STREET	RICHMOND	94804	CONTRA COSTA

September 20, 2018

California Department of Fish and Wildlife
Attn: Ryan Bartling, Environmental Scientist
5355 Skylane Blvd, Suite B
Santa Rosa, CA 95403
Via electronic delivery to: Ryan.Bartling@wildlife.ca.gov

Re: Comments on the Pacific Herring Fishery Management Plan Scoping

Dear Mr. Bartling,

The Environmental Action Committee of West Marin is based in Point Reyes Station and has been working to protect the unique lands, waters, and biodiversity of West Marin since 1971. Since our inception, we have been committed to the health of Tomales Bay. We submit these brief comments in regard to the Pacific Herring Fishery Management Plan (herring FMP), specifically as it relates to Tomales Bay.

Regarding the scope of the herring FMP, we request that the herring FMP addresses the following: 1) updates to the current commercial limits, 2) updates to the current recreational limits, and 3) whether additional research is needed to make these updates. In addressing the above three points, the herring FMP should consider direct and indirect environmental impacts to the Pacific herring (herring) fishery and other fisheries, to wildlife including special status bird species and protected marine mammals, cumulative impacts, and changing climate conditions.

Based on our knowledge of the historic Tomales Bay fishery, we also present our recommendations for recreational and commercial limits on the herring fishery, when additional research is needed, and how this research should be conducted.

Environmental Action Committee of West Marin | PO Box 609, Point Reyes Station, CA 94956
415-663-9312 | admin@eacmarin.org | www.eacmarin.org

We support the Pacific Herring Steering Committee (Committee)'s management objective as part of the herring FMP to "update existing commercial herring regulations where possible."[1] Many of these regulations are woefully out of date and are based on historic numbers and landings.

In regard to commercial regulation updates, we recommend that the commercial regulations be updated so that Tomales Bay is closed to commercial herring fishing due to a number of factors including extremely low herring numbers, environmental considerations, and poor market conditions. The current commercial season limit or quota is 350 tons[2], which is outdated since no commercial fishing has taken place in the Bay since 2007.[3] Furthermore, the most recent commercial herring fishing efforts in Tomales Bay resulted in dead unsalable fish and/or very low pricing in part due to poor market conditions.

Following the proposed closure of the Tomales Bay herring fishery, any future decisions to reopen the Tomales Bay herring fishery should only be made after a comprehensive and scientifically based assessment and analysis is made of the herring stocks, current and future spawning estimates, biomass, etc. led by qualified Department of Fish and Wildlife staff and/or other trained and independent researchers, with the involvement of multiple stakeholders. Regarding the Committee's management objective to "[d]evelop *collaborative* research opportunities to monitor and assess herring populations in Tomales Bay…"[4] we request that these opportunities are truly collaborative and include stakeholders representative of multiple interests including local West Marin fisherman, individuals from non-extractive industries, and environmental organizations.

Any future analysis to consider whether to reopen the Tomales Bay herring fishery should take into consideration all recent research including Dr. John Kelly's June 2018 paper *Echoes of Numerical Dependence: Responses of Wintering Waterbirds to Pacific Herring Spawns*, which found a functional relationship between water bird numbers and the availability of herring.[5]

We also support the Committee's management objective as part of the herring FMP to "[d]evelop regulations for the recreational herring fishery."[6] Regarding the recreational fishery in

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[1] *See* California Department of Fish and Wildlife, *Pacific Herring Fishery Management Plan*, *available at*:
https://wildlife.ca.gov/Fishing/Commercial/Herring/FMP
[2] *See* California Department of Fish and Wildlife, 2017-*18 California Commercial Herring Fishery FAQ Sheet*, *available at*:
https://nrm.dfg.ca.gov/FileHandler.ashx?DocumentID=151147&inline
[3] *See* California Department of Fish and Wildlife, *State-Managed California Commercial Pacific Herring Fishery*, *available at*: https://www.wildlife.ca.gov/Fishing/Commercial/Herring
[4] *See* California Department of Fish and Wildlife, *Pacific Herring Fishery Management Plan*, *emphasis added*, *available at*:
https://wildlife.ca.gov/Fishing/Commercial/Herring/FMP
[5] *See* John P. Kelly, *et al.*, *Echoes of Numerical Dependence: Responses of Wintering Waterbirds to Pacific Herring Spawns*, Marine Ecology Progress Series, June 11, 2018, page 253.
[6] *See* California Department of Fish and Wildlife, *Pacific Herring Fishery Management Plan*, *available at*:

Tomales Bay, consistent with the Fish and Game Commission Marine Resource Committee's July 2018 recommendation to limit recreational herring take and the submitted comments, we recommend a limit of two five-gallon buckets per day, which is approximately 75 lbs. A volume limit is preferable as most fishermen do not carry scales.

In closing, we also support the Committee's management objective to "[d]escribe habitat and ecosystem considerations"[7] in the herring FMP, and we thank you for your consideration of our comments.

Sincerely,

Morgan Patton
Executive Director

Ashley Eagle-Gibbs
Conservation Director

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https://wildlife.ca.gov/Fishing/Commercial/Herring/FMP
[7] *See id.*

State of California – Natural Resources Agency
DEPARTMENT OF FISH AND WILDLIFE
Santa Barbara Field Office
1933 Cliff Drive, Suite 9
Santa Barbara, CA 93109
www.wildlife.ca.gov

EDMUND G. BROWN JR., Governor
CHARLTON H. BONHAM, Director

July 5, 2016

Contact name
Tribal group name
Address

Dear Honorable Tribal Representative:

The California Department of Fish and Wildlife (Department) would like to inform you as a tribal representative that its Marine Region staff will be developing a Fishery Management Plan (FMP) for California's Pacific herring fishery, in accordance with Fish and Game Code sections 7070-7072 and provisions of the Marine Life Management Act (MLMA). Your input can be provided to the Department through direct communication and consultation or during the established opportunities for public involvement scheduled to begin in mid-2016. The Department would welcome direct communication and consultation on this proposed Project and any anticipated impacts on Tribal interests.

The MLMA establishes a statutory framework for sustainably managing California's ocean fisheries through the use of a FMP. The MLMA further requires that marine fisheries management be based on both the best available science as well as stakeholder input. The primary goal of the FMP will be to formalize a management strategy for Pacific herring which will be responsive to environmental and socioeconomic changes. It will also establish a decision-making process that preserves the sustainability of the fishery while considering the entire ecosystem. The Department has outlined a number of initial management objectives for the FMP process which include the following:

- Review and update the limited entry permit system to reflect the needs of the modern commercial fleet
- Streamline and modernize existing herring regulations where possible
- Develop a Harvest Control Rule for the San Francisco Bay fishery that sustains a commercial fleet, accounts for ecosystem considerations, and reflects current precautionary management
- Develop regulations for the recreational herring fishery
- Describe herring spawning habitat and associated management efforts statewide and provide recommendations for agency coordination for habitat management
- Develop collaborative research protocols and requirements for commercial herring fishing activities in Tomales Bay, Crescent City Harbor, and Humboldt Bay.

An overview of current management efforts for Pacific herring can be found on the Departments web site: https://www.wildlife.ca.gov/Fishing/Commercial/Herring

The Department is committed to understanding your Tribe's interest in development of the Pacific herring FMP prior to beginning our outreach with the general public. Our desire is to collaboratively address your interests early in the process.

The Department would welcome the opportunity to discuss our plans for developing the FMP. Your input would be especially helpful before August 2016, so that it can be considered before we begin conversations with the general public. Please contact Mr. Tom Barnes, Department of Fish and Wildlife, with your thoughts or comments. Mr. Barnes may be contacted by email at Tom.Barnes@wildlife.ca.gov, or by telephone at (858) 467-4233. If you would like to request formal government-to-government consultation, please contact Mr. Nathan Voegeli, Tribal Liaison, by email, tribal.liaison@wildlife.ca.gov, or by phone, (916) 651-7653.

We look forward to receiving your input.

Sincerely,

Craig Shuman, D. Env.
Regional Manager, Marine Region

ec: Nathan Voegeli, Attorney and Tribal Liaison
Department of Fish and Wildlife
tribal.liaison@wildlife.ca.gov

Valerie Termini, Executive Director
California Fish and Game Commission
Valerie.Termini@fgc.ca.gov

State of California – Natural Resources Agency
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www.wildlife.ca.gov

EDMUND G. BROWN JR., Governor
CHARLTON H. BONHAM, Director

March 28, 2018

[Contact name
Tribal group name
Address]

Dear Honorable Tribal Representative:

In July 2016, the California Department of Fish and Wildlife (Department) sent a letter to notify you that the Marine Region will be developing a Fishery Management Plan (FMP) for California's Pacific Herring (Herring) fishery, in accordance with Fish and Game Code sections 7070-7072 and provisions of the Marine Life Management Act. We are writing to provide an update on the status of the FMP, and to request your input, which will be integrated into a draft FMP. The Department continues to be committed to understanding [Tribe's] interest in Herring management, and welcomes direct communication and consultation on the FMP project.

During the two past years, the Department has worked with tribal communities, stakeholders, and industry partners to develop a comprehensive management strategy for Herring, which will be responsive to environmental and socioeconomic changes. The FMP will include a decision-making process that preserves the sustainability of the fishery while considering the entire ecosystem.

The Department has outlined a number of management objectives for the FMP, which include the following:

- Review and update the limited entry permit system to reflect the needs of the modern commercial fleet
- Develop a Harvest Control Rule for the San Francisco Bay fishery that sustains a commercial fleet, incorporates ecosystem indicators, and reflects current precautionary management
- Formalize the decision making process to set yearly commercial fishery quotas
- Develop regulations for the recreational Herring fishery
- Improve the description of Herring spawning habitat and associated statewide habitat management efforts and provide recommendations for habitat management
- Develop collaborative research protocols and requirements for commercial Herring fishing activities in Tomales Bay, Crescent City Harbor, and Humboldt Bay.

An overview of current management efforts for Herring can be found on the Department's web site: www.wildlife.ca.gov/Fishing/Commercial/Herring

The Department continues to seek tribal input on the Herring FMP process and to work collaboratively to resolve any concerns. We welcome your feedback and input before August 31, 2018, so that the Department can consider it before developing a final draft of the FMP for public review. The FMP is expected to be submitted to the Fish and Game Commission at the October 16-17, 2018, meeting and is scheduled for possible adoption at the December 12-13, 2018 meeting.

Please contact Ms. Kirsten Ramey, Department of Fish and Wildlife, by email at Kirsten.Ramey@wildlife.ca.gov, or by telephone at 707-445-5365 with comments or questions. If you would like to request formal government-to-government consultation, please contact Mr. Nathan Voegeli, Tribal Liaison, by email, tribal.liaison@wildlife.ca.gov, or by telephone at 916-651-7653.

We look forward to receiving your input and working together to ensure tribal interests and priorities are reflected in the Herring FMP.

Sincerely,

Craig Shuman, D. Env.
Marine Regional Manager

ec: Kirsten Ramey, Senior Environmental Scientist Supervisor
Marine Region
Kirsten.Ramey@wildlife.ca.gov

Nathan Voegeli, Attorney and Tribal Liaison
Office of General Counsel
tribal.liaison@wildlife.ca.gov

Valerie Termini, Executive Director
California Fish and Game Commission
Valerie.Termini@fgc.ca.gov

STATE OF CALIFORNIA
EDMUND G. BROWN JR., GOVERNOR

NATURAL RESOURCES AGENCY

California Fish and Game Commission
P.O. Box 944209
Sacramento, CA 94244-2090

California Department of Fish and Wildlife
Santa Barbara Field Office
1933 Cliff Drive, Suite 9
Santa Barbara, CA 93109

August 1, 2018

Honorable [Name, Title]
[Tribe name]
[Address]
[City, State Zip]

Subject: Notification Pursuant to California Environmental Quality Act Section 21080.3.1 of California Pacific Herring Fishery Management Plan

Dear Honorable Tribal Representative:

The California Fish and Game Commission (Commission) and the California Department of Fish and Wildlife (Department) would like to inform you as a tribal representative that the Commission is proposing development of a California Pacific Herring Fishery Management Plan (Project), including changes to regulations in Title 14 of the California Code of Regulations. The Commission is providing this formal notice as the Project lead agency pursuant to the California Environmental Quality Act (CEQA, Public Resources Code Section 21080.3.1).

Your input on the proposed Project can be provided to the Commission through consultation pursuant to CEQA sections 21080.3.1 and 21080.3.2 or during the public comment period planned to begin in August 2018. The Commission and the Department welcome direct communication and consultation prior to the public process on this proposed Project and any anticipated impacts on tribal interests or cultural resources.

The proposed Project would develop a comprehensive management strategy for Pacific herring (*Clupea pallasi*) through a fishery management plan (FMP), which may be of interest to your tribe. The proposed Project area is located within San Francisco Bay, Tomales Bay, Humboldt Bay, and Crescent City Harbor.

FMP development will include proposed changes to the California Code of Regulations, Title 14, sections 27.60, 28.60, 163, 163.5 and 164; these sections regulate the harvest of Pacific herring for the recreational and commercial fisheries in California. The Department previously reached out to your tribe on this same project with letters sent on July 18, 2016, and March 28, 2018. The FMP will be responsive to environmental and socioeconomic changes using a decision-making process that preserves the sustainability of the fishery while considering the entire ecosystem. The Department has outlined a number of management objectives for the FMP, which include:

- Consider the role of herring as a forage fish within the wider ecosystem
- Modernize the limited entry permit system

- Develop a harvest control rule for the San Francisco Bay fishery
- Create a framework for collaborative research in the northern fishing areas
- Update and streamline existing commercial regulations
- Develop recreational fishing regulations

The goal of the Commission and the Department is to understand tribal interests and concerns early in the proposed Project and to work collaboratively to resolve any concerns. The Commission's Tribal Consultation Policy can be viewed at http://www.fgc.ca.gov/policy/p4misc.aspx. The Department is committed to open communication with your tribe under its Tribal Communication and Consultation Policy, which is available through the Department's Tribal Affairs webpage at https://www.wildlife.ca.gov/General-Counsel/Tribal-Affairs.

If you would like more information on the proposed Project, please contact Kirsten Ramey at Kirsten.Ramey@wildlife.ca.gov or 707-445-5365. To request formal consultation with the Commission on the Project pursuant to CEQA section 21080.3.1, please respond in writing within 30 days to Executive Director Valerie Termini at Valerie.Termini@fgc.ca.gov or California Fish and Game Commission, P.O. Box 944209, Sacramento, CA 94244. To request consultation with the Department, please contact Tribal Liaison Nathan Voegeli at Tribal.Liaison@wildlife.ca.gov or Department of Fish and Wildlife, P.O. Box 944209, Sacramento, CA 94244. Please be sure to designate and provide contact information for the appropriate lead contact person.

We look forward to your response and input into the proposed Project.

Sincerely,

Valerie Termini
Executive Director
California Fish and Game Commission

Craig Shuman, D. Env.
Marine Regional Manager
California Department of Fish and Wildlife

ec: California Department of Fish and Wildlife

Nathan Voegeli, Tribal Liaison
Office of General Counsel
Tribal.Liaison@wildlife.ca.gov

Kirsten Ramey, Program Manager
Marine Region
Kirsten.Ramey@wildlife.ca.gov

California Commercial Pacific Herring Fishery Permit Survey
California Department of Fish and Wildlife

Please complete and return this survey by **July 31, 2017** or complete online using your herring permit number: **wildlife.ca.gov/HerringSurvey**

1. How long have you participated in the herring fishery (as crew or permit holder)?			Years:
2. How many crewmembers did you employ when you last fished your permit?			Number:
3. If you own a herring fishing vessel, what size is it?	Length: ft	Beam: ft	Capacity: tn

Currently, herring permits are issued to an individual, and that individual may apply to the Department to temporarily substitute their permit to someone else.

Please check the box that best describes your opinion about these potential changes:	**Yes**	**No**	**Not Sure**	**No Opinion**
4. Should permit holders be allowed to substitute their permit to another person?				
5. Should permits be assigned to a herring fishing vessel rather than an individual, as is common in many other state-managed fisheries?				
6. As permits become available, should preferential status be given to new entrants who have participated in the fishery as crew?				
Please explain your responses:				

The FMP presents an opportunity to modify the regulatory language in Section 163 of the California Code of Regulations.

Please check the box that best describes your opinion about these potential changes:	**Yes**	**No**	**Not Sure**	**No Opinion**
7. Are you in favor of modifying the requirements for vessel identification (163(d))?				
8. Are you in favor of modifying the requirements for marking gill nets 163(f)2(F).				
9. Are you in favor of modifying the requirements for gill net tending in San Francisco Bay (163(f)2(A)?				
10. Are you in favor of modifying the process for measuring mesh size, as currently described in 163(f)2(B)?				
Please provide suggestions for how regulatory language should be modified, consistent with the Dept.'s mission of resource protection. You may enclose extra sheets of paper when you return your survey.				

11. Are you interested in participating in discussions about designing a collaborative research protocol for use in areas outside SF Bay? Check one: Yes_____ No_____

Questions 12-17 are specific to the San Francisco Bay fishery.
The platoon fishing system was instituted in San Francisco Bay to minimize conflict and organize a much larger fleet. There is interest in streamlining the permit process by eliminating the Odd and Even platoons. Currently, each Odd or Even permit allows the holder to fish 65 fathoms (1 shackle) of gillnet every other week during the season.

DHAC proposal to eliminate platoons: Each Odd or Even permit could be converted to a single standard “Gillnet” permit, which would entitle the holder to fish a half shackle (32.5 fathoms) of gear every week during the season. CH permits could be converted to 2 standard gillnet permits equaling 1 shackle. These changes would not reduce the amount of gear currently allowed in the fishery.

Existing regulations allow herring permittees to hold up to 3 permits. If the platoon system were eliminated (as described above), the Department may consider allowing participants to hold up to 4 permits, each allowing use of a half shackle of gear (2 shackles total). The Department may then consider allowing these new 4-permit holders to convert to a single “full permit” to further simplify the permitting system.

Please check the box that best describes your opinion about these proposed changes:	**Yes**	**No**	**Not Sure**	**No Opinion**
12. Are you in favor of eliminating the platoon system?				
13. Are you in favor of converting to standardized gear permits that allow the holder to fish a half shackle of gillnet every week of the season?				
14. If the system described above is implemented, should permit holders be allowed to substitute their permits?				
15. Would you support allowing participants to own up to 4 permits?				
16. Would you support the issuance of “full permits” to those who hold 4 permits?				
Please explain your responses:				

17. Do you have other suggestions for modifying the platoon system? If so, please describe here:

18. In your opinion, what is a viable fleet size for the herring fishery given resource conditions, herring markets, and fishing area constraints for San Francisco Bay?
    Number of vessels_____ Number of full shackles per vessel_____

19. In your opinion, what is the minimum viable quota for the season (i.e., below this number, it doesn’t make sense to fish)? _____tons

20. If you would like to provide other comments about permitting or regulatory issues in the herring fishery, please return along with this survey in the envelope provided.

Thank you for completing this survey.

Appendix R Harvest Control Rule Framework Development and Guidance for Amending the Decision Tree

Introduction

During the process to develop a Fishery Management Plan (FMP) for Pacific Herring, *Clupea pallasii*, (Herring), the Steering Committee (SC) agreed that the preferred Harvest Control Rule (HCR) (Figure R-1, also see Appendix M) would be used to set a preliminary quota each year based on the estimated biomass of Herring in San Francisco Bay. The SC also proposed a framework wherein a preliminary quota could be modified each year based on a suite of environmental and ecosystem indicators, with quota increases recommended when ecosystem conditions are good (Figure R-2; green), moderate quota reductions recommended when ecosystem conditions warrant precaution (Figure R-2; yellow), and larger reductions warranted during extreme conditions (Figure R-2; red).

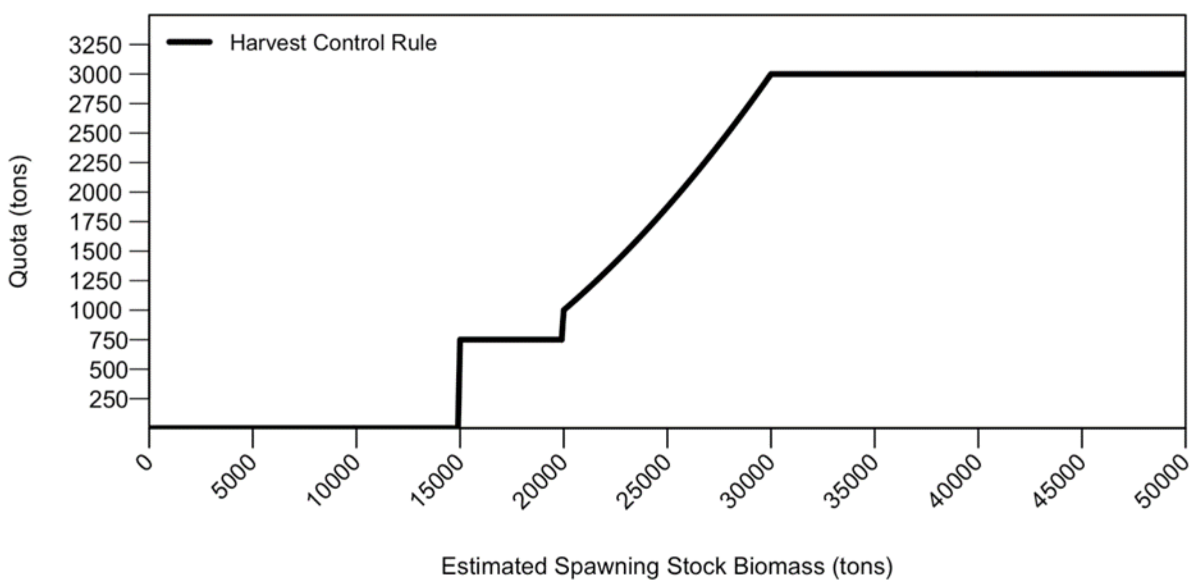

Figure R-1. Preferred Harvest Control Rule.

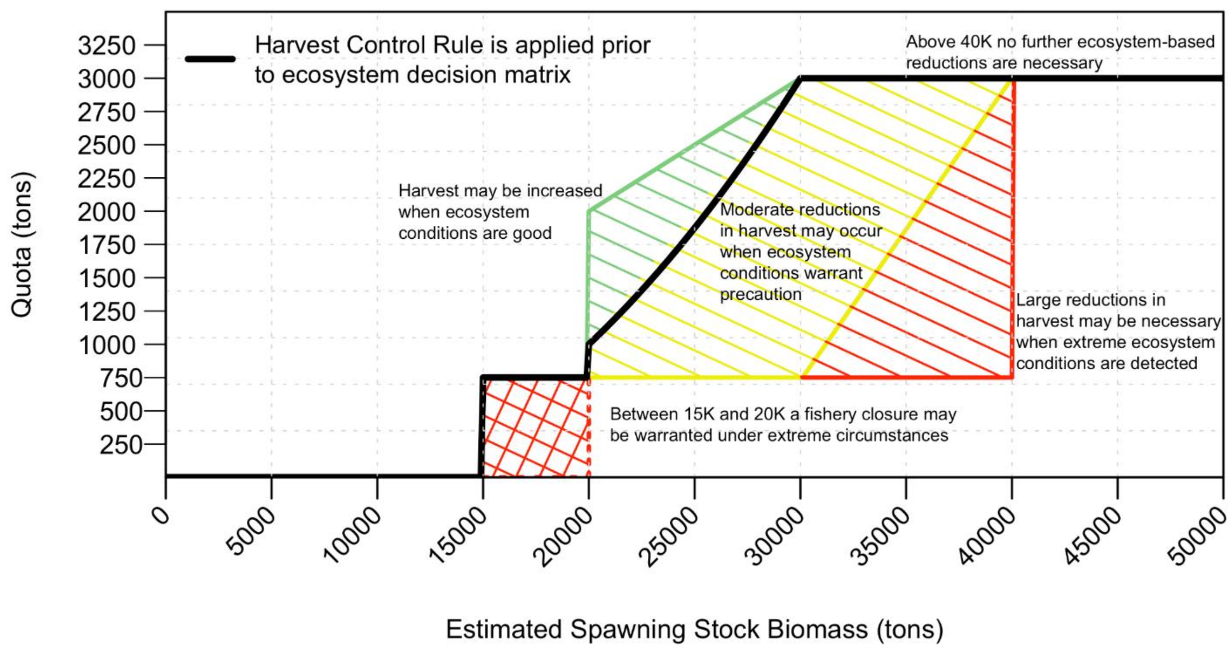

Figure R-2. Initial Harvest Control Rule framework, as proposed by the SC.

The proposed framework utilized a matrix of ecosystem indicators to assist the California Department of Fish and Wildlife (Department) in assessing and, if necessary, adjusting harvest to avoid undue ecosystem impacts based on the information available at the time of quota setting and Department scientists' discretion. This matrix included indicators on the productivity of Herring, the indices of relative variability of forage species in the region, and the population-level health of predators that have been shown to eat Herring. The matrix also provided guidance on how each indicator should be interpreted and recommendations for possible management responses in the event of an increase or decrease for each indicator. However, this matrix provided only qualitative guidance, and left any decisions regarding a change to the quota and how much change was warranted up to the discretion of the Department.

This framework was not selected because it was not supported by the best available science and included overarching conclusions that were not supported by references or data. In addition, an independent peer review of the science used to support the FMP was conducted, and the peer review committee had concerns about the use of qualitative guidance; the lack of strong scientific links between indicators, ecological response, and quota adjustment; and the large range of discretion for potential quota adjustments (Appendix O). Their primary concern was that, in the absence of well-defined indicators and thresholds, as well as predetermined rules for how quotas should be adjusted, there was the potential for subjective application of the guidance, which could lead to disagreement between stakeholders and managers about quota decisions each year. The peer review committee also expressed reservations about the use of indicators which had not been tested to determine whether future quota adjustments based on this framework were likely to be aligned with management objectives.

Given these reservations, the peer review committee made several suggestions for incorporating ecosystem considerations into the Herring FMP. The peer review committee concluded that the preferred HCR is conservative enough to account for ecosystem fluctuations and recommended the Department set quotas only using the HCR and describe the status of the ecosystem indicators in a summary report to provide context, as is done in federal fisheries management. This recommendation recognized that incorporating ecosystem indicators is very challenging and there is limited evidence linking the ecosystem indicators employed with any specific ecological responses (Appendix O). Alternatively, should the Department choose to move forward with ecosystem indicator-based adjustment to HCR-derived quotas, the peer review committee recommended developing statistically- or expert-based thresholds explicitly linking indicator levels to management actions. This would ideally involve the development of quantitative and/or semi-quantitative thresholds that are tested against historical scenarios to ensure that any quota adjustment is appropriate (Appendix O).

One of the goals in developing the Herring FMP was to incorporate ecosystem considerations into Herring management. In order to develop a transparent, reproducible process for determining when ecological conditions were unusual and additional quota adjustment may be warranted, the Department worked with the Project Management Team to develop the decision tree process described in Section 7.7. In reviewing the available data and studies, Department staff concluded that while there is broad evidence supporting the role of Herring as forage in the central California Current Ecosystem, there is limited evidence for direct links between either the availability of Herring as forage, or the relative variability of various forage indicators, and the health of specific predator populations. As a result, it is not clear that a specific change in quota is likely to have a measurable impact on the health of predator populations except during times of extremely low forage availability. Conversely, additional reductions in quota will have a negative economic impact on the fleet. The preferred HCR sets quotas that are conservative (Appendix M) and the Herring FMP provides many layers of precaution to ensure that Herring can fulfill their ecological role (Section 7.8). For these reasons, the magnitude of ecosystem-based adjustments to the quota were limited to 1% increases or decreases in harvest rate (Figure R-3; see also Section 7.7).

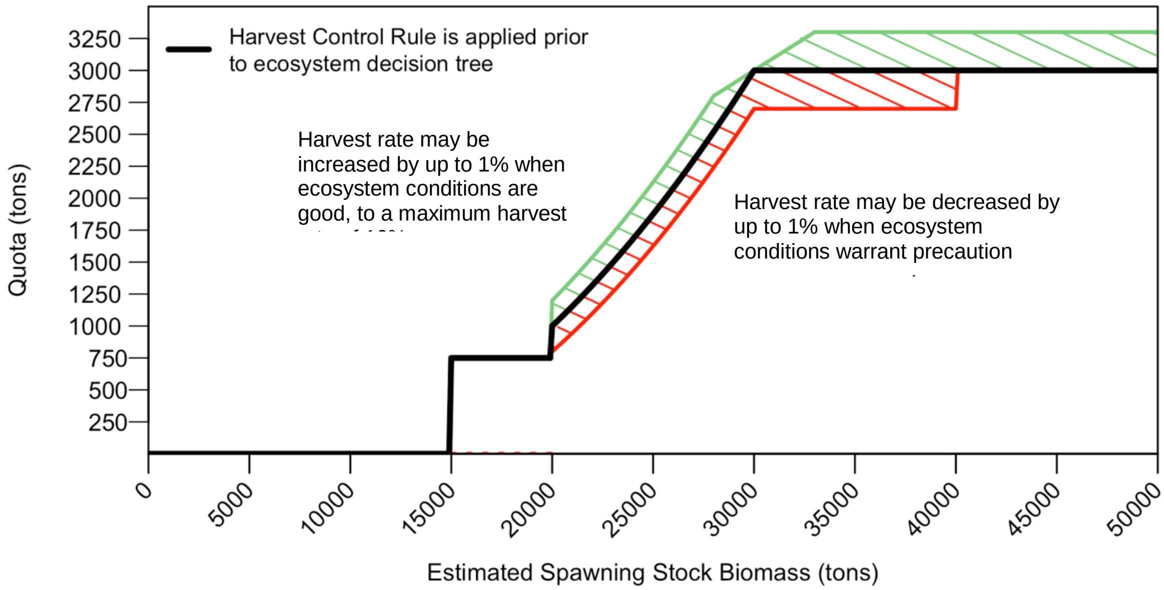

Figure R-3. Final Harvest Control Rule Framework.

Ecosystem-based fisheries management is a growing and continually evolving field. If additional information demonstrating evidence for direct connections between the health of predator populations and the availability of forage species becomes available, the Department may incorporate this information into the decision tree in order to set quotas based on the best available science without amending the FMP (Section 7.7.3 and Section 9.2). This is in line with the California Fish and Game Commission's forage species policy, which seeks to recognize the importance of forage fish to the ecosystem and establishes goals intended to provide adequate protection to these species. Specifically, the Department may incorporate new indicators into the decision tree, as well as alter or remove existing indicators or thresholds, without amendment to the Herring FMP (Section 9.2). The Department may also alter the magnitude of quota adjustment, provided these alterations do not exceed the bounds on harvest rate adjustment indicated in the final HCR framework (Figure R-3). Any potential future alteration to the magnitude of ecosystem-based quota adjustments beyond these bounds will require amendment of the Herring FMP.

Including additional and/or removing indicators should be considered in concert with existing indicators, because all indicators work together to provide a holistic picture of ecosystem conditions. Ideally, the inclusion of any additional indicators should be tested using MSE in order to understand their anticipated performance. The quantitative performance indicators (Appendix M and Section 7.1) should be used to evaluate the impact of the proposed indicators on the Herring stock and the economic viability of the fishery, though other ecosystem-specific performance metrics may also be developed. If it is not possible to conduct a MSE due to resource or capacity constraints, at minimum a retrospective analysis should be conducted to examine how often quotas would have been adjusted in past years under proposed management scenarios, and whether these adjustments align with management objectives.

Chapter 11. Literature Cited and References

Ainley DG, Boekelheide RJ. 1990. Seabirds of the Farallon Islands: Ecology, Dynamics, and Structure of an Upwelling-System Community: Stanford University Press. 488 p.

Ainley DG, Spear LB, Allen SG, Ribic CA. 1996. Temporal and Spatial Patterns in the Diet of the Common Murre in California Waters. The Condor 98(4):691-705.

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