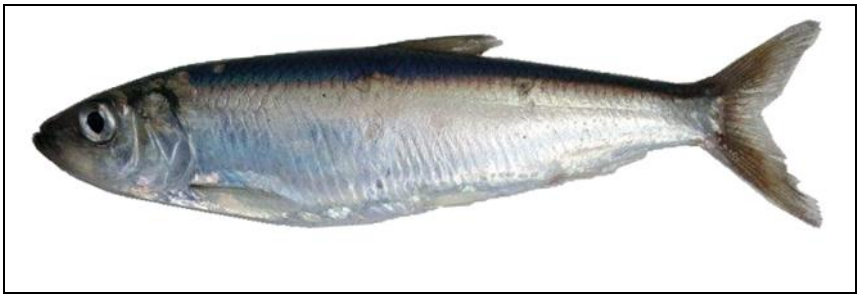
# California Pacific Herring Fishery Management Plan



Pacific Herring, *Clupea pallasii*.

October, 2019

**California Department of Fish and Wildlife**
**Marine Region**

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# 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*, by 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 socioeconomic 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,
- describe the effects of climate change on California's Herring stocks, and identify environmental and ecosystem indicators that can inform effective 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.

*Tiered Management Approach*

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 FMP adopts this multi-indicator predictive model as an option for estimating the coming season's SSB in San Francisco Bay, contingent upon availability of necessary input data and continued predictive power by the model. Spawn deposition surveys remain the default method for determining SSB.

*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 establishing a daily bag limit that is easily enforceable and provides for a satisfying and sustainable recreational experience while deterring illegal commercialization of the fishery.

Table of Contents

## 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 |

**List of Figures**

## List of Tables

## 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 California 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 Gordon and Betty Moore Foundation and 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).

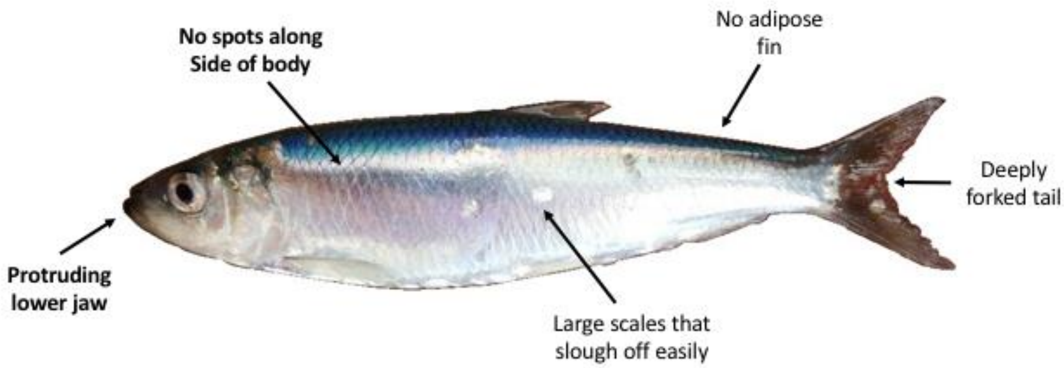


Figure 2-1. Herring, with identifying features noted.

## 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.

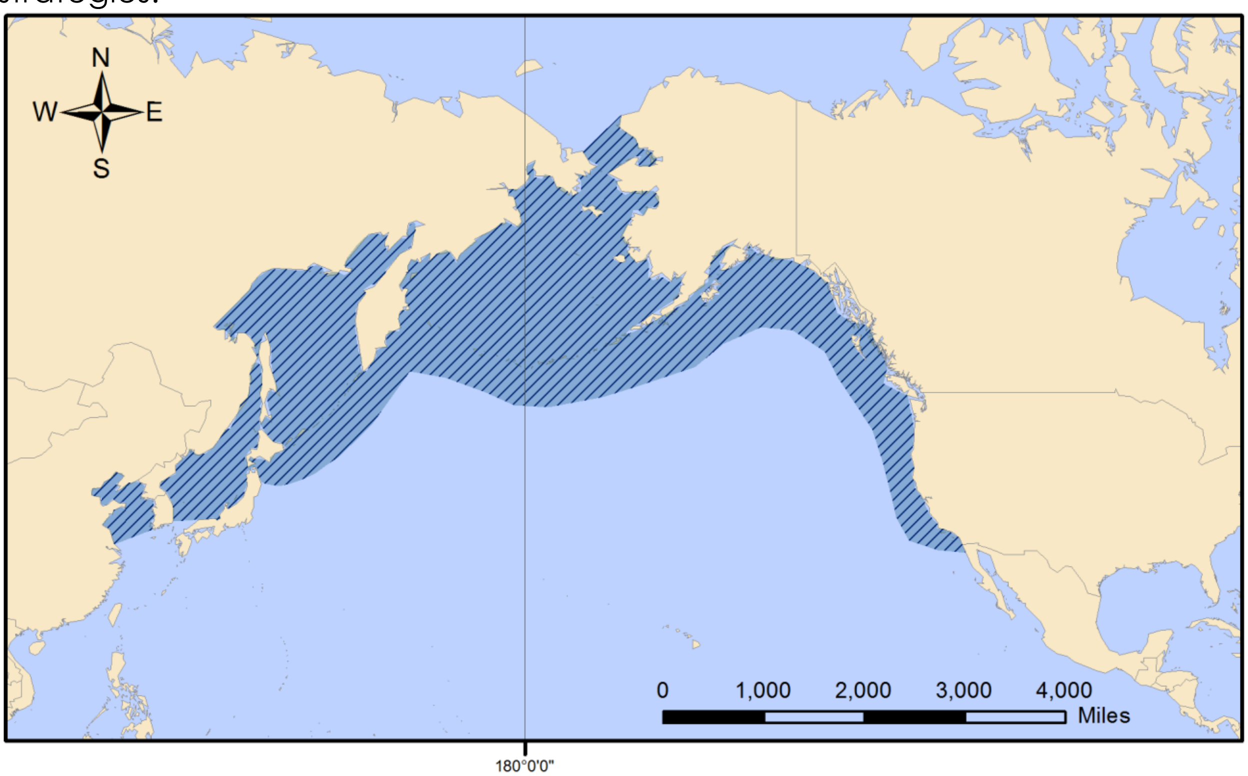


Figure 2-2. Approximate distribution of Herring throughout the northern Pacific.

## 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 (California 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 (California 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 (California 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 (California 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 (California 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.

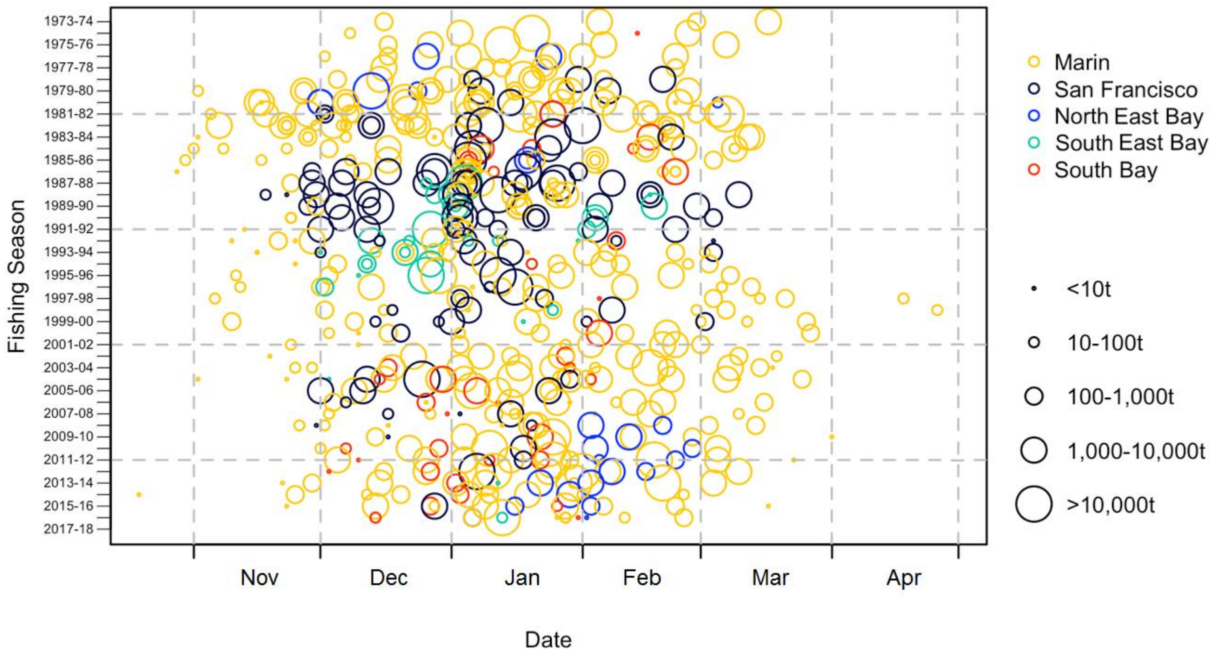


Figure 2-4. Distribution of dates (x-axis), magnitudes, and locations of observed spawns in San Francisco Bay from 1973-17 fishing seasons (y--axis). See Figure 2-12 for a map of these locations.

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 (California 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 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 (California 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 (Section 3.2).

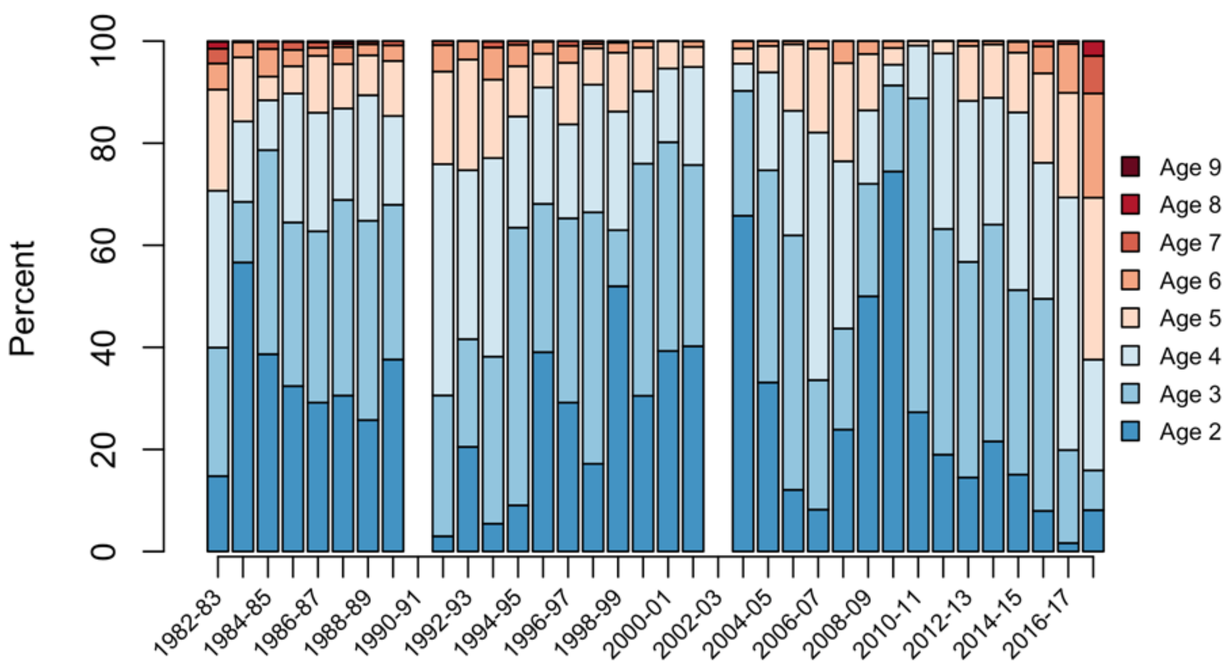


Figure 2-5. Percent at age, by number, of ripe fish for the San Francisco Bay spawning stock biomass. Based on age composition of the research catch (excluding age-1 fish), 1982-83 through 2017-18 seasons. Note that final age composition was not determined for the 1990-91 and 2002-03 seasons.

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 Number Sampled | 1974-75 Percent | 1975-76 Number Sampled | 1975-76 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.

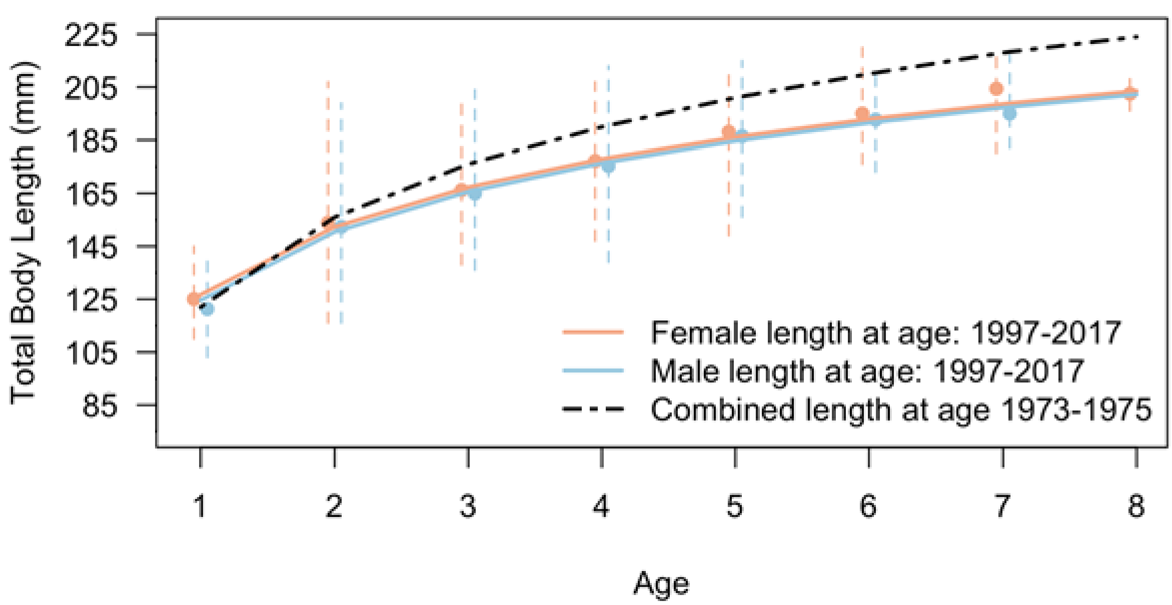


Figure 2-6. Mean length at age (dots), observed length distribution at age (dashed vertical lines), and modeled length at age for male (blue) and female (pink) Herring in San Francisco Bay between 1998-17 is contrasted with the modeled length-at-age for San Francisco Bay Herring from 1973-75 (black dot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

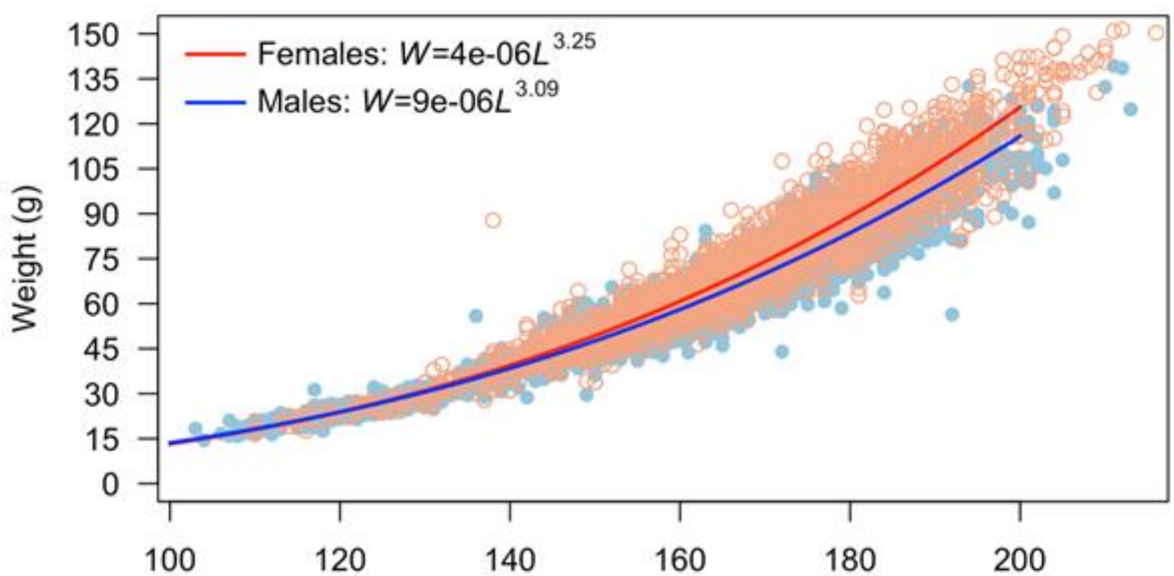


Figure 2-7. Length-weight relationship for mature, unspent San Francisco Bay Herring between 1998 and 2017 (n= 6296, 54% males).

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).

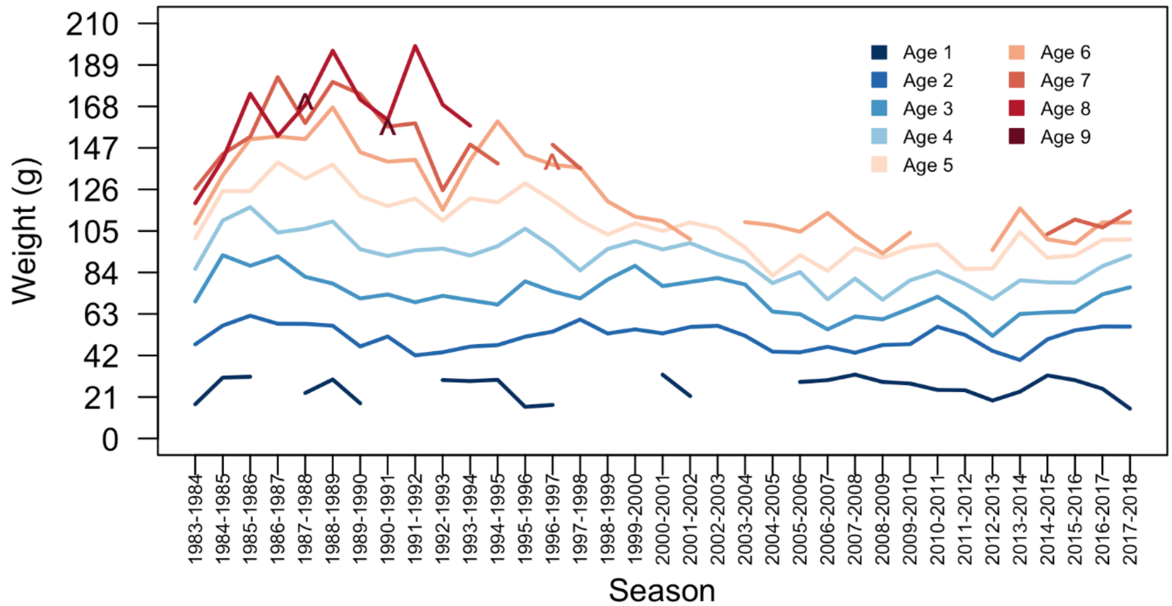


Figure 2-8. Mean weight at age observed in the research catch between the 1982-83 and 2017-18 seasons. Mean weight at age fluctuates from year to year but has declined for age three and older Herring.

### 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.

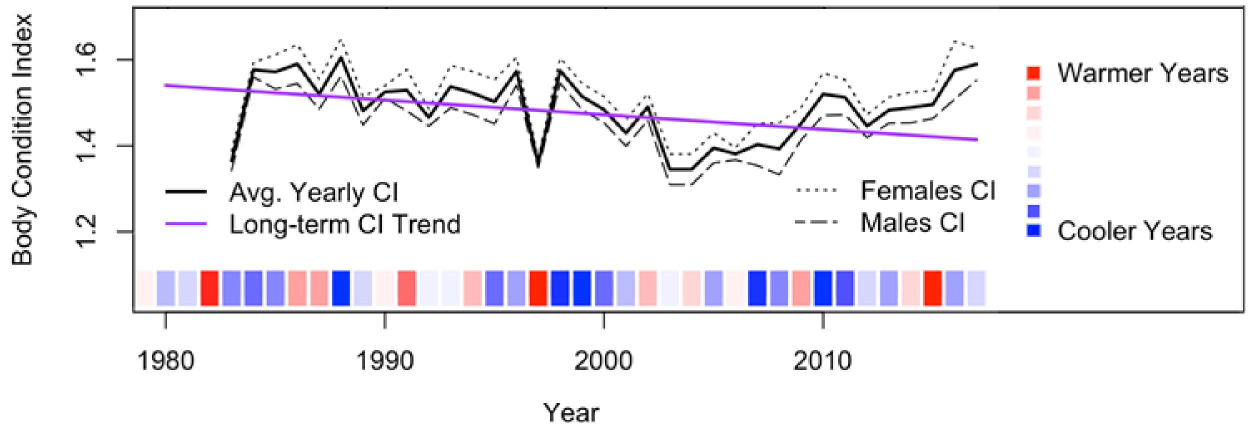


Figure 2-9. Yearly condition index for San Francisco Bay Herring and average SST anomaly[1] in the Eastern Pacific between 1980 and 2018.

## 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).

[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/

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 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).

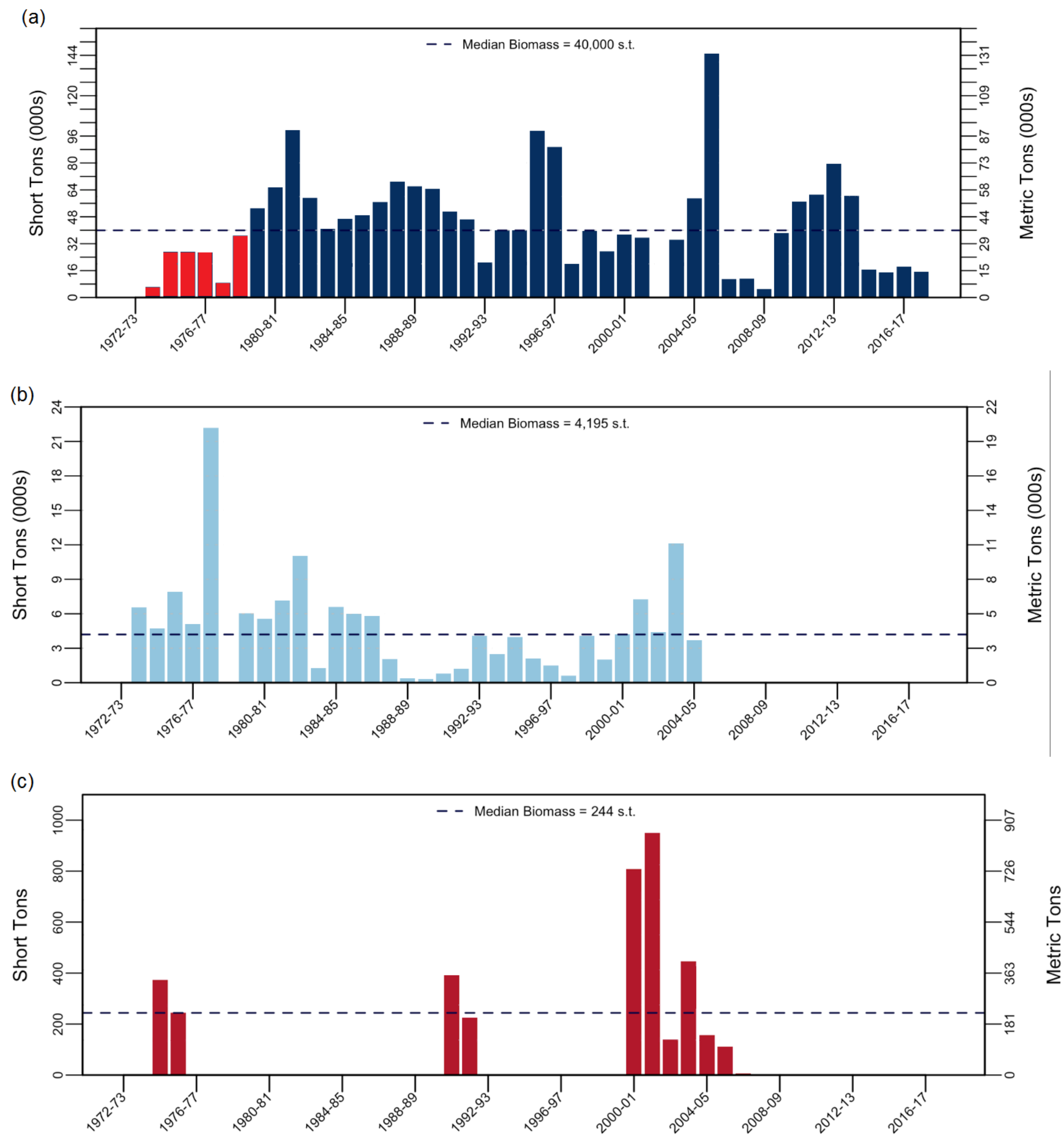


Figure 2-10. Reported estimates of SSB (including catch) for San Francisco Bay (a), Tomales Bay (b), and Humboldt Bay (c) for all seasons in which surveys were conducted. In San Francisco Bay, biomass estimates for seasons prior to 1979-80 represent intertidal spawns only. Note the y-axes scale differs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

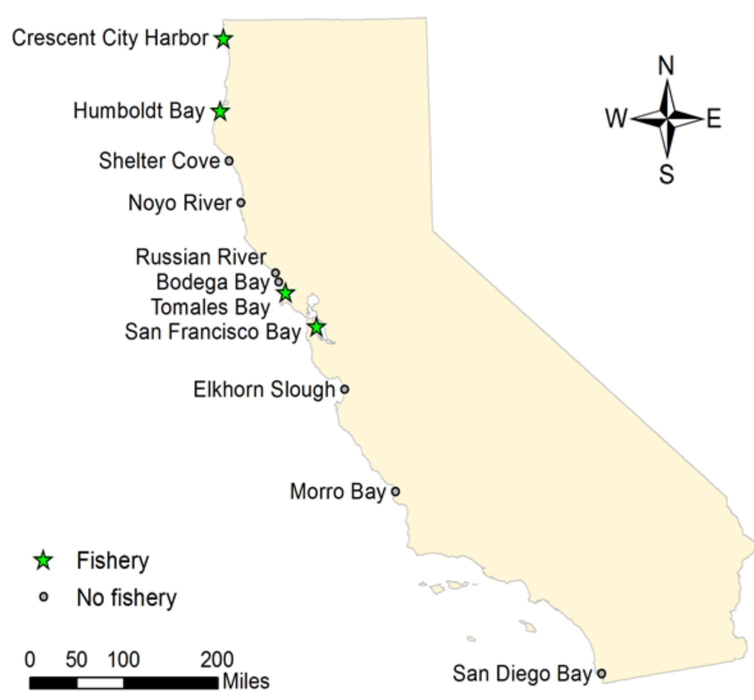


Figure 2-11. Map of observed Herring spawning locations and fisheries in California.

#### 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.

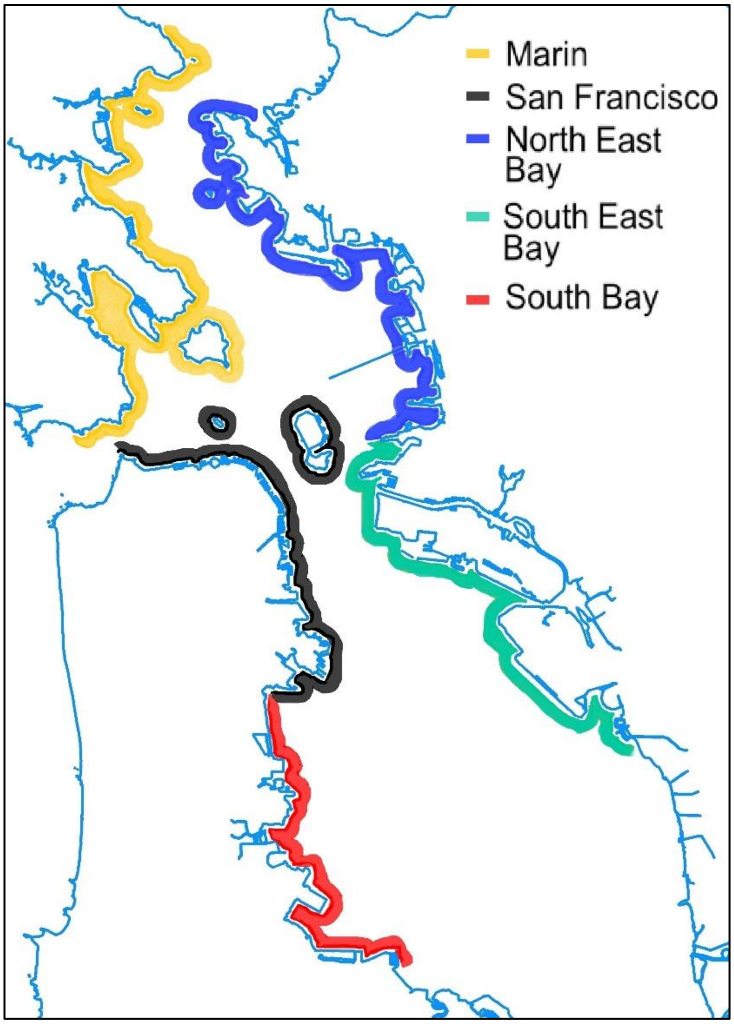

Figure 2-12. Observed spawning locations in San Francisco Bay from 1973 to 2019.

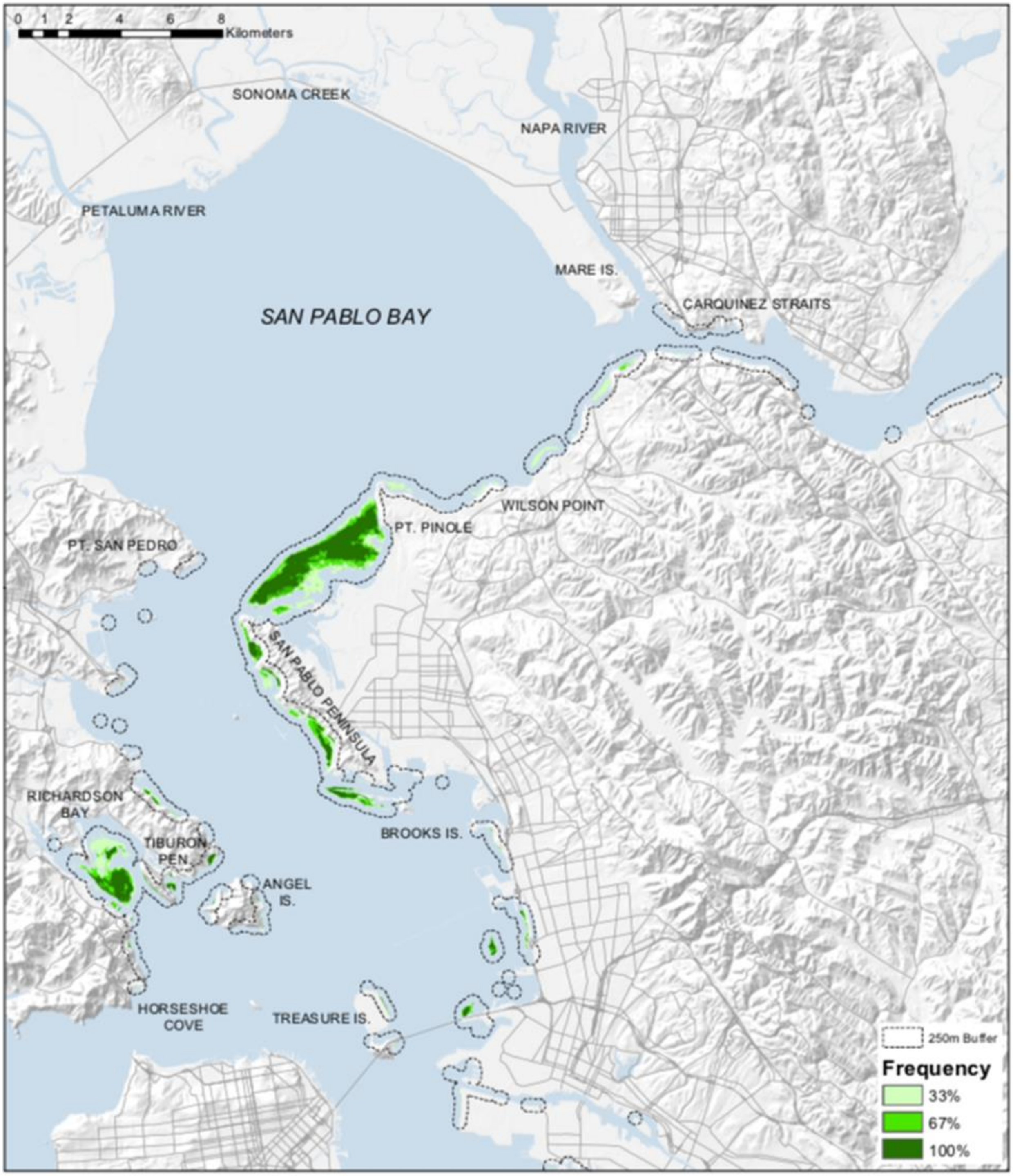


Figure 2-13. Eelgrass distribution and persistence in the northern portion of San Francisco Bay (Reproduced from Merkel and Associates (2014)).


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. Maximum spawning extents observed during the 2014-15 through 2017-18 seasons are presented in Appendix D.

#### 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) |

| **Threat** | **Physical Impacts on Habitat** | **Effects on Herring** | **References** |
|---|---|---|---|
| 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, 2005; 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) |

| Threat | Physical Impacts on Habitat | Effects on Herring | References |
| --- | --- | --- | --- |
| 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) |

| Threat | Physical Impacts on Habitat | Effects on Herring | References |
|---|---|---|---|
| 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.

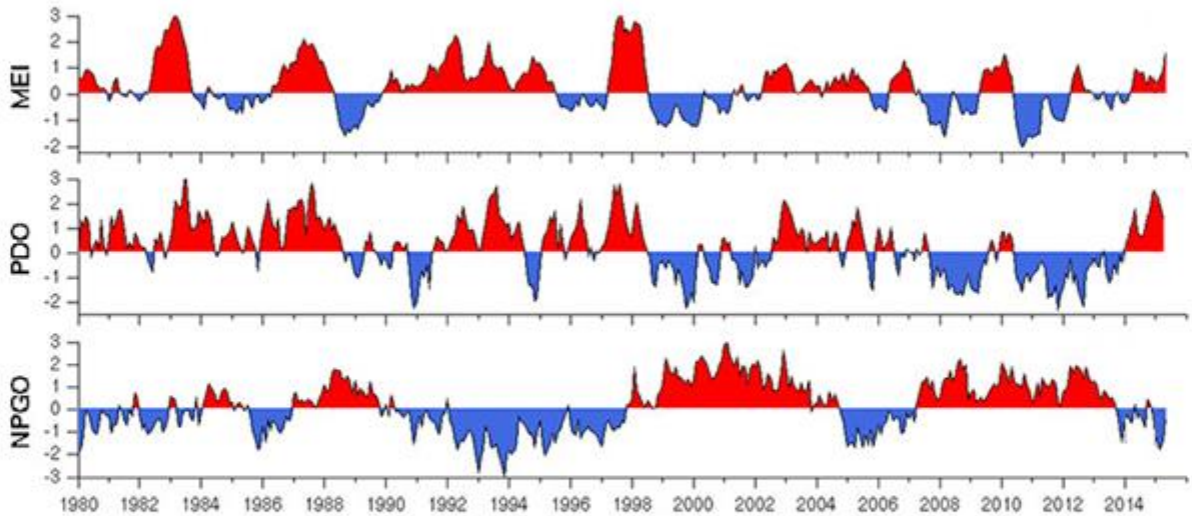


Figure 3-1. The Multivariate ENSO Index (MEI), PDO index, and NPGO between 1980 and 2016. Red MEI values denote El Niño (warm, low productivity) conditions and blue values denote La Niña (cool, more productive) conditions. Red PDO values are associated with warm regimes and blue values are associated 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 (California 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 | 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 | Percent | Marine Mammal | Percent | Bird | Percent |
|---|---|---|---|---|---|
| **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*)** | -- |

| **Fish** | **Percent** | **Marine Mammal** | **Percent** | **Bird** | **Percent** |
| --- | --- | --- | --- | --- | --- |
| 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 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.

[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

### 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.

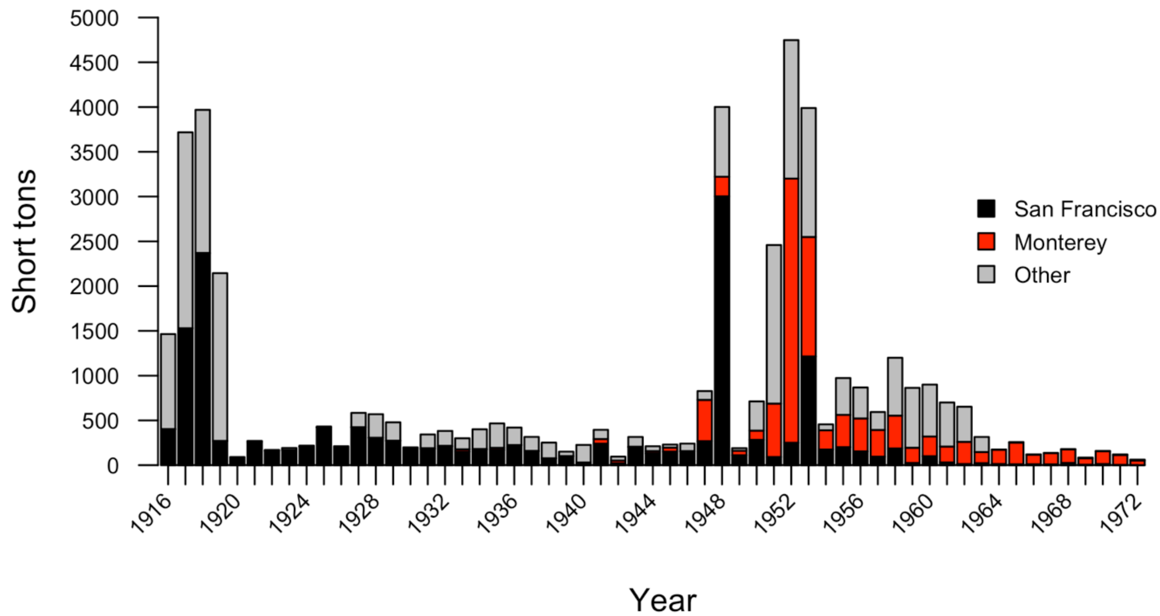


Figure 4-1. California historic Herring landings in San Francisco Bay (black), Monterey (red), and other locations (grey) from 1916-1972.

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).

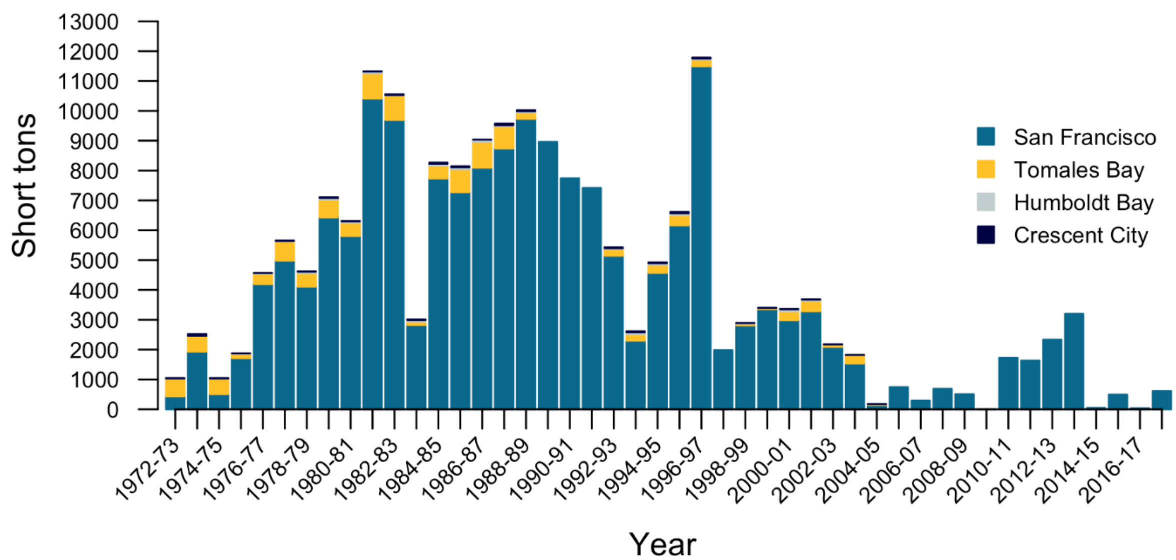


Figure 4-2. California Herring landings by area in short tons between 1973 and 2017 in San Francisco Bay (blue), Tomales Bay (yellow), Humboldt Bay (gray), and Crescent City Harbor (black). The commercial fishery was closed for the 2009-10 season. Note that this figure does not include landings from 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 (California 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 socioeconomic 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 socioeconomic 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.

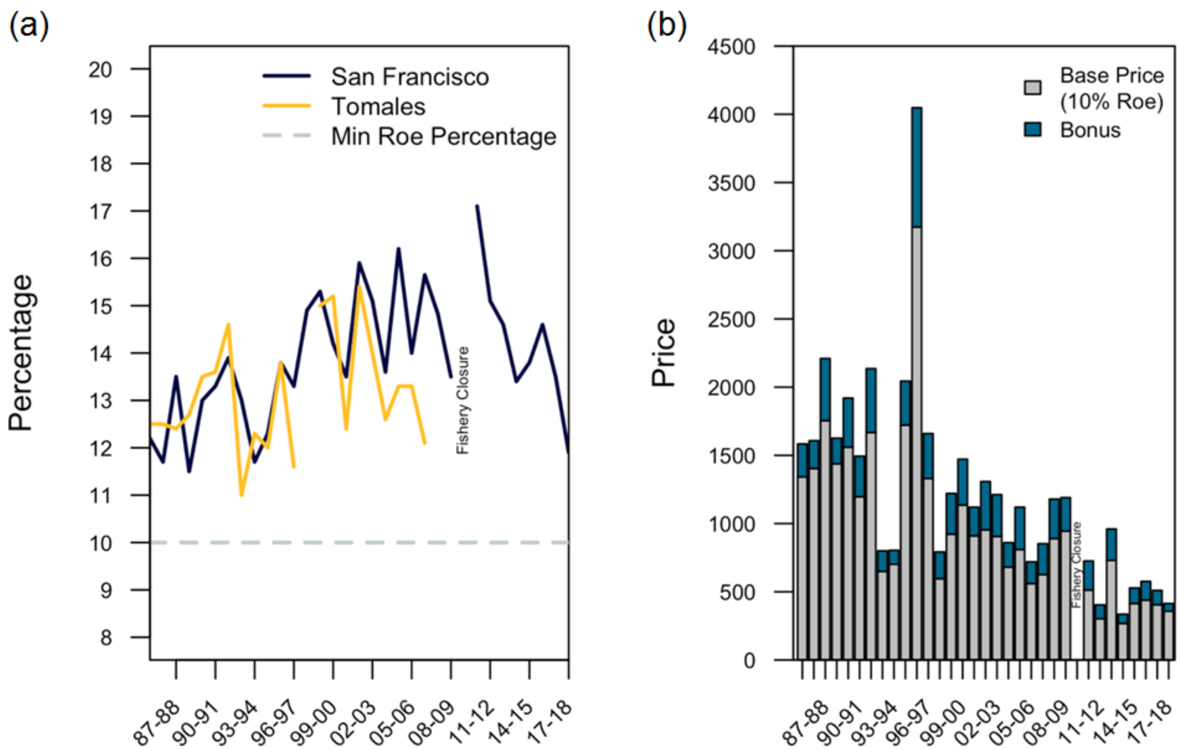


Figure 4-3. Roe percentage of gill net fishery (a) in San Francisco Bay (purple) and Tomales Bay (yellow) and pricing for the sac-roe fishery (b) including the base price (10% roe, grey) and bonus (blue).

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.

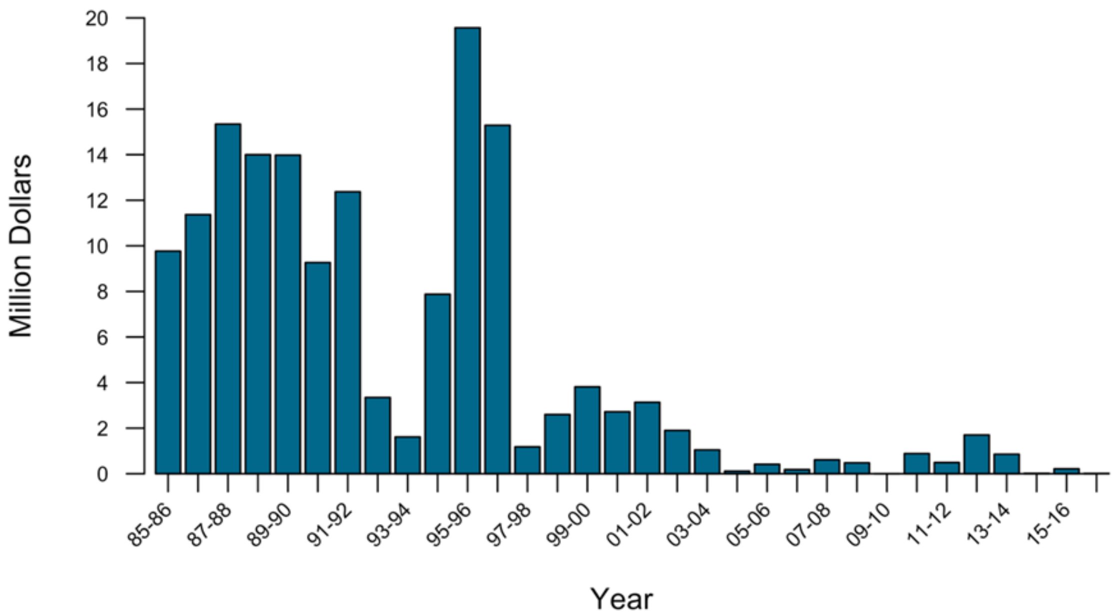


Figure 4-4. Ex-vessel value (in millions of dollars) for the California sac-roe fishery, 1985-2017.

### *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.

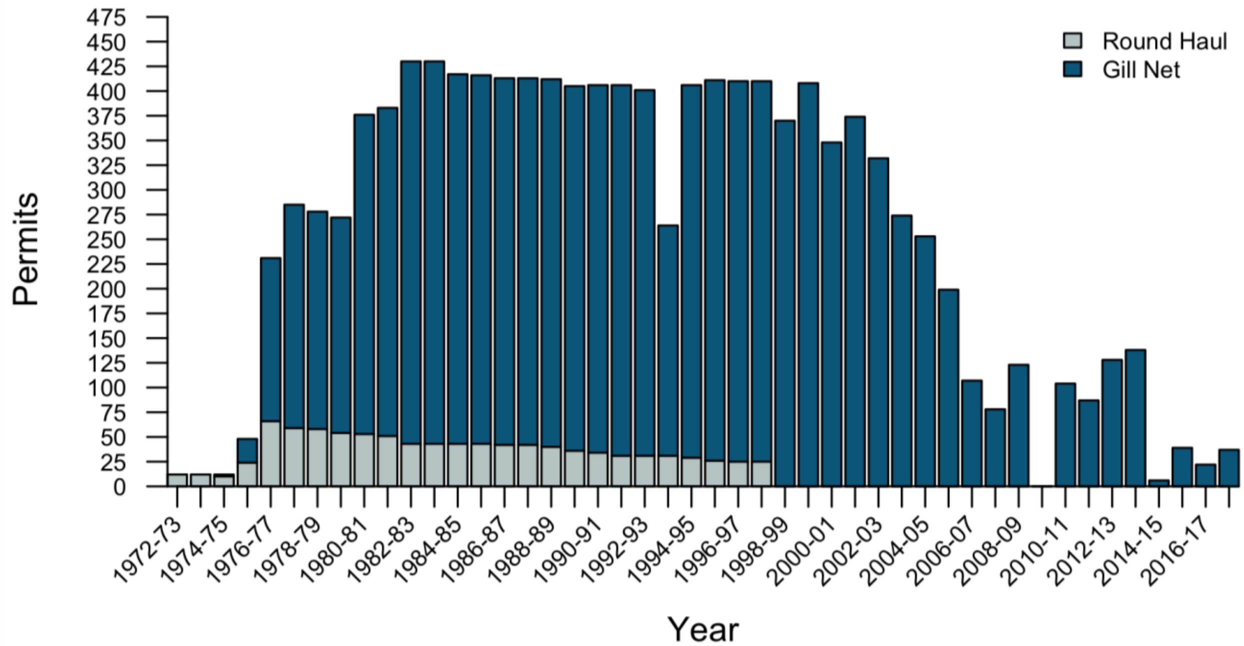


Figure 4-5. Number of permits fished in the sac-roe fishery by gear type each year since the beginning of the fishery in San Francisco Bay.

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 San Francisco Herring Association, 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.

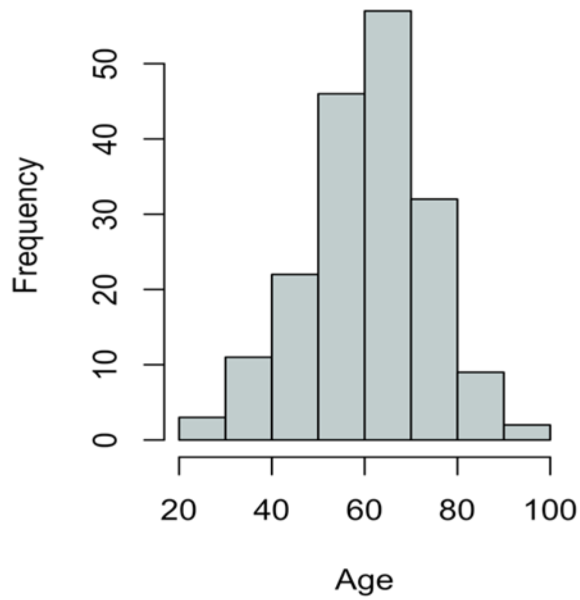


Figure 4-6. Age of permittees in the California sac-roe Herring fishery at the time of FMP development.

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 (and County for CA Residents) | Percent |
|---|---|
| California | 78% |
| Monterey | 34% |
| Marin | 13.5% |
| Sonoma | 8.5% |
| Mendocino | 5.6% |
| Contra Costa | 5.6% |
| Solano | 4.2% |
| San Mateo | 4.2% |
| San Francisco | 2.8% |
| Alameda | 2.8% |
| Other | 18.8% |
| Washington | 19% |
| Oregon | 2% |
| Other | <1% |

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. Commercial landings and ex-vessel value for the five most valuable fisheries each in San Francisco, Tomales, Eureka, and Crescent City ports in 2017.

| **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.

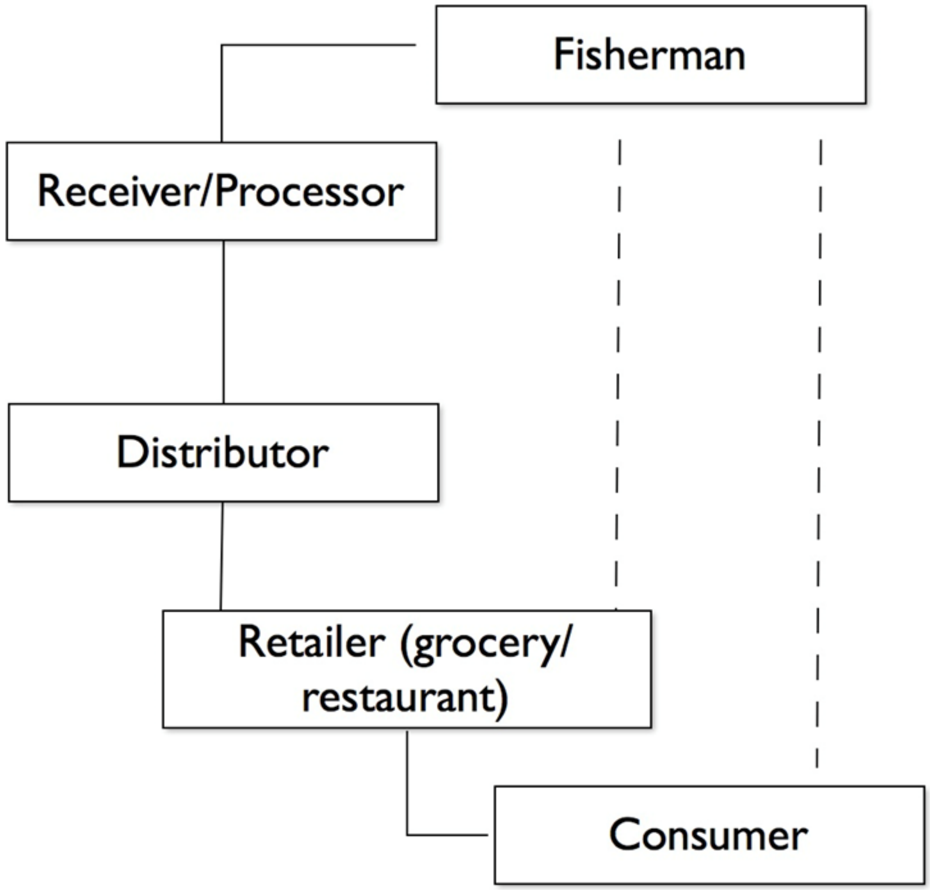


Figure 4-7. Supply chain for commercially-caught Herring caught in California. The black lines show the distribution channels for the Herring roe fishery. The dashed lines show potential channels for a local whole fish market. Note that under this FMP, commercially landed Herring may only be sold to 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 *Socioeconomic Considerations for the Northern Management Areas*

Much of the focus of regulatory changes to address socioeeconomic 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 socioeconomics 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 socioeconomic 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 (California 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.

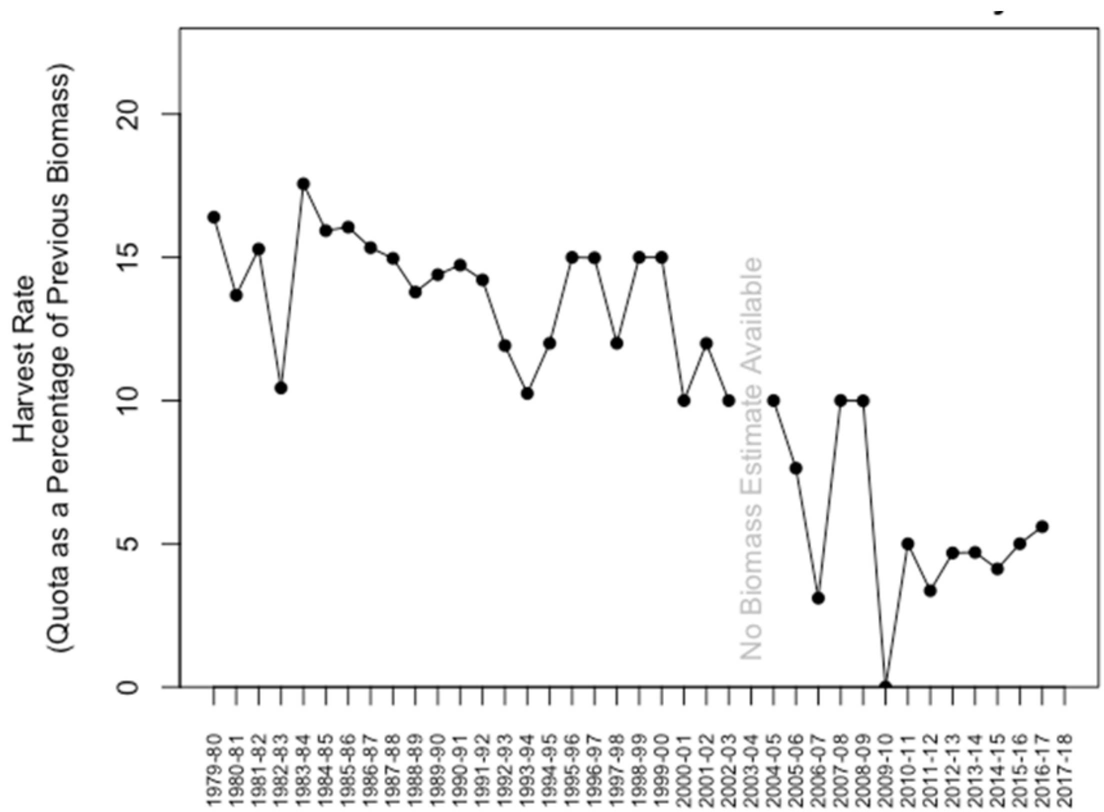


Figure 5-1. Intended harvest rates for the San Francisco Bay Herring fishery.

### 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 Minimum Mesh Size (in)** | **Gill net Maximum Mesh Size (in)** |
|---|---|---|
| 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 |

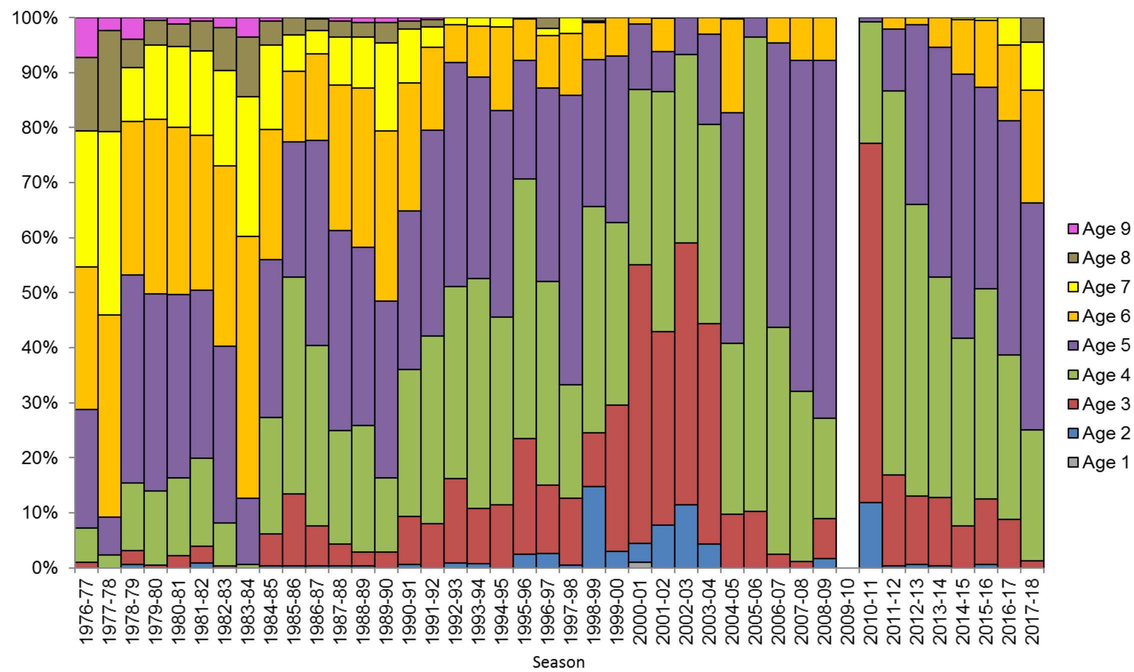


Figure 5-2. Age structure of the commercial Herring catch between the 1976-77 and 2017-18 seasons (the fishery was closed in 2009-10).

## 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.

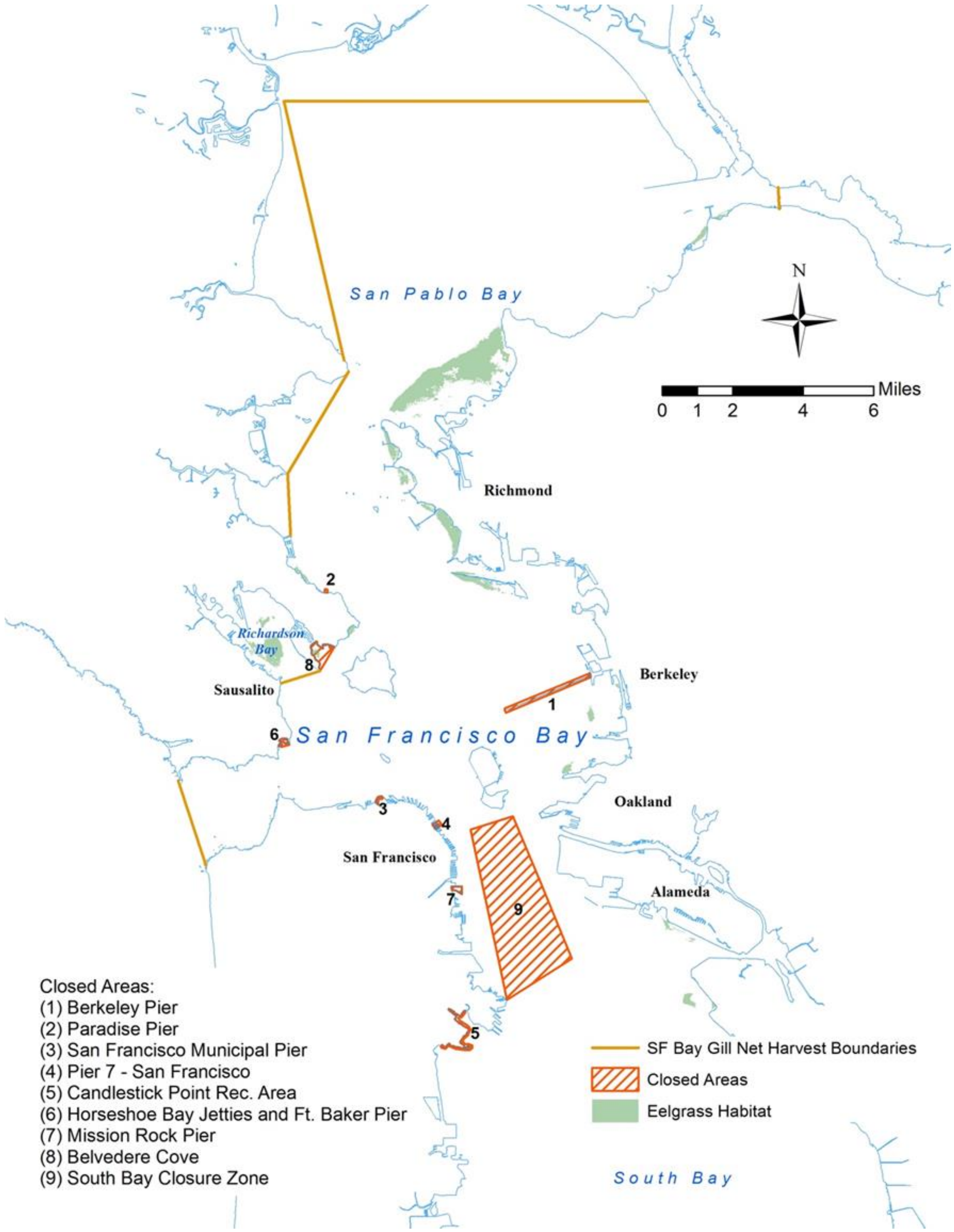


Figure 5-3. Spatial restrictions on Herring fishing in San Francisco Bay. Eelgrass habitat from Merkel and Associates (2014).

## 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 prior to the implementation of this FMP.

| 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. 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 socioeconomic 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 |

| Type of EFI Produced | Priority for Management | How EFI is used in management |
|---|---|---|
| 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 m² 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.

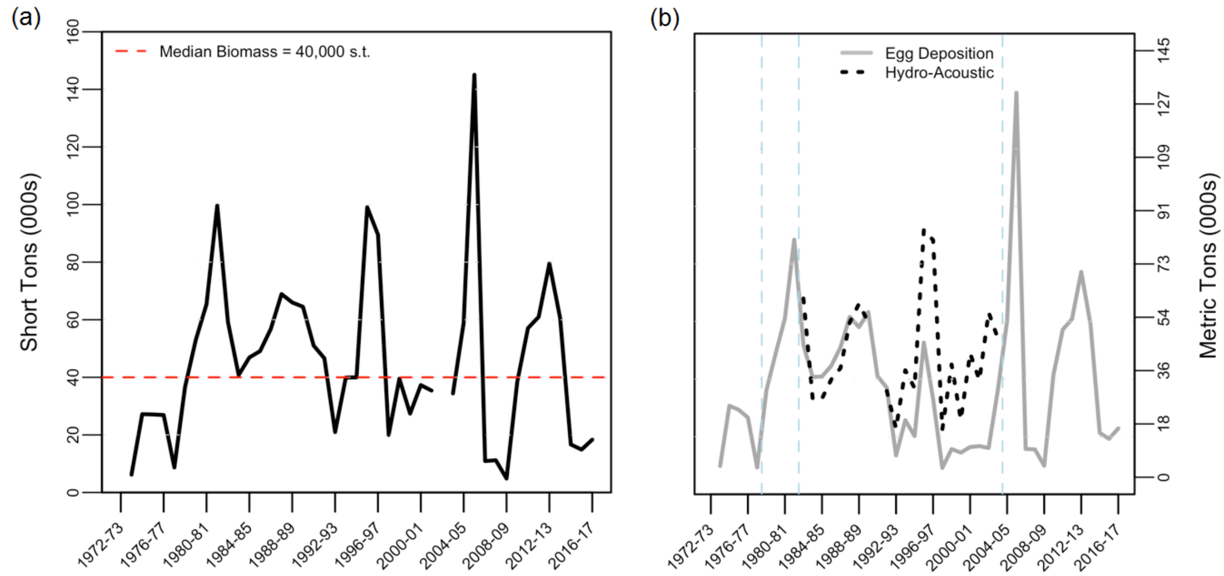


Figure 6-1. Department estimated yearly SSB of San Francisco Bay Herring between 1972-73 to 2016-17 in short and metric tons. The left panel (a) shows the reported biomass (with a median biomass of 40 Kt/36 Kmt), and the right panel (b) shows the individual biomass estimates from the spawn deposition 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.

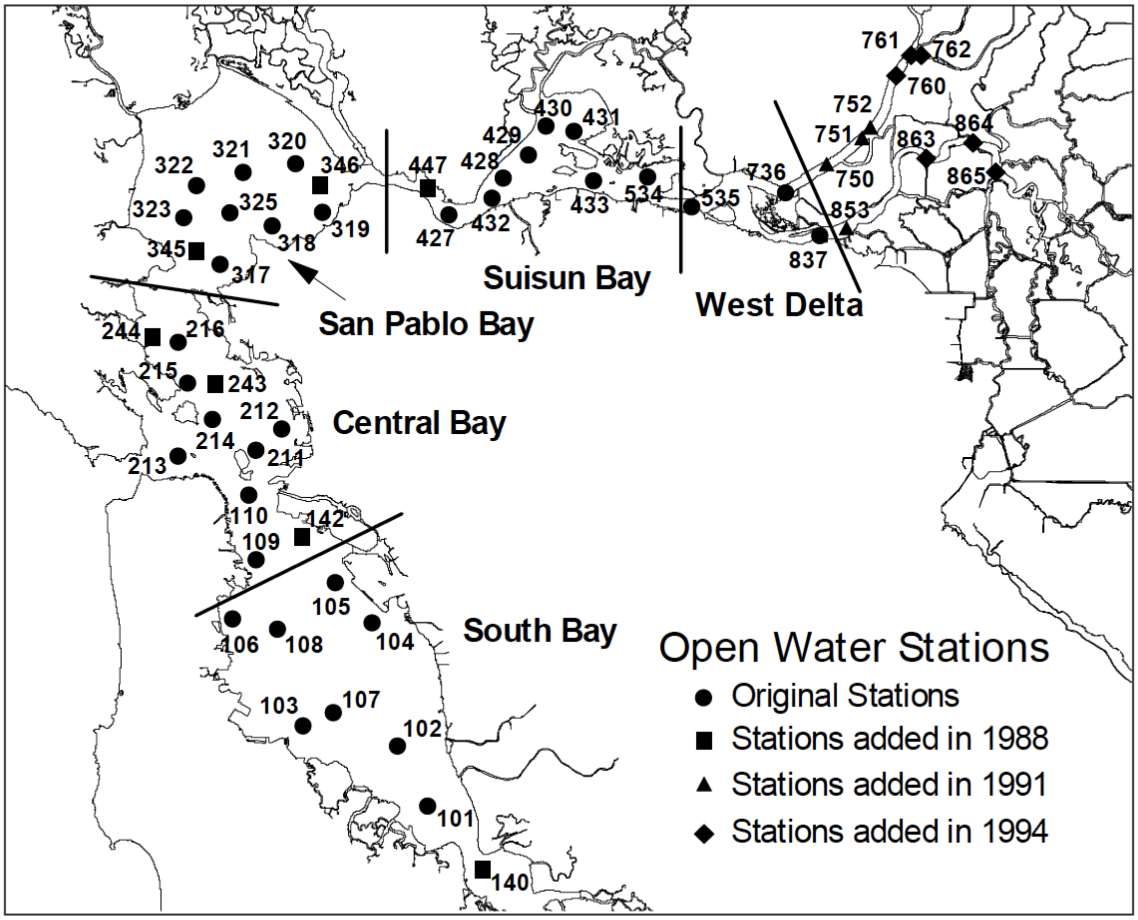


Figure 6-2. Station map for San Francisco Bay Department midwater trawls, from which YOY Herring abundance data are obtained.

### 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

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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.

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 (California 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, at the time of FMP development, 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*

#### 6.2.2.1 *Section Reserved*

#### 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,

[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.

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 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.

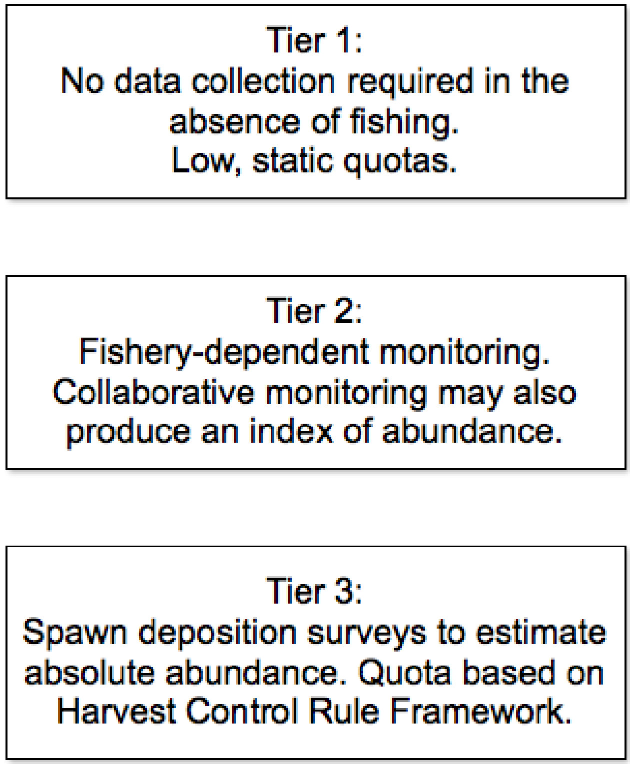



Figure 7-1. Schematic of tiered approach to Herring management, in which each management area falls into one of three tiers based on the level of fishing occurring. The level of monitoring effort is dictated by the size of the fishery, and the quota setting approach is determined by the information available.

### 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 11 tons (10 metric tons), which is 50% of the average historical landings and a 63% 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 as a rebuilding provision in years where either the employed Rapid Spawn Assessment indicates very poor spawning behavior, or spawn deposition survey-derived SSB estimates indicate an SSB that is overfished or otherwise depressed. For San Francisco Bay, the stock is considered overfished or otherwise depressed at SSB estimates below the 15,000-ton cutoff established by the HCR (see Section 7.7.1). For Tomales Bay and Humboldt Bay, the stock is considered overfished or otherwise depressed at stock sizes that are less than 20% of the long-term average biomass (including historical and contemporary SSB estimates) for each respective management area. For Crescent City Harbor, the stock is considered overfished or otherwise depressed at SSB estimates less than 66 tons, which is approximately three times the average historical catch in that management area.

### 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 may be 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. $SST_{Jul\text{-}Sep}$ — 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 °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:

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

***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:

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

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

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

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's use depends on the availability of required data and the model's continued predictive skill (see Section 7.6.2.1, Appendis E). When these two requirements are met,  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).

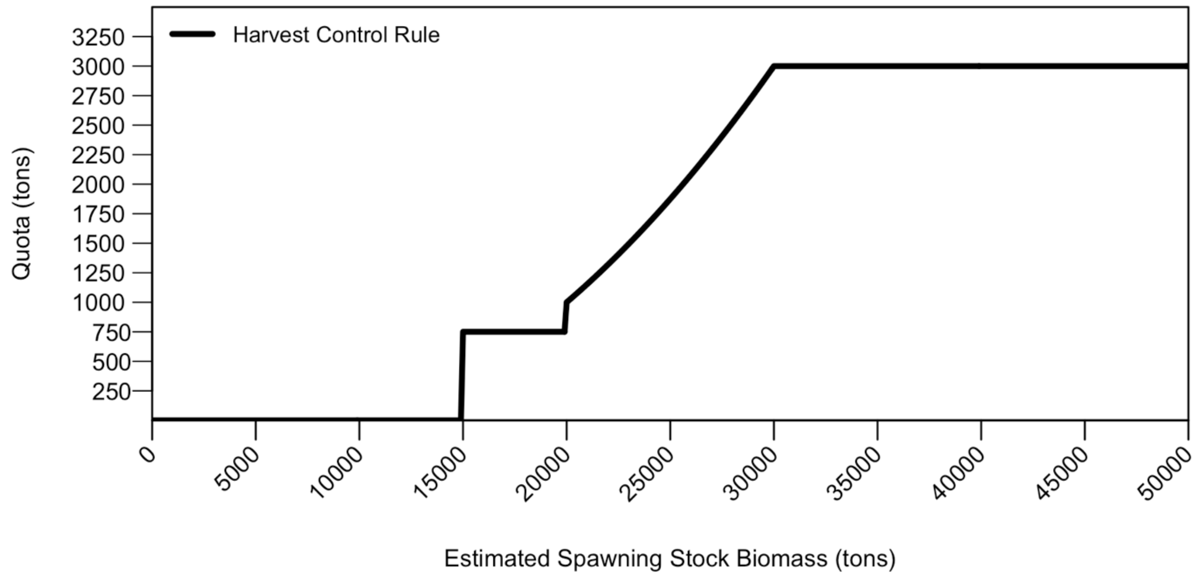



Figure 7-2. Harvest Control Rule describing the relationship between estimated SSB and unadjusted quota for subsequent season of the San Francisco Bay Herring commercial fishery.

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

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

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 report 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). |

| Data | Interpretation | Implications for Herring Management |
| --- | --- | --- |
| 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 | -- | -- |

| Data | Interpretation | Implications for Herring Management |
|---|---|---|
| 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. |

| Data | Interpretation | Implications for Herring Management |
|---|---|---|
| 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

[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

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 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 aid 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.

| Species | Question | Response / Adjustment |
|---|---|---|
| Herring | 1. Is the biomass estimate greater than 20,000 tons? | **No** - Do not adjust quota.<br>**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.<br>**Yes -** Proceed to 3. |
| Predators | 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.<br>**Yes** - Proceed to 4. |
| Predators | 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.<br>**Yes** - Consider reducing quota. |
| Predators | 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.<br>**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. |
| Regional Forage | 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. |
| Regional Forage | 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. |
| Regional Forage | 9. Are there currently > 5 forage indicators that are unusually low, and the Herring biomass is < 40,000 tons? | **No** - Proceed to 10.<br>**Yes** - Consider reducing quota. |
| Regional Forage | 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.<br>**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, the target harvest rate may be increased by up to 1% (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, the target harvest rate may be increased by up to 1% (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.

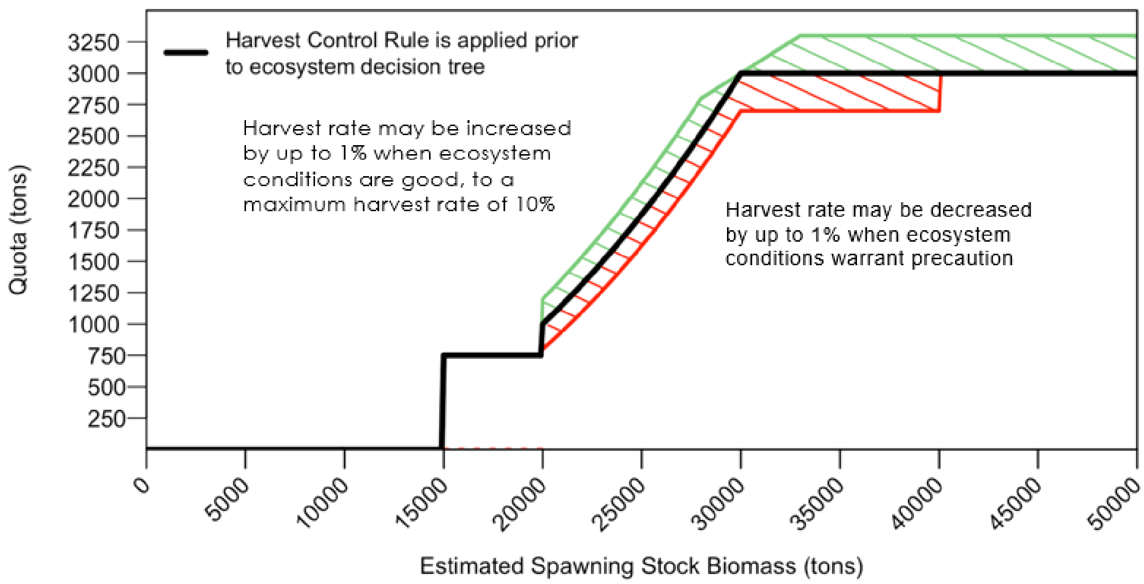



Figure 7-3. Possible range of quotas under the harvest control framework after the ecosystem decision tree is applied.

### 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 | 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 | 1200 on Jan 2 to 1200 on March 15. |
| **Humboldt Bay** | 1200 on January 2 until 1200 on March 9 | 1200 on Jan 2 to 1200 on March 15. |
| **Crescent City** | 1200 on January 14 until 1200 on March 23 | 1200 on Jan 2 to 1200 on March 15. |

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 that a daily bag limit for recreational fishing be adopted through regulation. The FMP recommends a daily bag limit be established at an appropriate amount to provide a reasonable and sustainable amount of recreational harvest for participants. The possession limit should also be designed to be clear and easily enforceable. For reference, two 5-gallon buckets of Herring are equivalent to 100 lb of Herring, or, approximately 260 Herring per bucket. Currently, there are no estimates of the recreational catch available, but a 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 updated in the Enhanced Status Report.

### 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 will be periodically updated in the Enhanced Status Report. 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? |
| 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 bycatch levels of the fishery? |
| 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 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? |
| Change to season dates | There is a shift in the prime spawning season (earlier or later). | 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? |
| Change to weekend closure times | There is a desire by permit holders to alter or eliminate the weekend closure. | How does this change alter the temporal refuge spawning schools may get receive? |
| Change to weekend closure times | There is a desire by permit holders to alter or eliminate the weekend closure. | 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 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? |
| Additional regulations for recreational fishery | The total recreational catch continues to increase, causing concern for the status of the resource. | 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 Section 7.7.2.3, provided the supporting science is clearly documented (Appendix R).

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 *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.

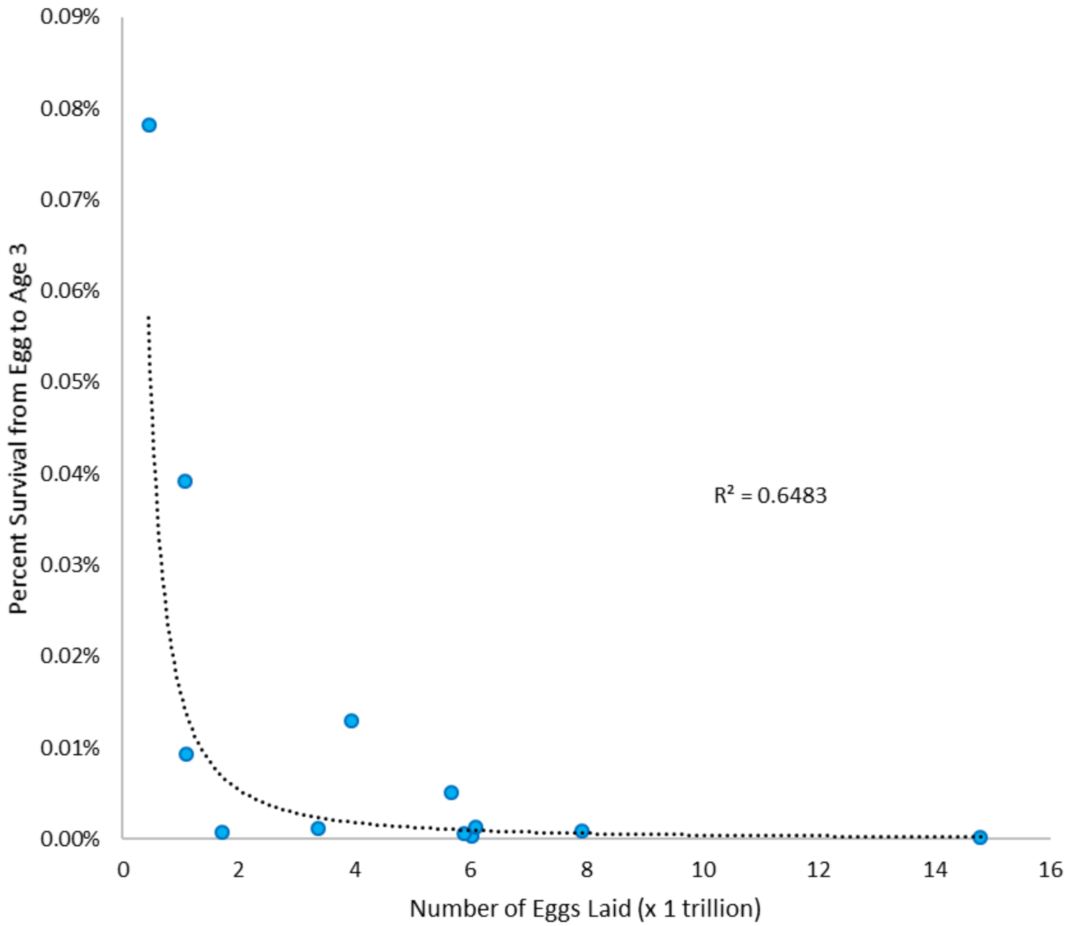



Figure 1. Number of eggs laid (times one trillion) in San Francisco Bay from 2003-04 through 2014-15 and the percent survival of that cohort to age-3. Calculations used for number of eggs spawned and survival from egg to age-3. The number of eggs spawned each season was calculated by multiplying the 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

This document omits appendices B, C, I, K, L, O, and the majority of appendix Q, which cannot be formatted for online accessibility. Please contact CDFW for a formal copy that includes these missing appendices.

# Appendix C Coleraine Stock Assessment Model Report

This document omits appendices B, C, I, K, L, O, and the majority of appendix Q, which cannot be formatted for online accessibility. Please contact CDFW for a formal copy that includes these missing appendices.

## 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.

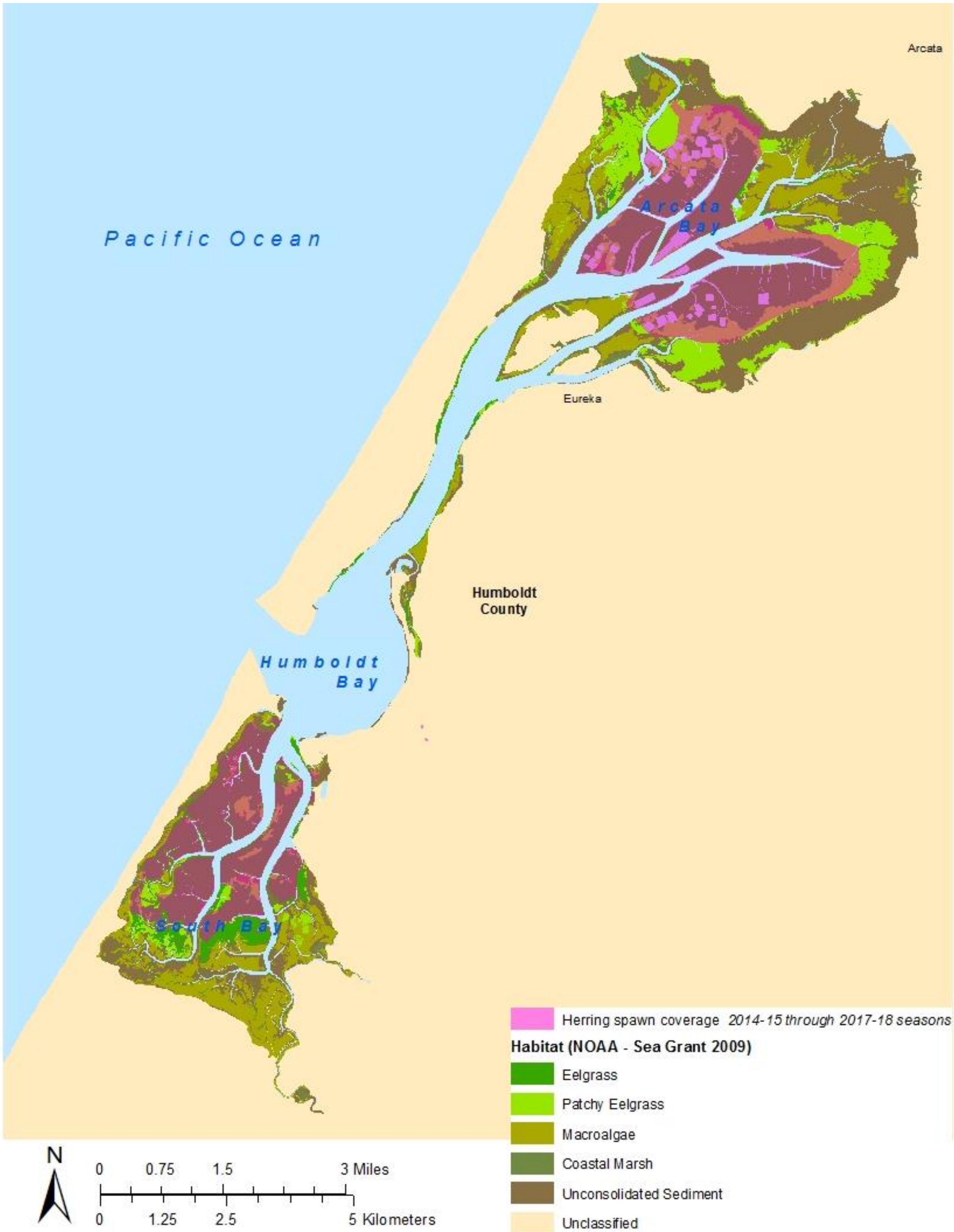



Figure D3. Eelgrass and other habitat types in Humboldt Bay (Schlosser and Eicher, 2012) and Herring spawn coverage.


Figure D4. Eelgrass and other habitat types in the Eel River estuary (Schlosser and Eicher, 2012).

Figure D5. Eelgrass habitat in Ten Mile River estuary.

Figure D6. Eelgrass habitat in the Noyo River estuary (Merkel and Associates, 2016).


Figure D7. Eelgrass habitat in the Big River estuary.

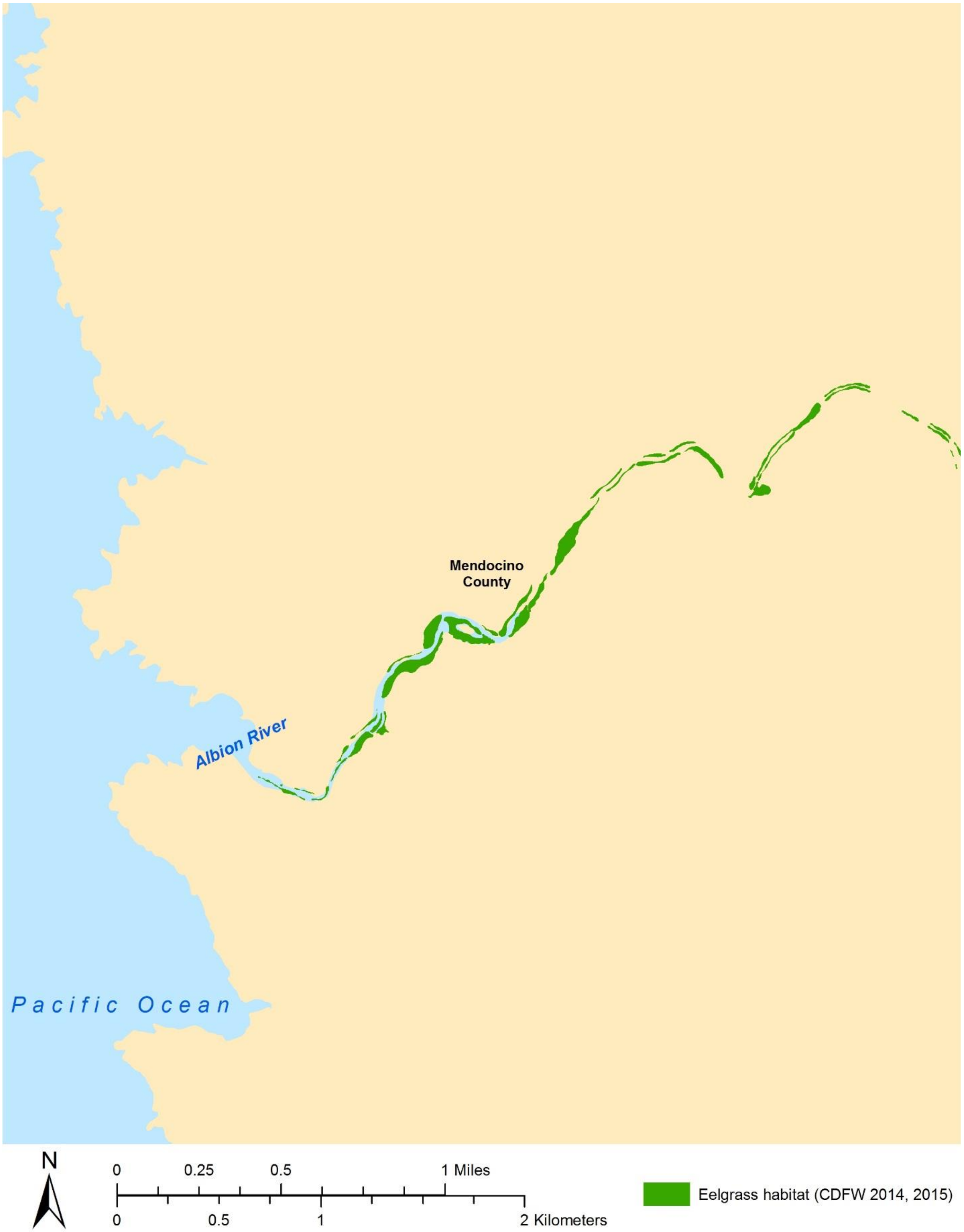



Figure D8. Eelgrass habitat in the Albion River estuary.


Figure D9. Widgeongrass (*Ruppia maritima*) habitat in the Russian River estuary.

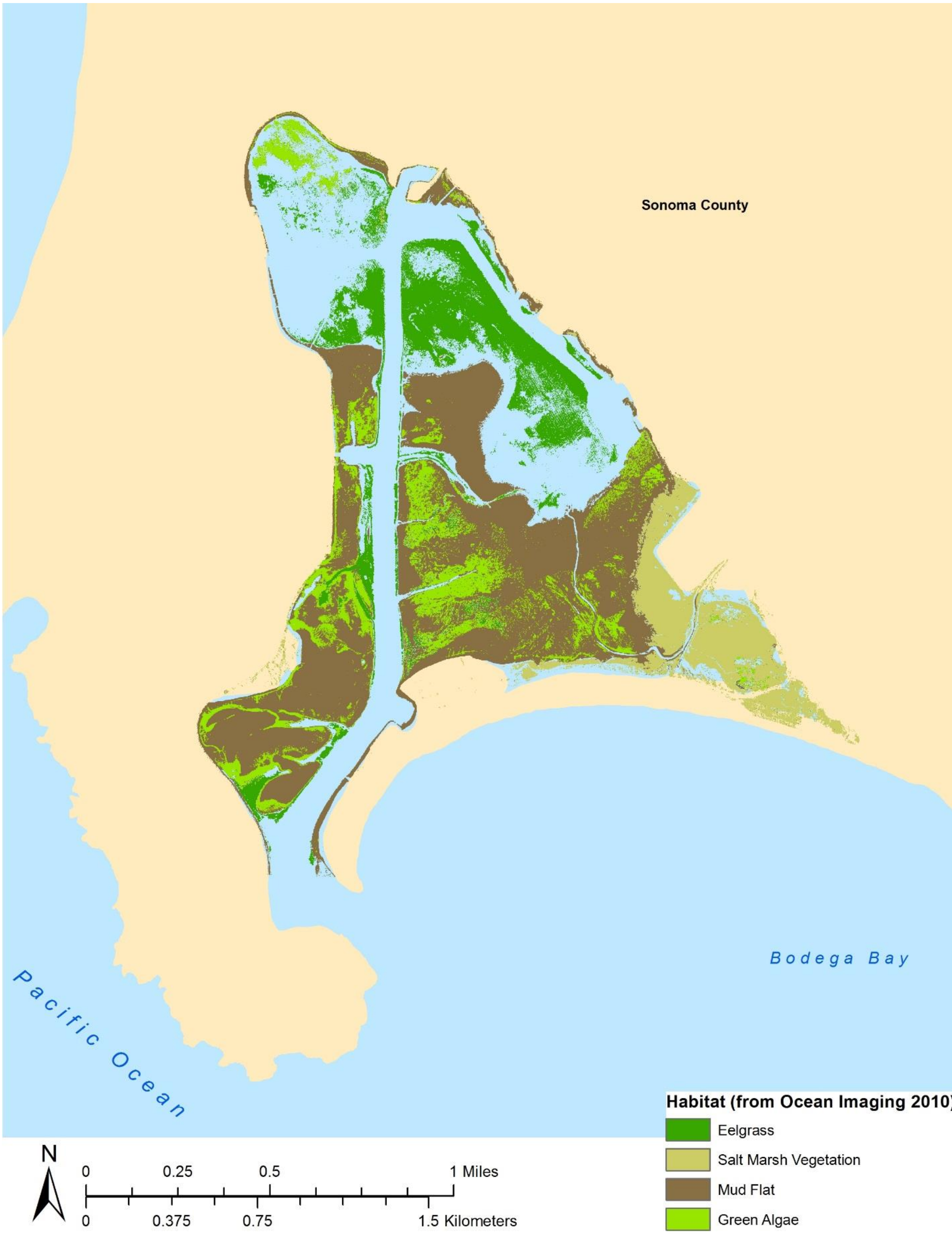



Figure D10. Eelgrass and other habitat types in Bodega Harbor.

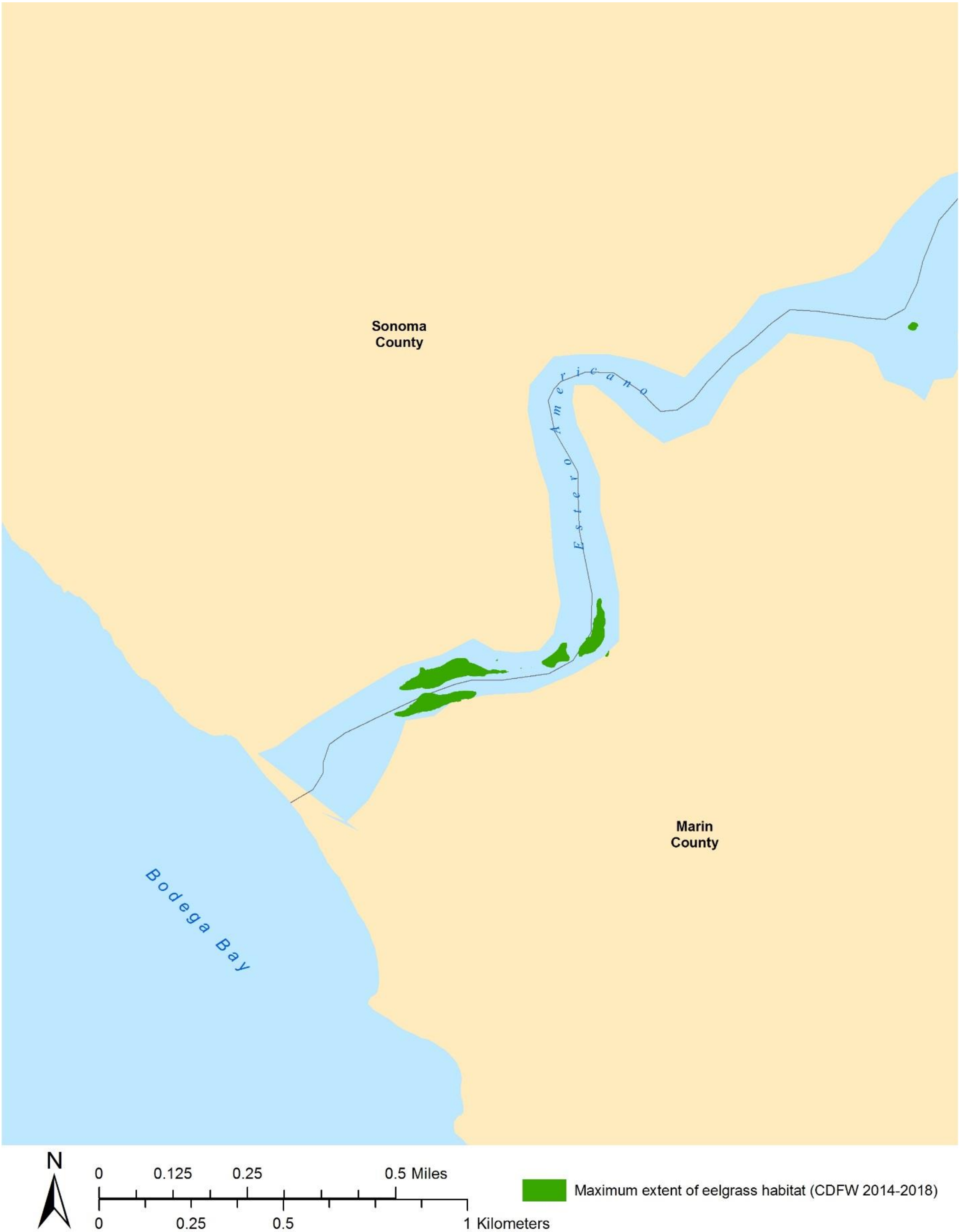



Figure D11. Eelgrass habitat in Estero Americano.


Figure D12. Eelgrass habitat in Estero de San Antonio.


Figure D13. Eelgrass habitat in Tomales Bay.


Figure D14. Eelgrass habitat in Drakes Estero and Estero de Limantour.

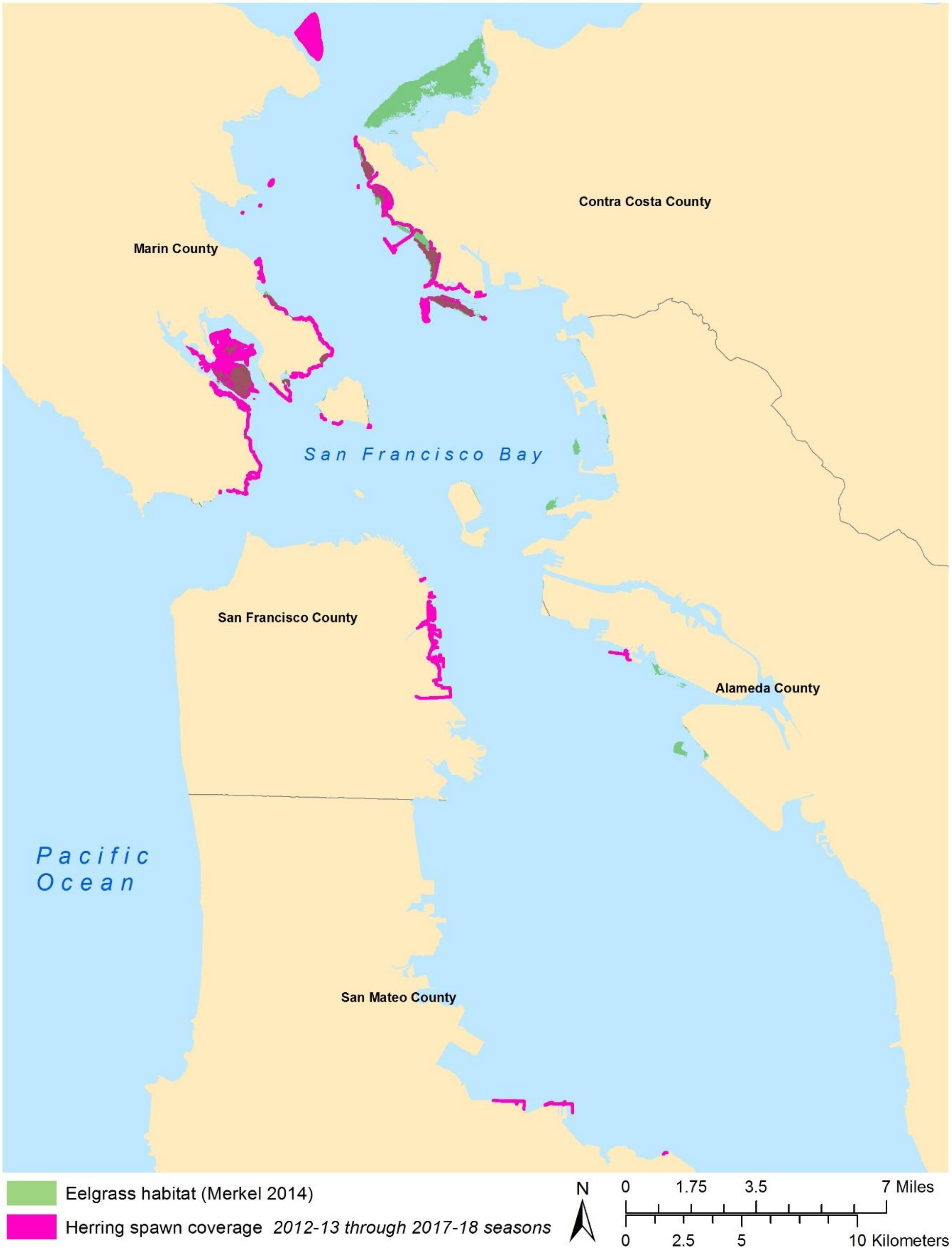



Figure D15. Eelgrass habitat and Herring spawn coverage in San Francisco Bay.

Figure D16. Eelgrass habitat in Elkhorn Slough (Wasson and others, 2019).

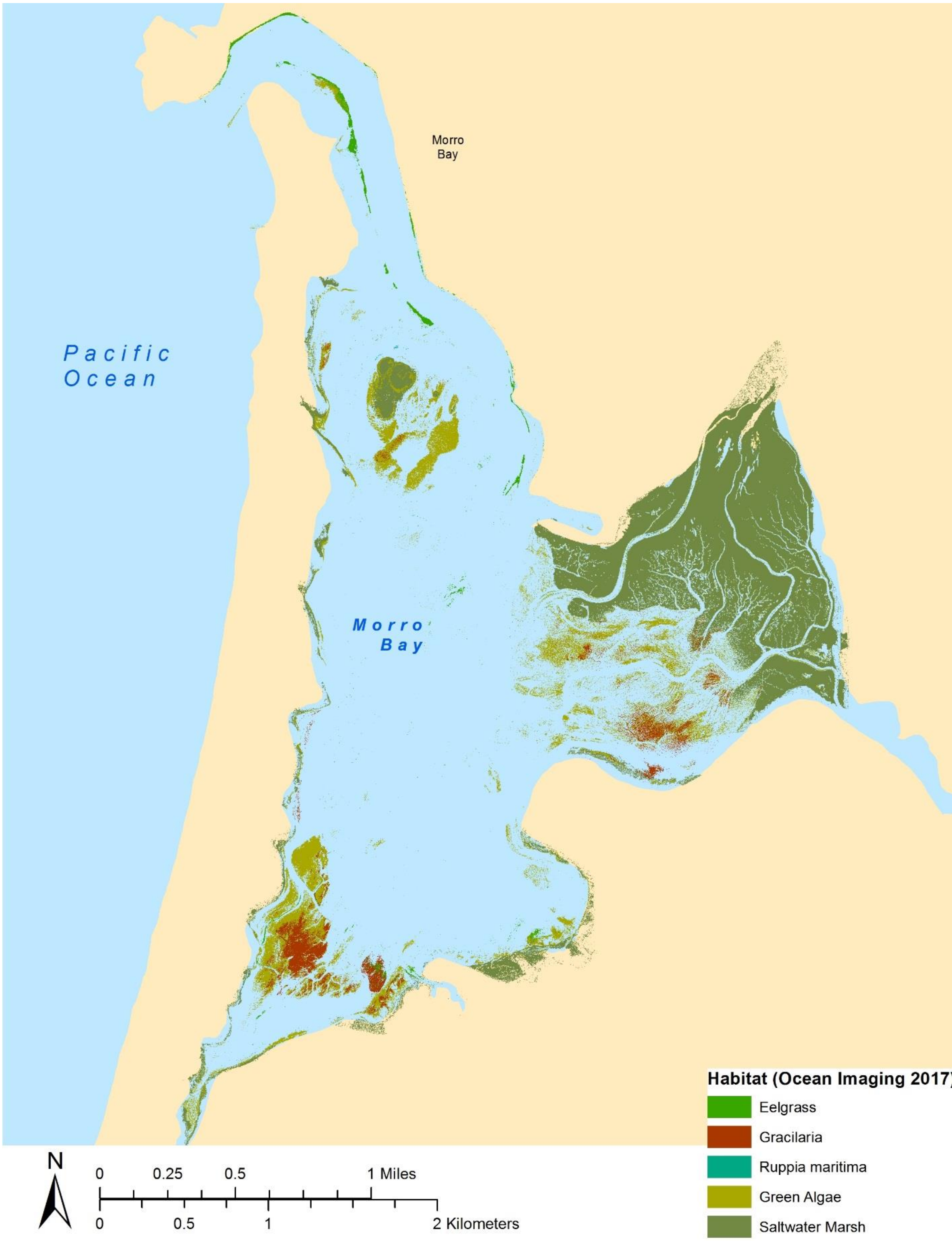



Figure D17. Eelgrass and other habitat types in Morro Bay.

# Appendix E Forecasting Herring Biomass in San Francisco 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.

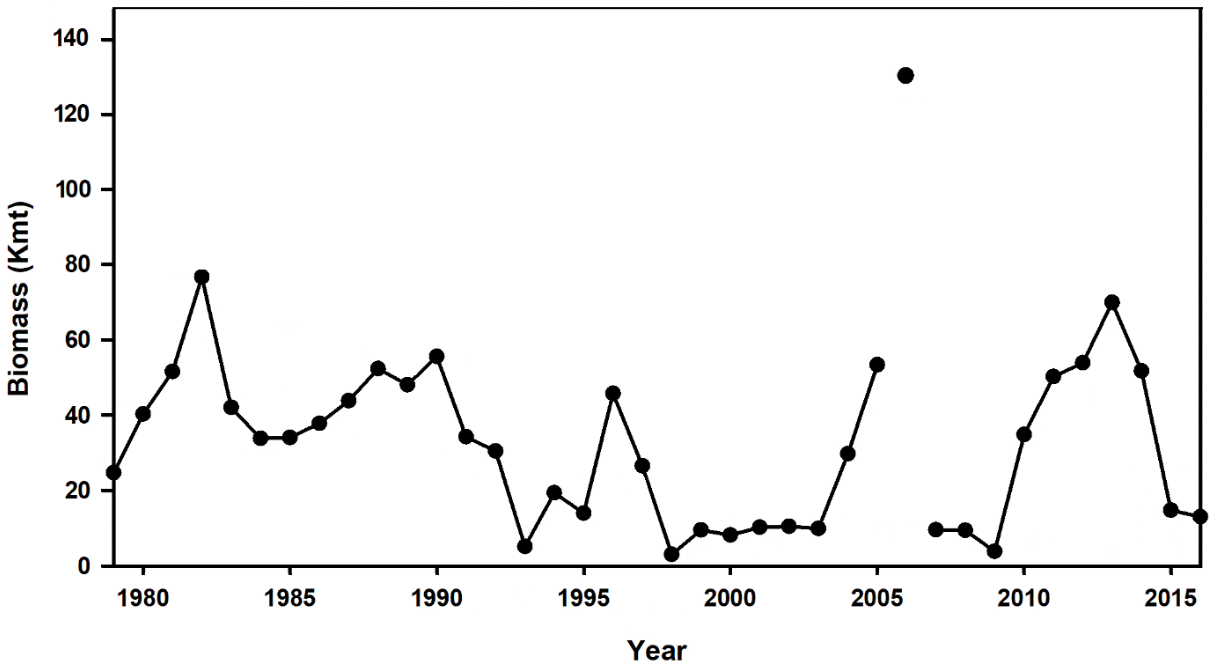



Figure E-1. Herring SSB in thousand metric tons (Kmt) for the San Francisco Bay estimated from egg deposition surveys, summed from December to March each year. Note: These values are from a truncated season so are lower than those in the published Department report because they do not include some spawning 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" ($\rho$)) 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 $\rho$ can range from -1 to +1, and magnitude of $\rho$ 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 $\rho$ will be higher (closer to +1). In cases where one increases while the other decreases (a negative correlation), the magnitude of $\rho$ 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 |

| Data | Label | Period | Location | Units | Temporal resolution | Source |
|---|---|---|---|---|---|---|
| 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 three-factor models out-performed simpler one- and two-factor models 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 69% compared to 77% to 119%) (Sydeman and others, 2018) (Table E-3). The three-factor model that provided the best prediction for the current year SSB included: $SSB_{yr-1}$, $YOY_{yr-3}$ and $SST_{(Jul-Sep)\ yr-1}$. Notably, current Department fishing quotas are based on $SSB_{yr-1}$.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 r2 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 |
|---|---|---|---|
| $SSB_{yr-1}$[1] | 0.57 | 3.36 | < 0.005 |
| $YOY_{yr-3}$[2] | 0.025 | 6.42 | < 0.0001 |
| $SSB_{yr-1}$[3] | 0.25 | 1.58 | 0.13 |
| $YOY_{yr-3}$ | 0.02 | 3.85 | < 0.001 |
| $SSB_{yr-1}$[4] | 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 |

[1] $SSB \sim SSB_{yr-1}$

$F_{1,22}$ = 11.3, p-value < 0.01, Adjusted $R^2$ = 0.31, AIC = 204, Predictive Error = 119%

[2] $SSB \sim YOY_{yr-3}$

$F_{1,23}$ = 31.1, p-value < 0.0001, Adjusted $R^2$ = 0.56, AIC = 201, Predictive Error = 77%

[3] $SSB \sim SSB_{yr-1} + YOY_{yr-3}$

$F_{2,21}$ = 16.6, p-value < 0.0001, Adjusted $R^2$ = 0.58, AIC = 193, Predictive Error = 81%

[4] $SSB \sim SSB_{yr-1} + YOY_{yr-3} + SST_{(Jul-Sep)\ yr-1}$

$F_{3,20}$ = 15.9, p-value < 0.0001, Adjusted $R^2$ = 0.66, AIC = 189, Predictive Error = 69%

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.

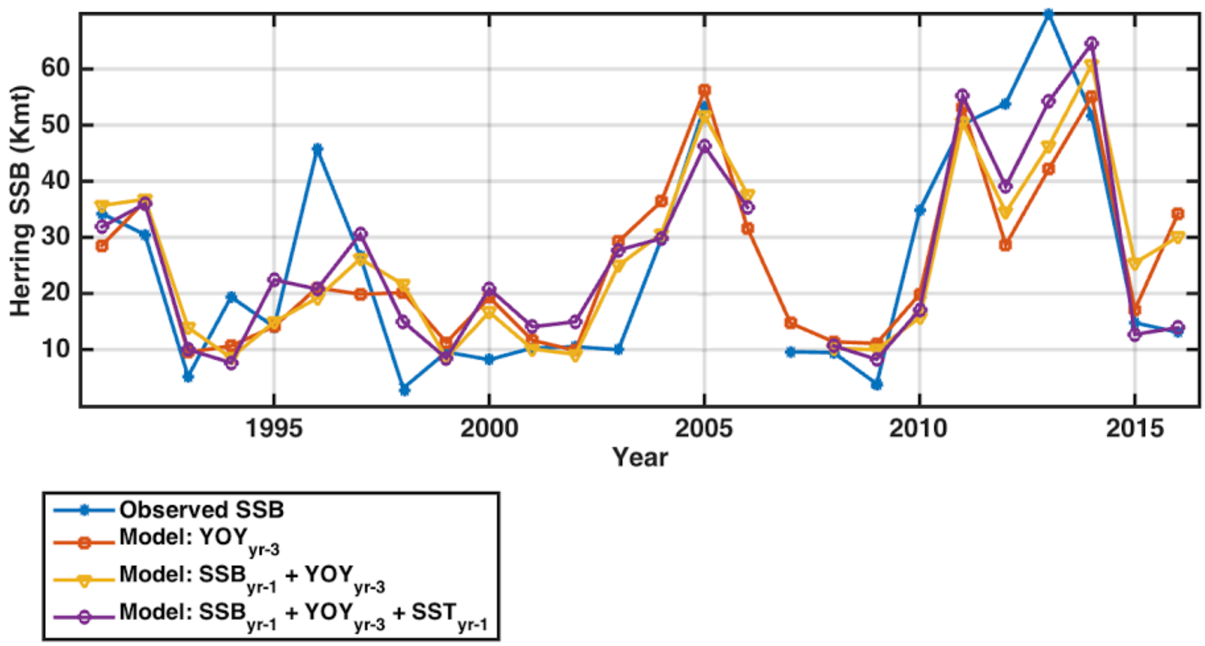



Figure E-3. Observed and modeled San Francisco Bay Herring SSB time series for 1991 to 2016. Note: There is no observation for 2006 since it was identified as an outlier during analysis. Observed biomass is shown in blue and other colors indicate the different models for biomass that include the terms 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) + ($SST_{(Jul-Sep)\ 2017}$ * -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.
$SSB \sim SSB_{yr-1} + YOY_{yr-3} + SST_{(Jul-Sep)\ yr-1}$
$F_{3,20} = 15.9$, 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 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-1Known 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).

| **Species** | **Percent** |
|---|---|
| Spiny Dogfish | 29% |
| Humpback Whale | 13% |
| Pacific Hake adults | 11% |
| Black Rockfish | 10% |
| Chinook Salmon | 9% |
| Coho Salmon | 9% |
| Caspian Tern | 7% |
| Common Murre | 7% |
| Northern Fur Seal | 7% |
| Rhinoceros Auklet | 6% |
| Harbor Seal | 5% |
| California Sea Lion (*Zalophus californianus*) | 4% |
| Double-Crested Cormorant | 2% |
| Jack Mackerel | 2% |
| Fin Whale | 2% |
| Harbor Porpoise | 2% |
| Sperm Whale | 2% |
| Marbled Murrelet | 2% |
| Pacific Hake juveniles | 1% |
| Sablefish | 1% |
| Least Tern | <1% |
| Cassin's Auklet | <1% |
| Sooty Shearwater | <1% |
| L-B Common Dolphin | <1% |
| S-B Common Dolphin | <1% |

B. Predators of adult Herring not assessed in Szoboszlai and others (in revision) study.

| Species |
|---|
| Ancient Murrelet |
| Arctic Loon |
| Arrowtooth Flounder |
| Bat Ray |
| Blue Shark |
| Bonaparte's Gull |
| Brandt's Cormorant |
| California Gull |
| Chum Salmon |

| |
|---|
| Common Merganser |
| Copper Rockfish |
| Cutthroat Trout |
| Dall's Porpoise |
| Glaucous-Winged Gull |
| Gray Smoothhound |
| Gray Whale |
| Jumbo Squid |
| Lingcod |
| Mew Gull |
| Orca Whale |
| Pacific Cod |
| Pacific White-Sided Dolphin |
| Pelagic Cormorant |
| Pigeon Guillemot |
| Red-Breasted Merganser |
| Sei Whale |
| Shortspine Thornyhead |
| Soupfin Shark |
| Steller Sea Lion |
| Western Grebe |
| Western Gull |
| Yelloweye Rockfish |
| Yellowtail Rockfish |

C) Spawn-eating predators (Bayer, 1980; Weathers and Kelly, 2007).

| **Species** |
|---|
| American Coot |
| American Widgeon |
| Barrow's Goldeneye |
| Black Brant |
| Black Scoter |
| **Bonaparte's Gull** |
| **Brandt's Cormorant** |
| Bufflehead |
| Canvasback |
| Common Goldeneye |
| Common Loon |
| Eurasian Wigeon |
| **Glaucous-Winged Gull** |
| Greater Scaup |

| |
|---|
| Harlequin Duck |
| Hooded Merganser |
| Horned Grebe |
| Lesser Scaup |
| Long-Tailed Duck |
| Mallard |
| **Mew Gull** |
| Northern Pintail |
| **Pelagic Cormorant** |
| **Red-Breasted Merganser** |
| Redhead |
| Ring-Billed Gull |
| Ruddy Duck |
| Surf Scoter |
| **Western Grebe** |
| **Western Gull** |
| White-Fronted Goose |
| White-Winged Scoter |

## 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

| 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.

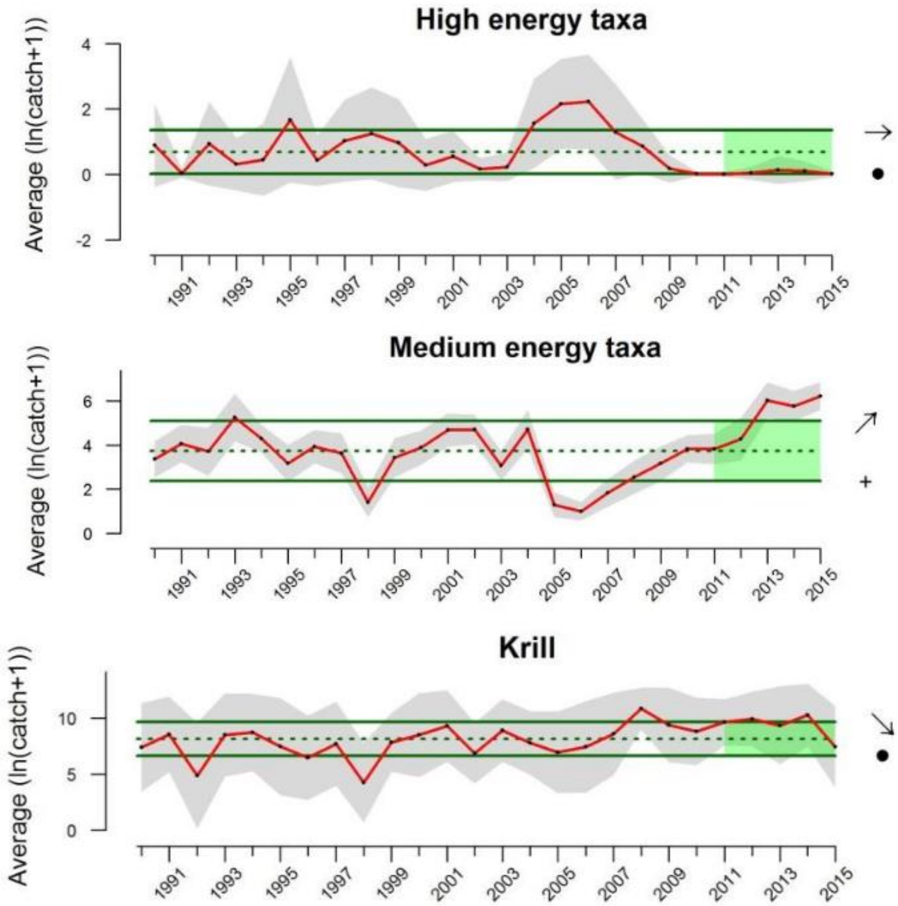



Figure F-1. Geometric mean CPUEs (#/haul) of key forage groups in the central CCE. High energy taxa includes sardine and anchovy, while medium energy taxa includes Market Squid and YOY groundfish. Horizontal lines show the mean (dashed line) ± 1.0 s.d. (solid lines) of the full time series. Arrows at 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.

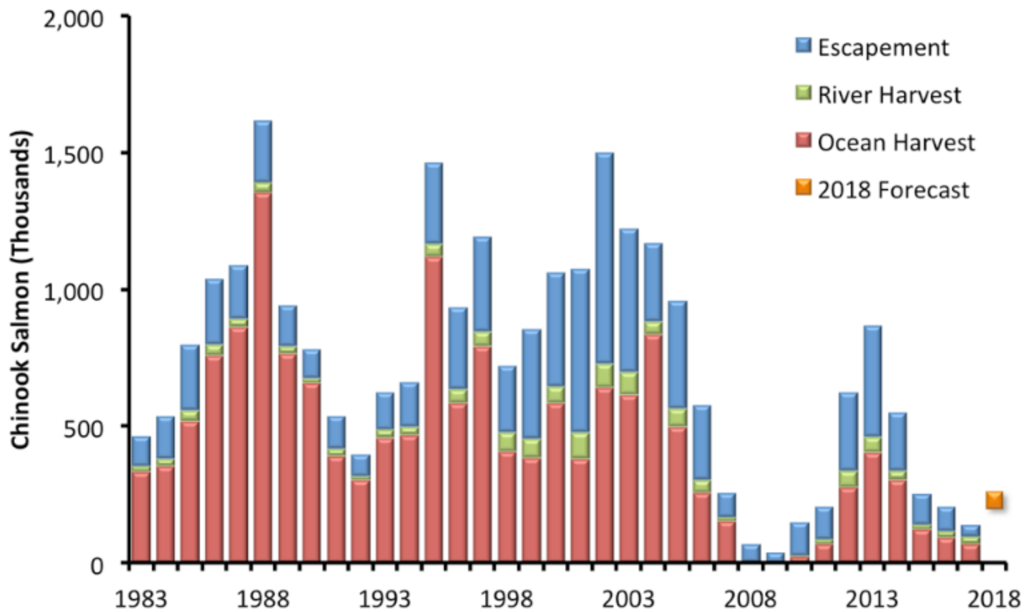


Figure F-2. Sacramento River fall-run Chinook Salmon population index, composed of escapement, river harvest, and ocean harvest (Reproduced from https://fishbio.com/field-notes/the-fish-report/poor-returns-2017-salmon-season).

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 F-7. Decision tree to assess predator-prey conditions in the central CCE.

| | | | |
|---|---|---|---|
| **Herring** | 1. Is the biomass estimate greater than 20,000t? | **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 < 40,000t? | **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 < 40,000t? | **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 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 < 40,000t? | **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. |

## 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

This document omits appendices B, C, I, K, L, O, and the majority of appendix Q, which cannot be formatted for online accessibility. Please contact CDFW for a formal copy that includes these missing appendices.

# 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 | -- |

| Season | Sector | Number of Permits | Sector Quota | Notes |
|---|---|---|---|---|
| -- | 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[1] | | 5 (product) |
| **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) |

| Season | Sector | Number of Permits | Sector Quota | Notes |
|---|---|---|---|---|
| -- | 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 | -- |

| Season | Sector | Number of Permits | Sector Quota | Notes |
|---|---|---|---|---|
| -- | 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) |

| Season | Sector | Number of Permits | Sector Quota | Notes |
|---|---|---|---|---|
| -- | 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) |

[1]Two of the roe-on-kelp permittees were the successful bidders for allotments (A and B).

## Appendix K History of Round Haul Elimination

This document omits appendices B, C, I, K, L, O, and the majority of appendix Q, which cannot be formatted for online accessibility. Please contact CDFW for a formal copy that includes these missing appendices.

# Appendix L Mesh Size Changes and Rationale

This document omits appendices B, C, I, K, L, O, and the majority of appendix Q, which cannot be formatted for online accessibility. Please contact CDFW for a formal copy that includes these missing appendices.

## 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.

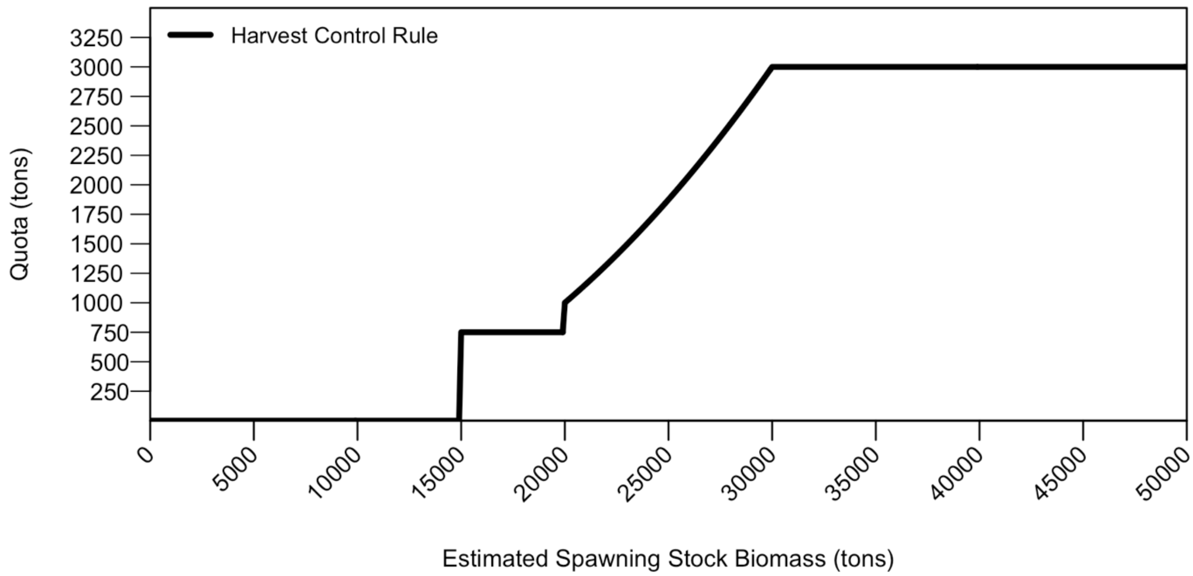



Figure M-1. Agreed on HCR for San Francisco Bay Herring.

**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 socioeconomic 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 |
| Natural mortality | 3 | Variable M | M varies from year to year within each simulation (sd between 0.0 and 0.1) |
| Natural mortality | 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 |
| Selectivity relative to maturity | 6 | Selectivity matches maturity | Assumes San Francisco Bay Herring mature earlier than BC Herring, and that all mature fish are vulnerable to the gear |
| Selectivity relative to maturity | 7 | Domed selectivity | Assumes that selectivity is domed shaped |
| Selectivity relative to maturity | 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 |
| Productivity | 10 | Lower Autocorrelation | Assumes that autocorrelation in recruitment deviations is lower |
| Productivity | 11 | High Autocorrelation | Assumes that autocorrelation in recruitment deviations is higher |
| Productivity | 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 |
| Observation error | 16 | Negatively Biased | Assumes the survey routinely underestimates the true SSB |
| Observation error | 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).

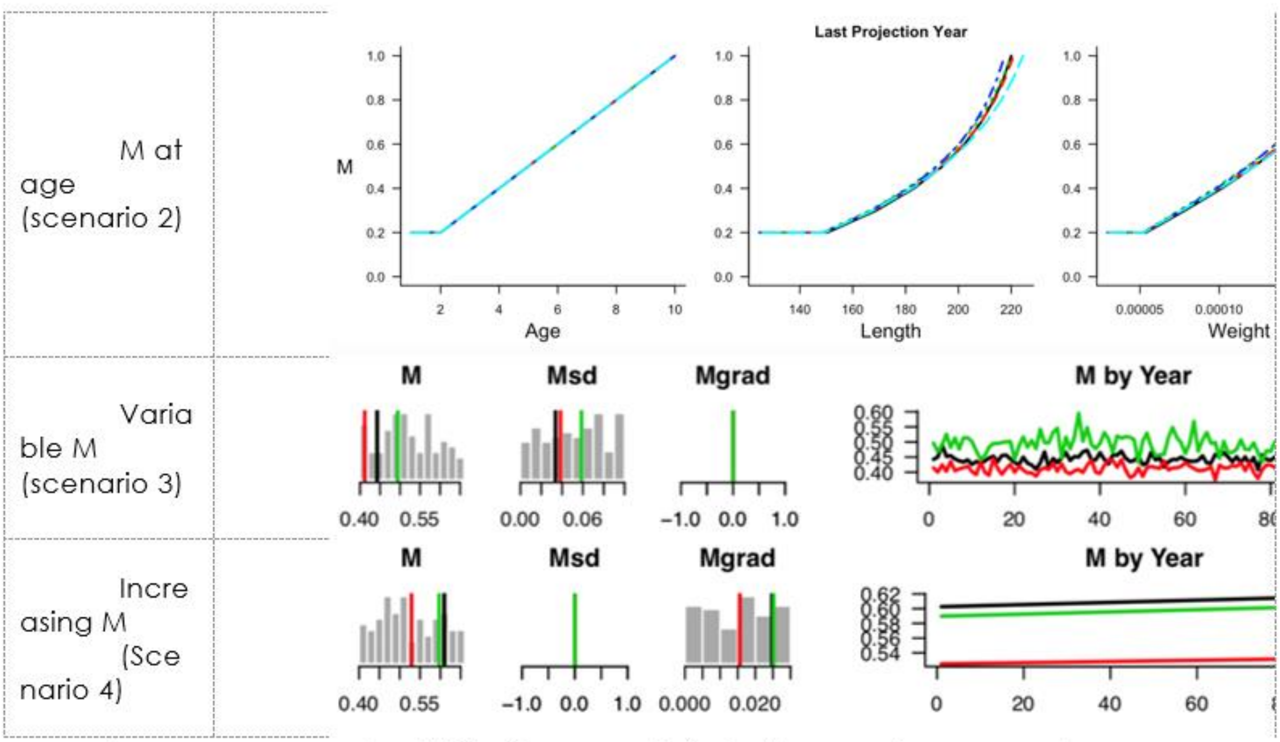



Figure M-2. Parameter distributions associated with scenarios 2, 3, and 4.

## 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).

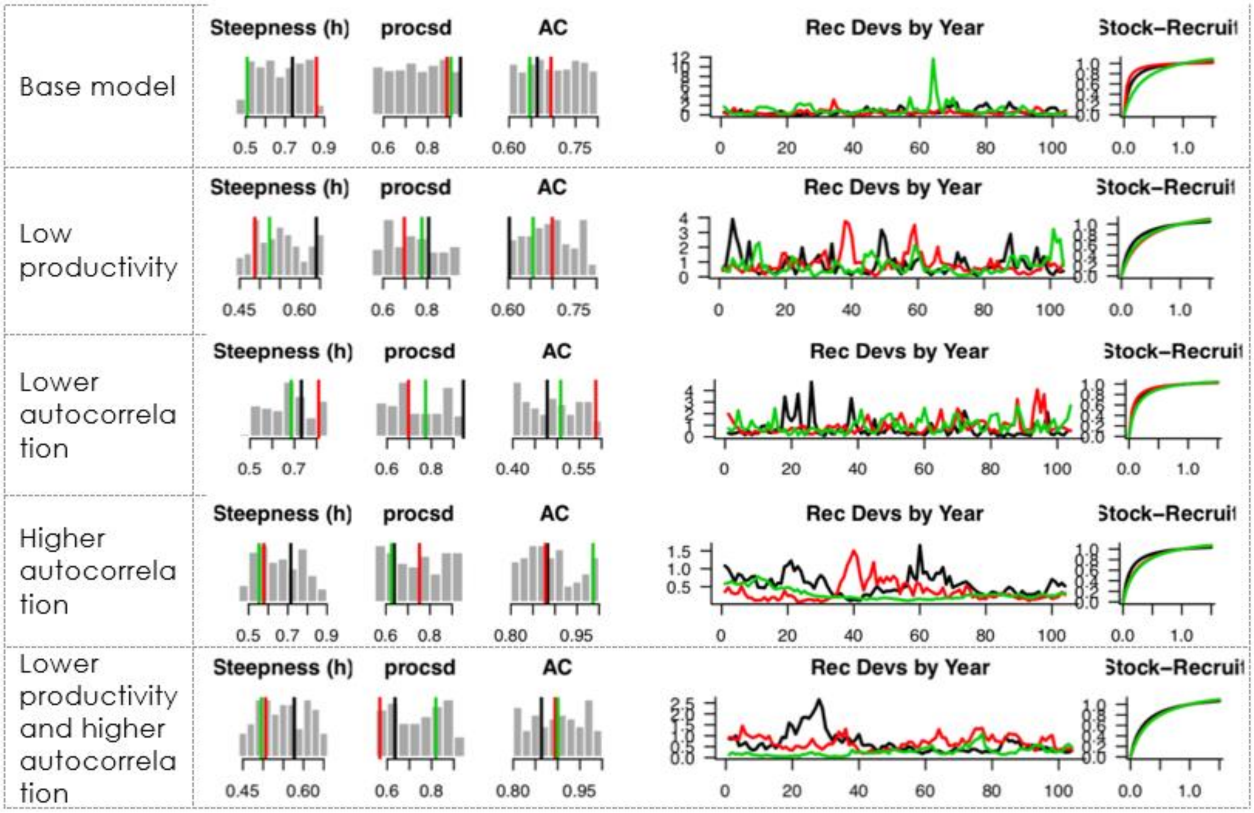


Figure M-3. Parameter distributions associated with Scenarios 1 and 9-12.

## 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).

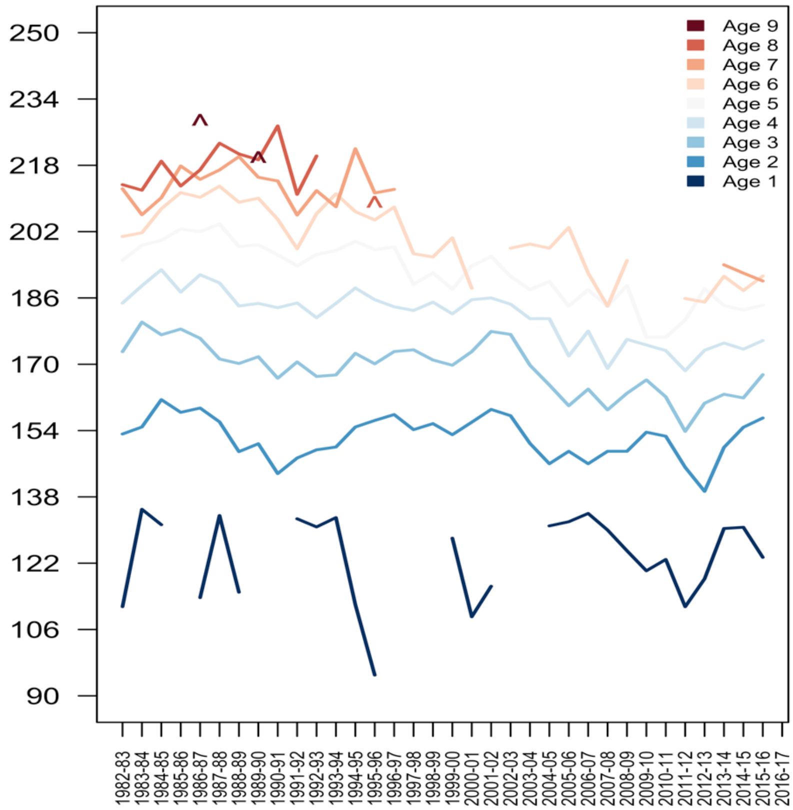



Figure M-4. Mean length at age of San Francisco Bay Herring observed in the research catch between 1982-83 and 2016-17.

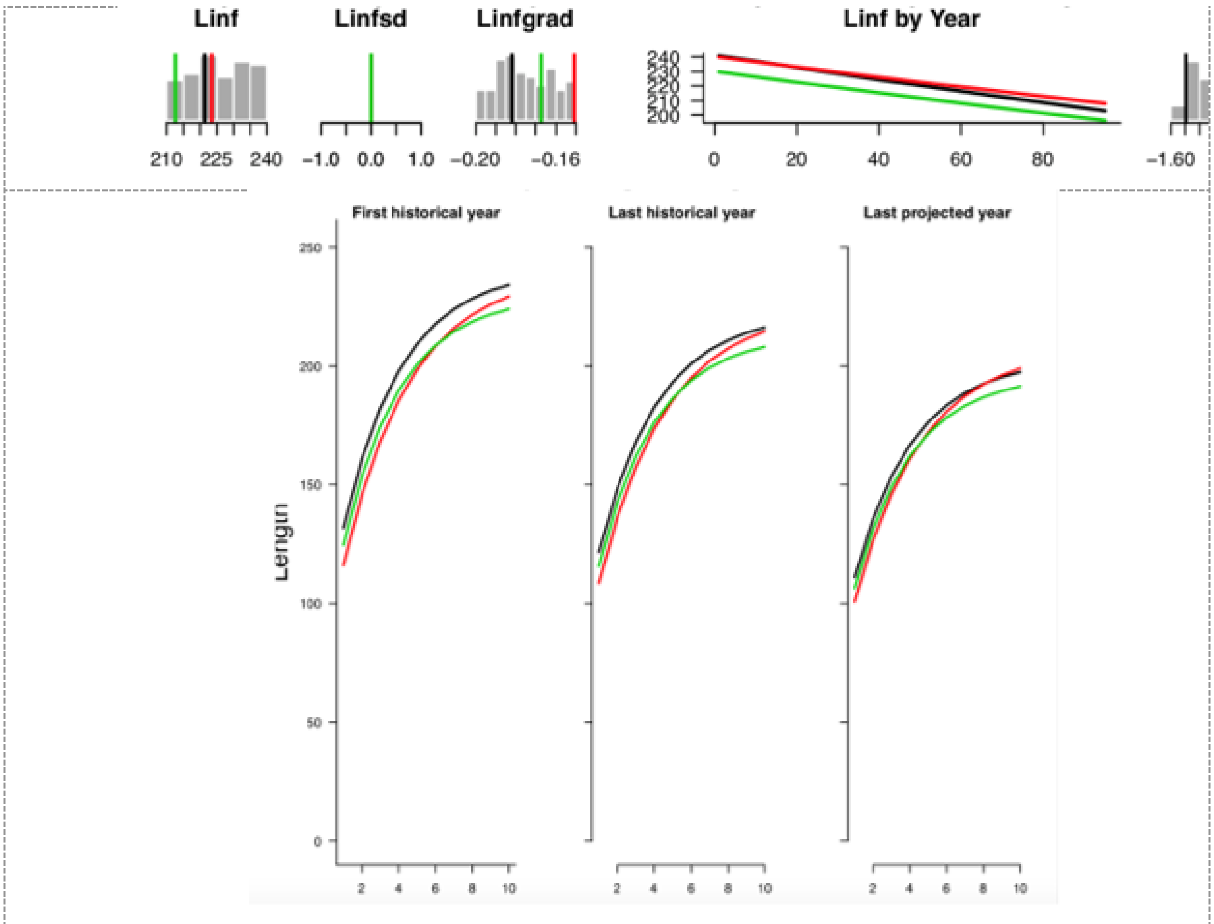


Figure M-5. Sampled growth parameters for decreasing growth (top panel), and the derived length at age for three random samples in the first historical year, last historical year, and last year of the projected simulations.

## 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).

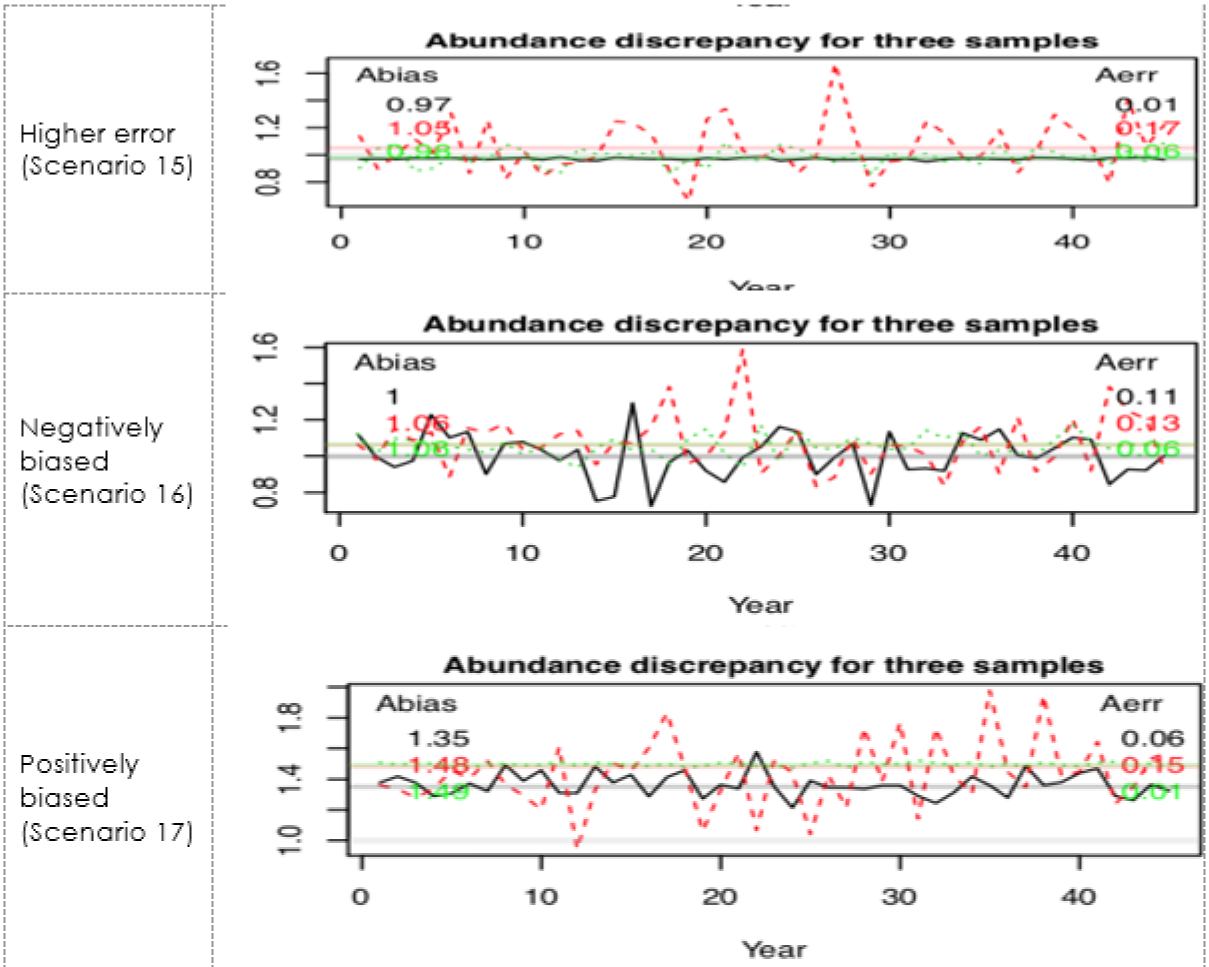



Figure M-6. Randomly drawn sample illustrating different functional forms of observation error.

## Candidate HCRs

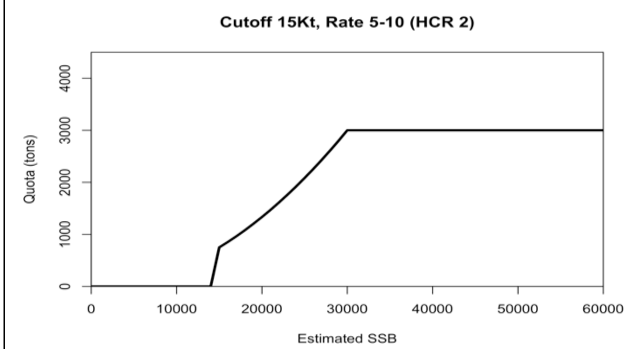
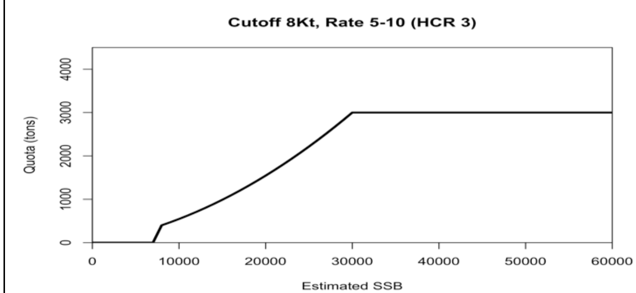
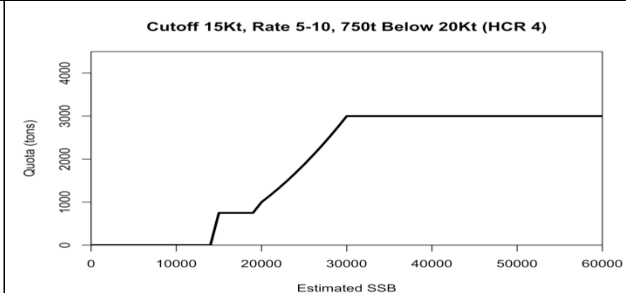
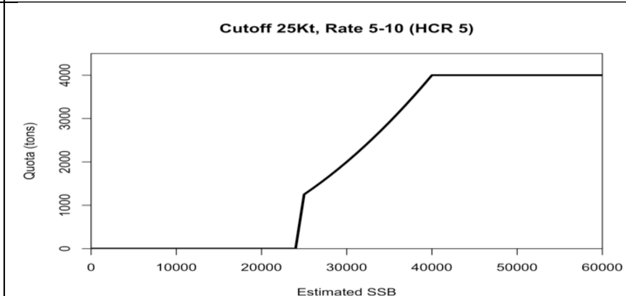
In the early phase of this project we explored a wide range of HCR formulations that met the criteria agreed upon by the SC. These included HCRs with harvest rates that ramped up to meet their target (hockey stick formulation), HCRs with only two harvest rates depending on whether the stock was above 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.

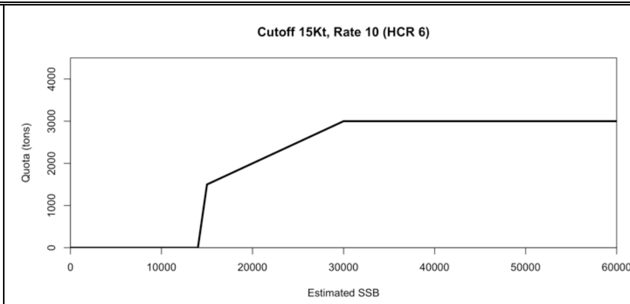
In this analysis we present the results of seven different potential HCRs (Table M-3). HCR 1 is Total Allowable Catch (TAC) that is permanently set to zero, which provides context about the probability of achieving targets and limits even under no harvest, and HCR 7 is fishing at the fishing mortality 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.

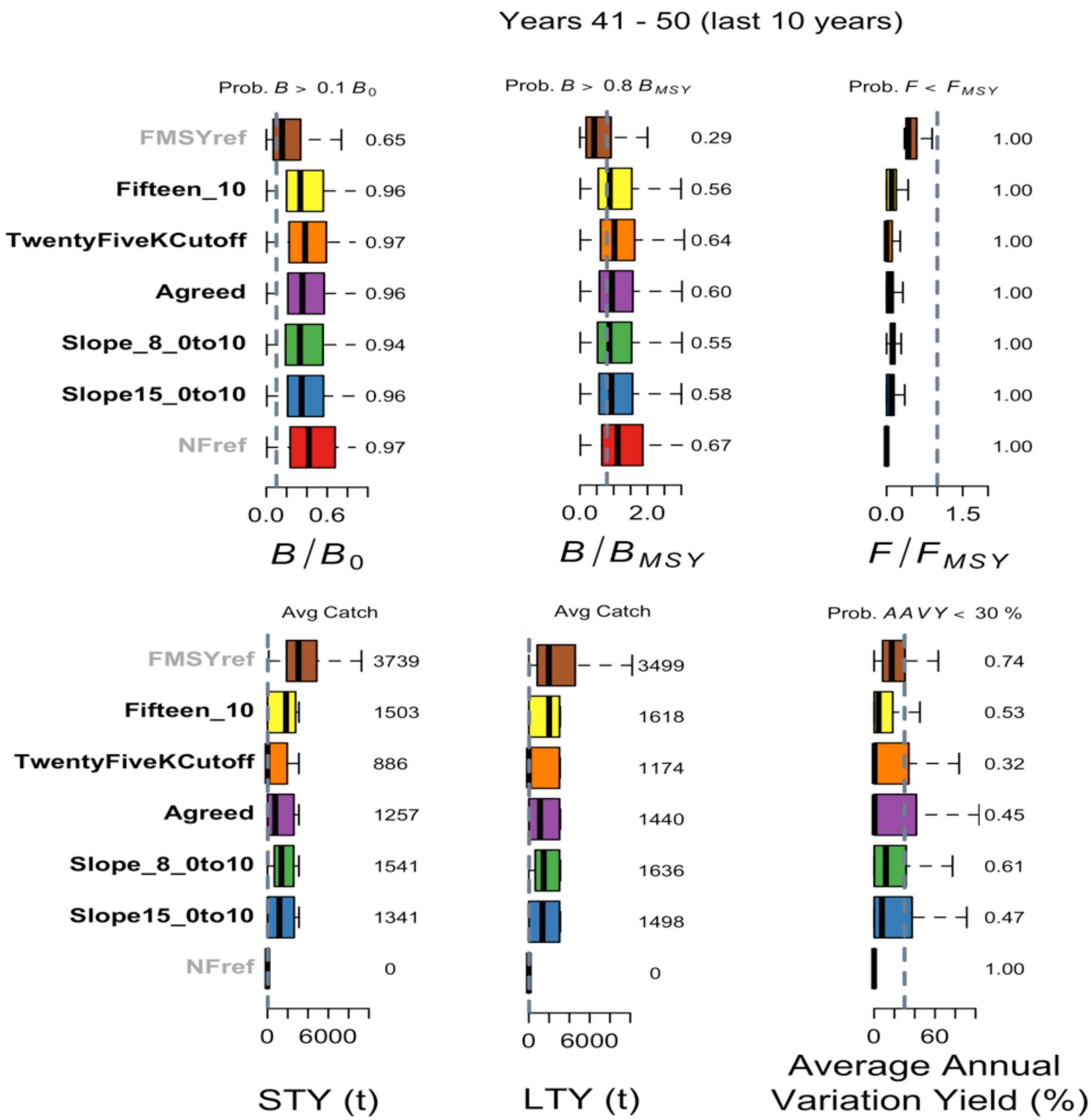



Figure M-7. Boxplots of performance metrics under the base model assumptions. The vertical dashed lines represent performance matrix thresholds.

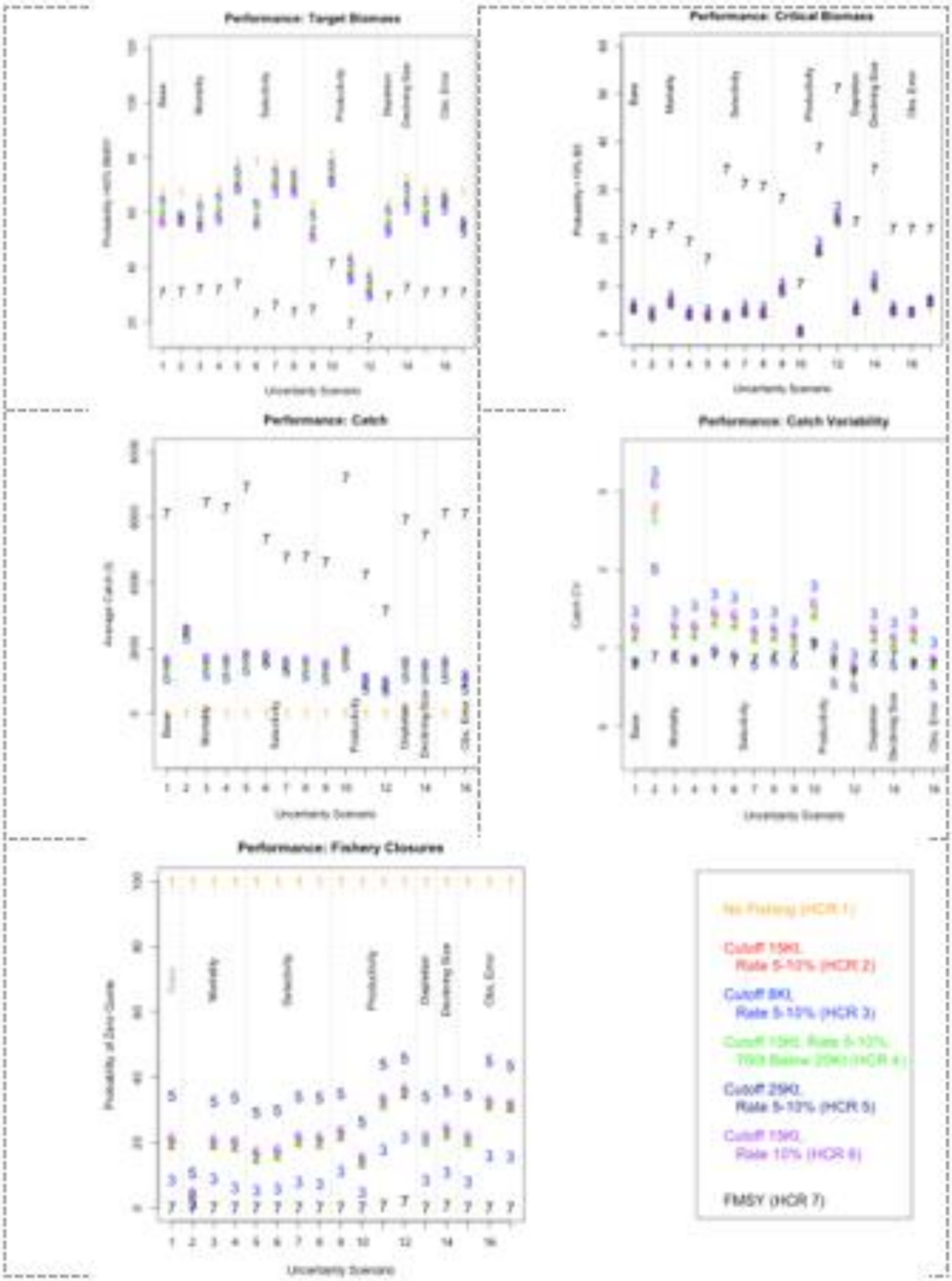



Figure M-8. Performance metrics across all 17 uncertainty scenarios.

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., $\tilde{\sigma}_i$). Hence, each parameter or variable denoted with a tilde represents a sample from a distribution. For example, the symbol $\tilde{\sigma}_i$ 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 $\theta$: $p = opt(\Delta \mid \theta)$. For example $q = opt(\widetilde{D}|E, \widetilde{M}, \tilde{R}_0)$ represents optimization of the catchability *q* in order to obtain depletion $\widetilde{D}$ given fishing effort *E*, natural mortality rate $\widetilde{M}$ and unfished recruitment $\tilde{R}_0$ (where $\widetilde{D}$, $\widetilde{M}$ 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. $\mathrm{Ny+1, a+1} = \sum \mathrm{N_{y,a,k}}\, \mathrm{e^{-Z_{y,a,k}}}$

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. $Ly, a = L_{y,\infty}\left(1 - \exp\left(-\kappa_y(a - t_0\right)\right)$

where $\kappa_y$ 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 $\beta$ 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 $\varepsilon_R$ 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 $\theta_{AC}$ 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 $\varepsilon_R$ 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 $\widetilde{D}$ (spawning biomass relative to unfished levels):

17. $q = opt(\widetilde{D} \mid E_y, s_{y,a}, R_a, \tilde{\theta}_{Mdisc}, M, \tilde{h}, W\ )$

Meeting the condition:

18. $\frac{S_c}{S_0} = \widetilde{D}$

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 $\omega_B$ 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 $\sigma_{bB}$ and therefore sampled values of $\tilde{b}_B$ close to 1) or a biased (e.g. high $\sigma_{bB}$ 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

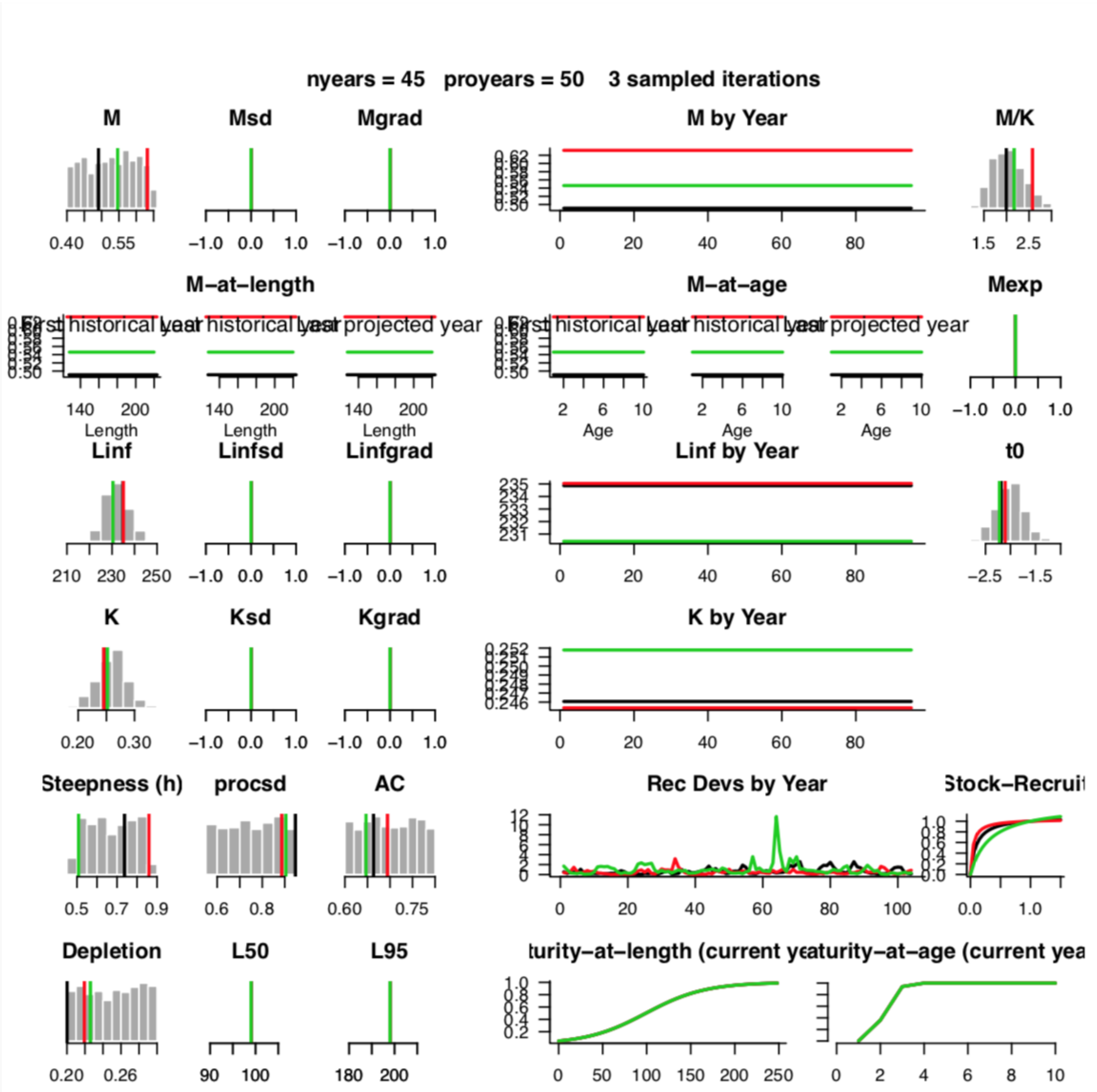



Figure M-B-1. Sampled derived biological parameters for San Francisco Bay Herring under the base model assumptions.

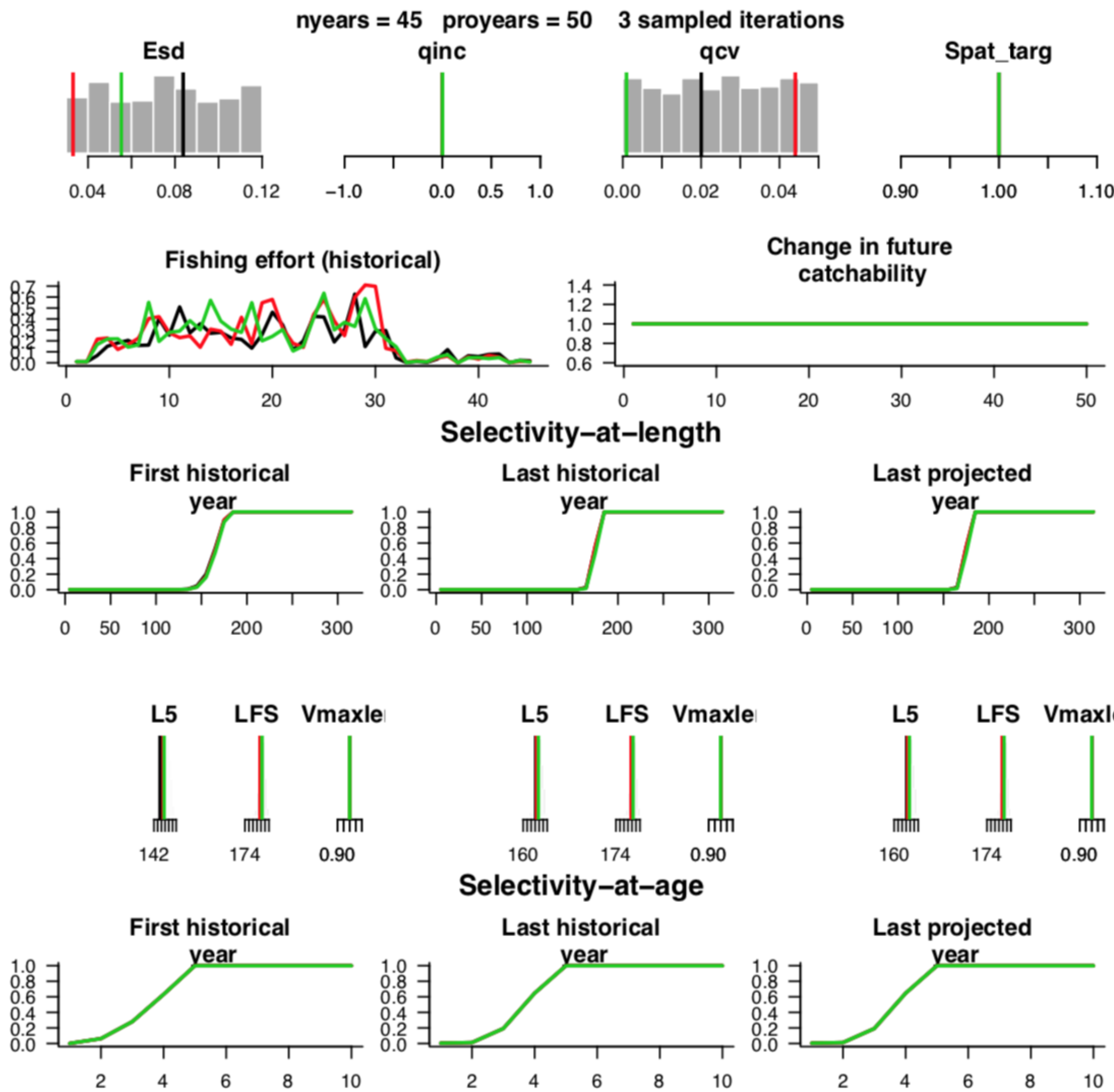



Figure M-B-2. Sampled and derived fleet parameters for San Francisco Bay Herring under the base model assumptions.

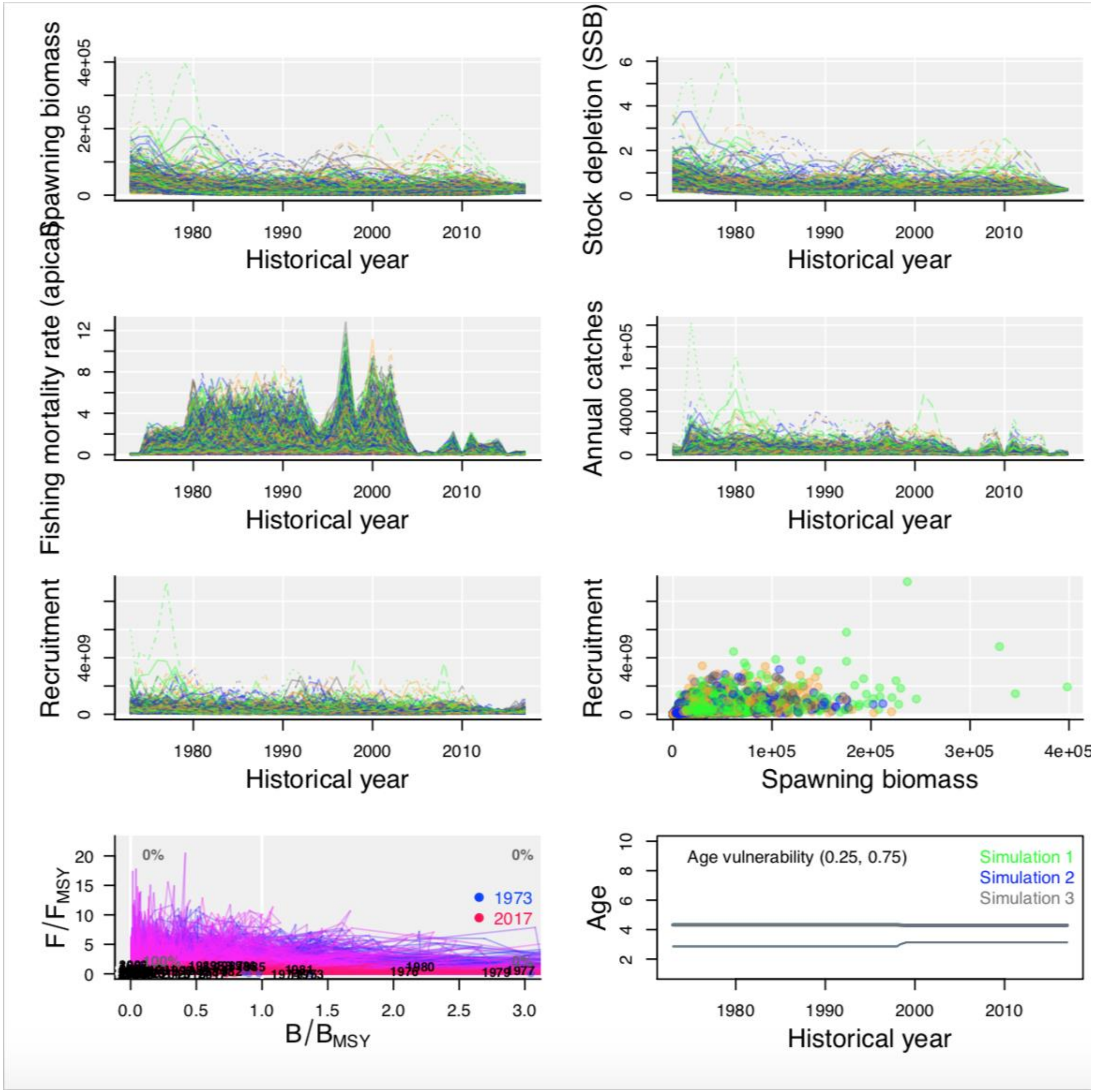



Figure M-B-3. Historical simulations under base model assumptions.

# Appendix N Herring Eggs on Kelp 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.

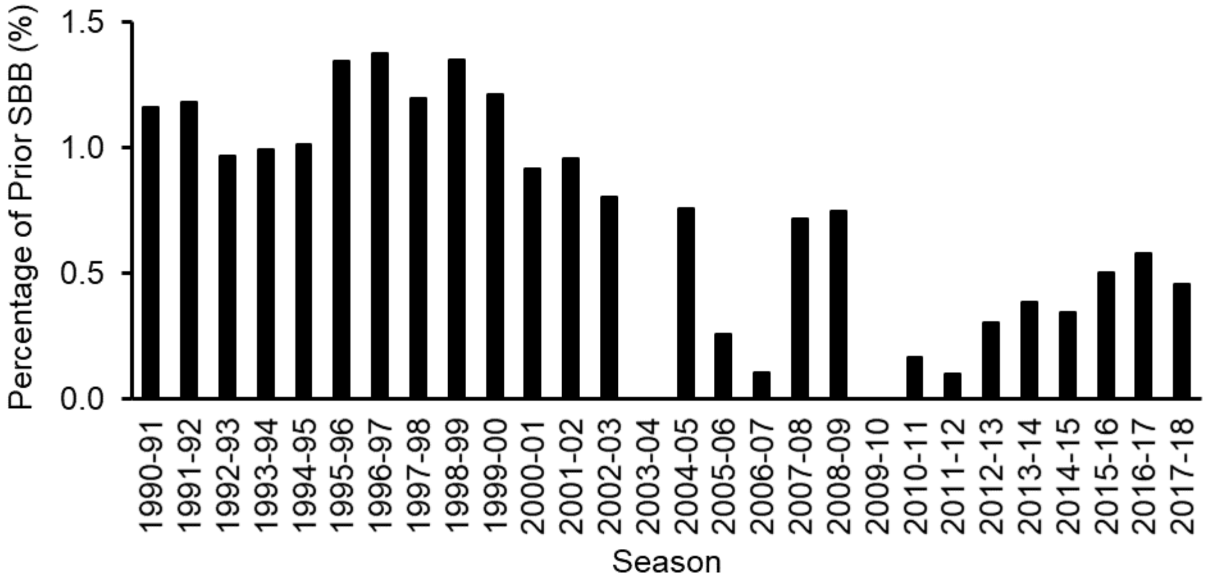



Figure N-1. HEOK quota as a percentage of the previous season SSB estimate from the 1990-91 to 2017-18 season. Note that in the 2003-04 season there was no SSB estimate available, and in the 2009-10 season the fishery was closed.

**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).

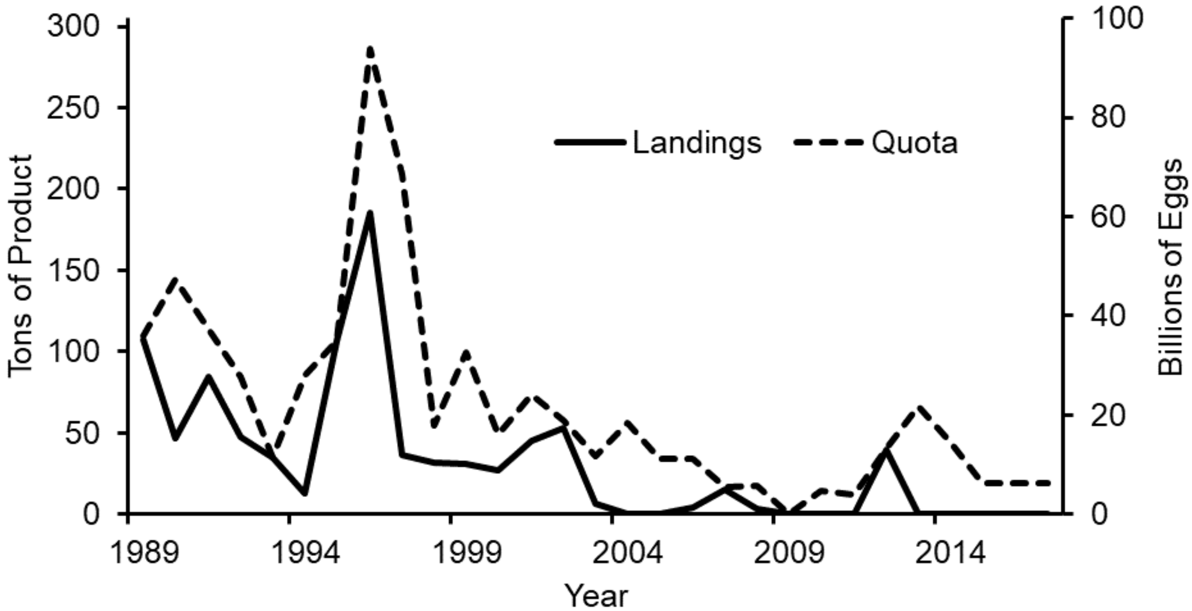



Figure N-2. Historical HEOK landings and quota in tons of product (left axis) and billions of eggs (right axis) between the 1989-90 season and the 2017-18 season. Note there has been no HEOK fishing since the 2012-13 season.

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

This document omits appendices B, C, I, K, L, O, and the majority of appendix Q, which cannot be formatted for online accessibility. Please contact CDFW for a formal copy that includes these missing appendices.

## 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 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 Fishery Management Plan Scoping Process, Stakeholder Involvement, and Public Outreach

This document omits appendices B, C, I, K, L, O, and the majority of appendix Q, which cannot be formatted for online accessibility. Please contact CDFW for a formal copy that includes these missing appendices

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 Committee (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.

## 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).

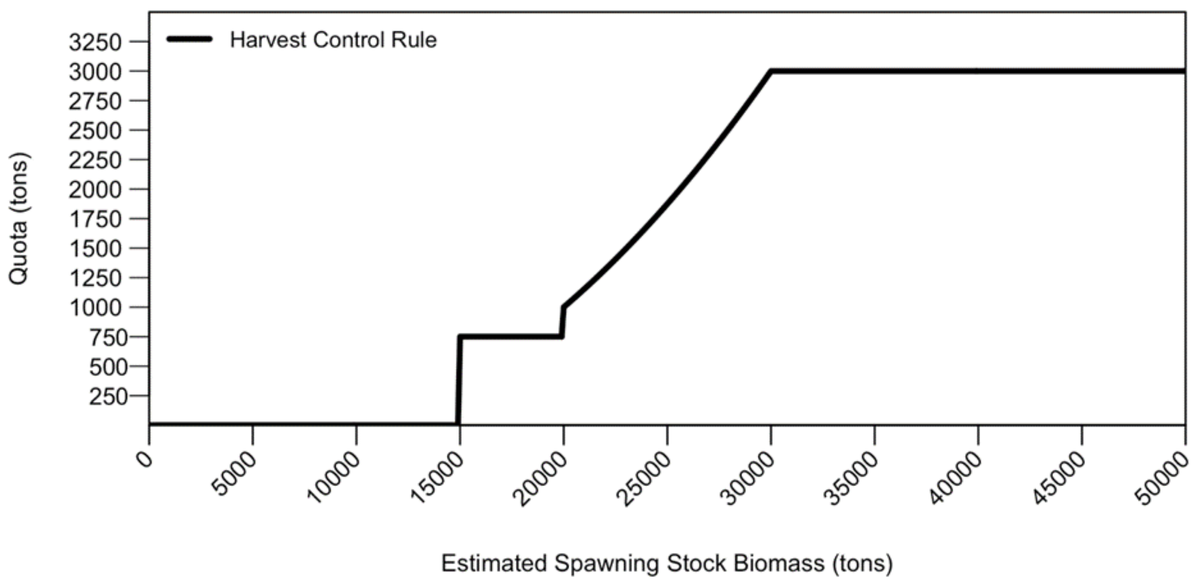



Figure R-1. Preferred Harvest Control Rule.

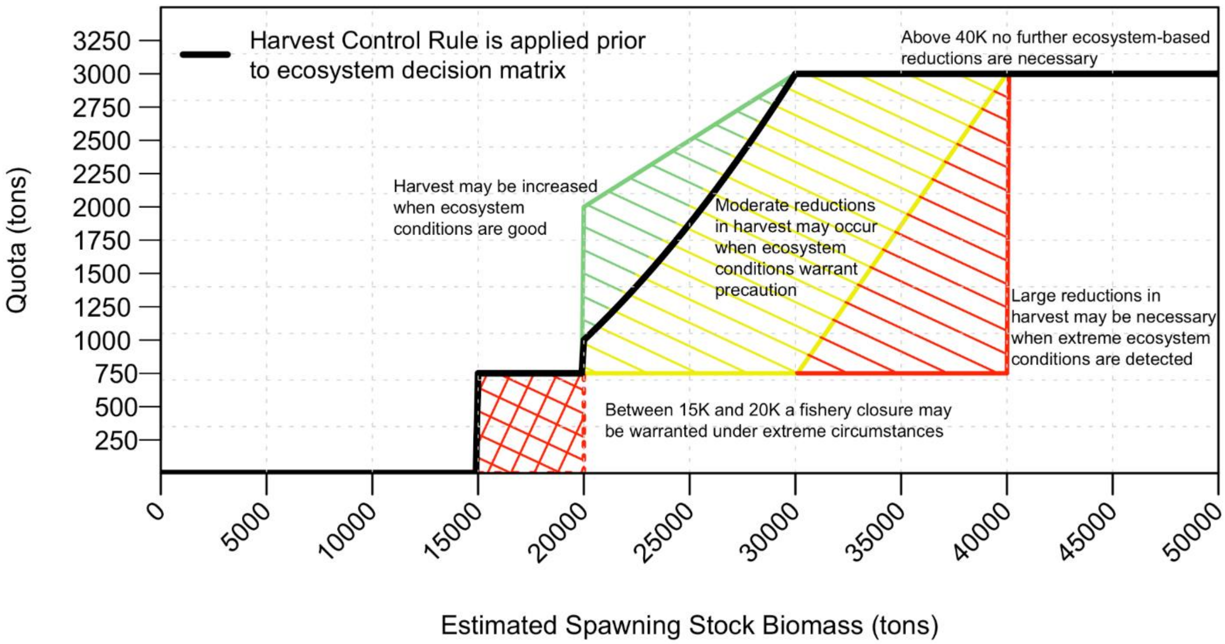



Figure R-2. Initial Harvest Control Rule framework, as proposed by the SC.

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 for adjusting quotas was not selected. 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.

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).

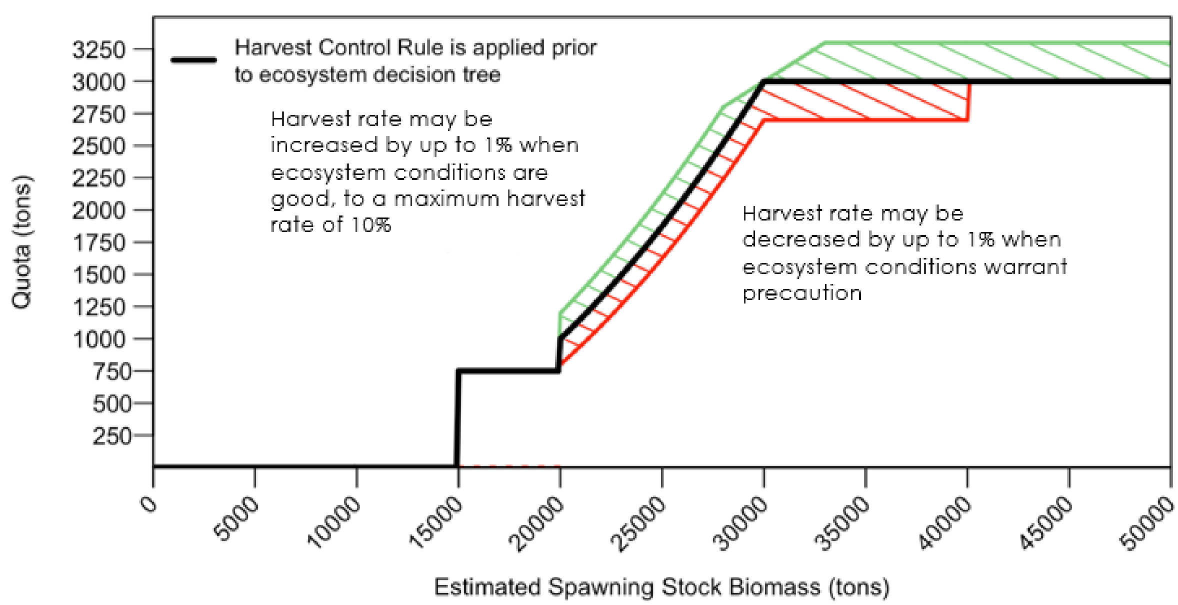



Figure R-3. Final Harvest Control Rule Framework.

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).

Adding 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.

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.

Implementation of a broader range of ecosystem-based adjustments to a management strategy could be achieved through an FMP amendment (Chapter 9). The peer review committee provided recommendations that can be used to build a transparent, quantitatively based, and tested ecosystem approach to improve the application of ecosystem indicators and the management of the fishery (Appendix O).

## Appendix S Public Comments Received, Responses, and Changes to the Draft California Pacific Herring Fishery Management Plan

The Draft California Pacific Herring Fishery Management Plan (Draft Herring FMP) was received by the California Fish and Game Commission (Commission) at their June 2019 meeting. This appendix presents summaries of public comments received by the Commission on the Draft Herring FMP during the public comment period, and California Department of Fish and Wildlife (Department) responses indicating how public comments were addressed (Table S-1). This appendix also summarizes all changes to the Draft Herring FMP (Table S-2), which includes corrections to minor errors, as well as changes made in response to public comments received.

The Final Draft Herring FMP was received by the Commission for adoption at its October 2019 meeting; additional changes as adopted by the Commission in response to public comments, and corrections to minor errors, are included in this appendix and summarized in Table S-3.

Table S-1. Summary of public comments received on the Draft Herring FMP and Implementing Regulations, and Department responses.

| Commenter Number | Commenter Name, Organization If Applicable, Comment Format, and Date | Herring FMP Section or New Title 14, CCR (Implementing Regulations) Section Referenced | Comment Summary | Response |
|---|---|---|---|---|
| 1 | **Edward Zeng**<br>Recreational Participant<br>Email dated 6/18/2019 | FMP Section 7.8.7; Title 14, CCR §28.62 | **1-a.** The Herring FMP proposes a daily limit of 100 lb. For reasons stated in email (missing spawn windows, health of Herring consumption, low gear requirement for recreational Herring take, low overall recreational catches), Mr. Zeng requests that the daily bag limit be raised to a minimum of 300 lbs. | There are not adequate data available to assess the magnitude of recreational Herring catches, so it is unknown if overall recreational Herring catches are low. The daily limit of 10 gallons was chosen to allow for a satisfying recreational experience for individuals while ensuring that total Herring harvest remains sustainable. |
| 2 | **Hua Bai**<br>Recreational Participant<br>Email dated 6/18/2019 | FMP Section 7.8.7; Title 14, CCR §28.62 | **2-a.** Although a recreational limit is useful to prevent excess take, it is not practical to require recreational participants to have a scale that can weigh 100 lbs., as this requires purchase of extra equipment. An easier rule could be a big cooler full of Herring. Cooler can be sized so it is around 100lb to 200lb. This limit is easy to implement by all parties. | The daily bag limit of ten gallons is equivalent to two 5-gallon buckets, which are commonly owned pieces of equipment that allow participants and enforcement to assess compliance without having to weigh the Herring. |

| Commenter Number | Commenter Name, Organization If Applicable, Comment Format, and Date | Herring FMP Section or New Title 14, CCR (Implementing Regulations) Section Referenced | Comment Summary | Response |
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| 3 | **Charlie Zhao**<br>Recreational Participant<br>Email dated 6/22/2019 | FMP Section 7.8.7; Title 14, CCR §28.62 | **3-a.** Because recreational take depends on targeting an ongoing spawning event, this type of fishing is typically a once-per-year opportunity. Mr. Zhao typically tries to take an entire year's worth of fish in a single trip (roughly equal to two 27-gal containers from Costco, for one-gallon zip lock bag consumption weekly for family all year). Even if people are commercializing recreational catch illegally, it does not affect ability of other recreational fishers to catch what they need. Mr. Zhao believes Herring are abundant, and that the commercial fishery takes much more, and has greater impact on population, than recreational take. There should not be a limit on rec take, and if there must be one, it should be set in volume for ease of measurement in field. Proposes 50 gallons as a reasonable limit if we must have one. | The ten-gallon bag limit presented in implementing regulations is in line with the Department's goal of maintaining a satisfying recreational experience for participants. Recreational fishing limits are not intended to supply participants with a weekly food source throughout the year. |

| Commenter Number | Commenter Name, Organization If Applicable, Comment Format, and Date | Herring FMP Section or New Title 14, CCR (Implementing Regulations) Section Referenced | Comment Summary | Response |
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| **3** | **Charlie Zhao** (Continued) | FMP Section 7.8.7; Title 14, CCR §28.62 | **3-b.** Setting a recreational limit on Herring disproportionately affects minorities because of much higher consumption of Herring among certain minority groups. As health care becomes more and more expensive and drags on the economy, Herring consumption should be encouraged instead of limited. | The Department is responsible for protecting the long-term sustainability of the Herring resource, to the extent possible, and to ensure that all of California's recreational participants can benefit from this resource for many years to come. |

| Commenter Number | Commenter Name, Organization If Applicable, Comment Format, and Date | Herring FMP Section or New Title 14, CCR (Implementing Regulations) Section Referenced | Comment Summary | Response |
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| 4 | **Alastair Bland**<br>Recreational Participant<br>Email dated 7/4/2019 | FMP Section 7.8.7; Title 14, CCR §28.62 | **4-a.** Concerned about proposal to limit recreational participants to two 5-gallon buckets or less per day. Four 5-gallon bucket (~150 lb) would be more reasonable than two buckets. A four-bucket limit would eliminate gross overtake, would remove incentive to illegally sell recreationally caught fish, would allow recreational participants to catch all that's needed for a year (share w/ family and friends) during a single spawn event. The Herring FMP's claim that recreational stakeholders expressed interest in 2-bucket limit misconstrues context of statement at 2018 Public Outreach meeting w/ stakeholders in Sausalito. Mr. Bland finds it personally offensive that commercial participants have called for tight limits on recreational catch, given that commercial fishery takes a far greater amount of Herring and sells for non-consumptive use, than recreational participants, who mostly eat their catch. | This limit allows recreational participants to take up to ten gallons (approximately 100 pounds or 520 fish) per person. Families that would like to retain a greater number of fish are able to have more people participate in fishing. All comments at the 2018 Sausalito meeting were recorded in order to accurately capture stakeholder feedback. |

| Commenter Number | Commenter Name, Organization If Applicable, Comment Format, and Date | Herring FMP Section or New Title 14, CCR (Implementing Regulations) Section Referenced | Comment Summary | Response |
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| 4 | **Alastair Bland**<br>Second email dated 7/5/2019 | FMP Section 7.8.7; Title 14, CCR §28.62 | **4-b.** Second comment letter further stressing that the Herring FMP's assertion that feedback from recreational sector informed proposed limit is essentially an overstatement. | Stakeholder feedback is an important part of the Herring FMP development process. All comments at the 2018 Sausalito meeting were recorded in order to accurately capture stakeholder feedback. Stakeholder support for the Department's proposed limit was expressed at this meeting and in follow up correspondence, in addition to some feedback that the limit should be higher. |
| 5 | **John Vogel**<br>Recreational Participant<br>Email dated 7/23/2019 | FMP Section 7.8.7; Title 14, CCR §28.62 | **5-a.** The proposed limit for recreational Herring harvest is too low. Recreational Herring is a unique fishery with opportunity to catch only once or twice a year. He understands the need to prevent over harvest, but is not aware of a significant number of recreational participants harvesting huge quantities for illicit commercialization or waste. Wants a five 5-gallon bucket as a limit. | The limit for recreational take allows participants to take up to ten gallons (approximately 100 pounds, or 520 fish) per person. Families that would like to maximize the amount of fish they take legally may choose to have more family members participate in fishing. While the Department understands that, due to the pulse nature of spawning events, there may be limited fishing opportunities in a season, this limit is designed to balance providing a satisfying recreational experience with the needs of the resource. |

| Commenter Number | Commenter Name, Organization If Applicable, Comment Format, and Date | Herring FMP Section or New Title 14, CCR (Implementing Regulations) Section Referenced | Comment Summary | Response |
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| 6 | **Bradley S. Cain**<br>Recreational Participant<br>Email dated 7/24/2019 | FMP Section 7.8.7; Title 14, CCR §28.62 | **6-a.** Displeased with 1 bucket limit for recreational take of Herring. 4 or 5-bucket limit is more reasonable. Spawning is unpredictable in nature and it is difficult for rec fishers to get to an active spawning event. Sometimes miss spawns entirely. When a decent spawn event can be effectively targeted, currently take enough to stock freezer for entire year's use (consumption and bait). One bucket would not allow this as it wouldn't last a year. Additionally, 1 bucket limit is overly restrictive given volume of commercial catch annually. Rec fishers do not impact fishery, unlike commercial. Please reconsider and adopt a limit of no less than 4 buckets per day. | The limit for the recreational Herring fishery is not designed to supply participants with a year-long supply of either bait or daily food. The goal of this limit is to sustainably manage the resource, which can experience intense recreational fishing pressure during nearshore spawning events, while allowing fishers a satisfying recreational experience. The proposed limit takes into consideration the needs of the Pacific Herring resource as well as that of both the commercial and recreational sectors. |

| Commenter Number | Commenter Name, Organization If Applicable, Comment Format, and Date | Herring FMP Section or New Title 14, CCR (Implementing Regulations) Section Referenced | Comment Summary | Response |
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| **7** | **Kirk Lombard**<br>Recreational Participant, Blogger and Author, Fishmonger<br>Email dated 7/24/2019 | FMP Section 7.8.7; Title 14, CCR §28.62 | **7-a.** The proposed recreational limit range goes too far. Supports limits in general. A zero-bucket limit is an overreaction. Makes six points about recreational take of Herring, including limited number of days they are accessible from shore, and that most people only take a few buckets during spawns (problem of over harvest stems from a few bad apples). Mr. Lombard contrasts recreational take with commercial gillnet take (recreationally-caught fish are eaten locally, gillnet catch is exported) emphasizing local benefit of recreational take and poor quality of gillnet-acquired fish for eating. He points out high utilization by Asian Americans and high level of complaint from non-Asian Americans and commercial fishermen. Mr. Lombard suggests that one bucket only seems like a large quantity to individuals who do not fish for Herring, since a single bucket only lasts 3 months, and emphasizes the healthy aspects of eating low-on-the-food chain species caught locally. | While the Department understands that Herring are only available during a few nearshore spawning events, those events can experience intensive recreational pressure, with hundreds of participants targeting Herring. The limit is designed to allow participants a satisfying recreational experience while limiting the impacts of harvest on the schools that spawn in these nearshore areas. |

| Commenter Number | Commenter Name, Organization If Applicable, Comment Format, and Date | Herring FMP Section or New Title 14, CCR (Implementing Regulations) Section Referenced | Comment Summary | Response |
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| **7** | **Kirk Lombard**<br>(Continued) | FMP Section 7.8.7; Title 14, CCR §28.62 | **7-b.** Prefers for the lower end of recreational Herring limit range be two 5-gallon buckets, if not 3-4. | At the FMP adoption meeting on October 10, 2019, the Fish and Game Commission selected a ten-gallon recreational bag limit from the 0-10 gallon range provided by the Department. Additionally, language in the FMP referring to a specific bag limit range has been removed. |
| **8** | **Russell Johnston**<br>Marine Science Institute, UC Santa Barbara<br>Email dated 7/25/2019 | FMP<br>General | **8-a.** General support for adoption pending specific listed changes. | The Department appreciates support for the Herring FMP and has responded to comments received as appropriate. |
| **8** | **Russell Johnston**<br>(Continued) | FMP Appendices | **8-b.** Provide all appendices as part of FMP and organize so as to be readily navigated by the public. | Appropriate page numbering has been applied and all appendices are included in in the Final Herring FMP. Pending adoption, for ease of download, the FMP body and appendices will be made available separately. |

| Commenter Number | Commenter Name, Organization If Applicable, Comment Format, and Date | Herring FMP Section or New Title 14, CCR (Implementing Regulations) Section Referenced | Comment Summary | Response |
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| 8 | **Russell Johnston** (Continued) | FMP Section 2.13.2.3, Appendix D | **8-c.** Include Humboldt Bay spawn areas in maps of spawn areas depicted in Chapter 2 and Appendix D. | Habitat maps for management areas where no commercial activity occurs at the time of Herring FMP development are presented in Appendix D. However, the Humboldt Bay map in the Draft Herring FMP Appendix D did not include spawn areas. Detailed maps of recent observed spawning locations are available for Humboldt Bay and have been be included in the Final Herring FMP. Section 2.13.2.3 has been edited to refer the reader to Appendix D for Humboldt Bay spawn areas. |
| 8 | **Russell Johnston** (Continued) | FMP Executive Summary, General | **8-d.** Present all FMP goals equally, including compliance with forage species policy and incorporation of ecosystem indicators. | The primary management goals outlined in the Herring FMP are those described in the MLMA, which provides the legal framework for fisheries management in California. For this reason, these goals are given primacy in the Herring FMP. However, the Commission's forage species policy also played an important role in the development of the FMP objectives, as described in the Herring FMP. |

| Commenter Number | Commenter Name, Organization If Applicable, Comment Format, and Date | Herring FMP Section or New Title 14, CCR (Implementing Regulations) Section Referenced | Comment Summary | Response |
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| 9 | **Nick Sohrakoff**<br>Commercial Participant, Director's Herring Advisory Committee President, FMP Steering Committee Member<br>Email dated 7/29/2019 | FMP Section 4.7.2 | **9-a.** The SFBHRA (San Francisco Bay Herring Research Association) did not file a lawsuit. The lawsuit in referenced was filed by the SFHA (San Francisco Herring Association). Please correct the draft changing SFBHRA to SFHA to reflect the proper entity that filed the lawsuit. | This error has been corrected in the Final Herring FMP. |
| 9 | **Nick Sohrakoff**<br>Oral Comment w/ Anna W. (Commenter 10) at FGC Meeting 8/8/2019 | FMP<br>General | **9-b.** General expression of support – DHAC supported FMP 12 years ago, SC was a successful collaborative effort, would like to fund a genetic study with Audubon for stocks in CA and southern Oregon. | The Herring FMP was the result of a great deal of work by many different stakeholders, and the Department hopes to continue future collaborations to benefit the resource. |

| Commenter Number | Commenter Name, Organization If Applicable, Comment Format, and Date | Herring FMP Section or New Title 14, CCR (Implementing Regulations) Section Referenced | Comment Summary | Response |
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| **10** | **Geoff Shester**, Oceana and FMP Steering Committee; **Anna Weinstein**, Audubon California and FMP Steering Committee; **Irene Gutierrez**, NRDC; **Greg Helms**, Ocean Conservancy; **Andrea Treece**, Earthjustice; **Paul Shively**, Pew Charitable Trusts<br>Letter dated 7/25/2019<br>**(NGO Letter)** | FMP Appendices | **10-a.** Appendix R is currently missing from the FMP due to an error. Based on an agreement by the Steering Committee, this Appendix was intended to describe an increased range of catch limit adjustments resulting from ecosystem considerations that the Department may use as scientific information improves, without an FMP amendment. We request that Appendix R be included in the FMP and that the public be afforded the opportunity to review and provide comments on its contents prior to final adoption of the FMP. | Appendix R was drafted, but omitted from the Draft Herring FMP in error. Appendix R was included in an updated Draft FMP that was made available for public viewing and comment, and is included in the Final Herring FMP. Appendix R contains information on the development of the Harvest Control Rule framework, as well as guidance for amending the decision tree as the field of ecosystem-based fishery management develops. Any increase in the bounds on ecosystem-based quota adjustment beyond those indicated in Chapter 7 (Figure 7-3) and Appendix R (Figure R-3) will require an amendment. |

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| 10 | **NGO Letter** (Continued) | FMP Section 7.5.3 | **10-b.** We request the FMP include clear, objective criteria for determining whether a Tier 2 stock is overfished and clarify what the rebuilding provisions are for overfished Tier 2 stocks. The MLMA requires that FMPs must specify criteria for identifying when a stock is overfished, include measures to end or prevent overfishing, and provide a mechanism for rebuilding in the shortest time period possible (FGC §7086). While the draft FMP identifies criteria for determining whether the San Francisco Bay stock is overfished as well as rebuilding provisions (Section 7.8.1), it does not contain criteria for determining whether any of the stocks outside San Francisco Bay stocks would be considered overfished when they are in Tier 2. It also does not specify how the San Francisco Bay stock would be considered overfished if it is moved to Tier 2 status in the future. The FMP does not provide objective criteria for what constitutes "very poor spawning behavior" or "an SSB too small to support fishing." For example, this could be remedied by clarifying how "low" or "very poor spawning behavior" is determined in the Rapid Spawn Assessments for Tier 2 stocks and stating in the FMP that this is the criteria for overfished. | Section 7.5.3 has been amended in the Final Herring FMP to include specific criteria for determining when a given management area's spawning stock biomass is considered overfished or otherwise depressed under Tier 2. If the stocks drop below these respective limits, the quotas will be set to zero to promote stock rebuilding. This brings the management plan into compliance with the MLMA, which states that FMPs must specify overfishing limits and rebuilding plans. |
| 10 | **NGO Letter** (Continued) | FMP Appendices | **10-c.** The number and size of the Appendices substantially increase the size of the overall FMP document, which as presented, will complicate navigation of the FMP by the public. While each Appendix provides important information and is referenced in the body of the FMP, we suggest the | Appropriate page numbering has been applied to all appendices in the Final Herring FMP. Pending adoption, for ease of download, the FMP body and appendices will be made available separately. |

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| | | | Appendices be available as separate documents from the main body of the FMP, and that each Appendix contain consistent page numbering and formatting to improve navigation of the FMP. | |
| 10 | **NGO Letter**<br>(Continued) | FMP<br>General | **10-d.** Throughout the document, the term "quota" is used when referring to the annual catch limit. The term quota is problematic because in other contexts "quota" may refer to a minimum quantity or goal, rather than a maximum limit. To maintain consistency and clarity for the public, we request the FMP not use the term "quota" and instead use the term "catch limit." | The term "quota" is frequently used interchangeably with "catch limit" in fisheries management. In addition, the Marine Life Management Act uses the term "quota" rather than "catch limit" in specifying the types of conservation and management measures that should be described in an FMP (Section 7802(c)). Furthermore, the term quota has been used historically in documents related to management of California's Pacific Herring fishery. For consistency with these documents, the Final FMP retains use of the word "quota". |

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| **10** | **NGO Letter** (Continued) | FMP Section 2.13.2.2, Appendix D | **10-e.** In Section 2.13.2.3 (p. 2-26), the Department's maps of Herring spawning areal extent and most-used spawning areas for Humboldt Bay should be included, in the manner San Francisco Bay's maps appear in that section. Also, these updated maps should be put into the Habitat section (pg. 319). | Habitat maps for management areas where no commercial activity occurs at the time of FMP development are presented in Appendix D. However, the Humboldt Bay map in the Draft FMP Appendix D did not include spawn areas. Detailed maps of recent observed spawning locations are available for Humboldt Bay and have been be included in the Final FMP. Section 2.13.2.3 has been edited to refer the reader to Appendix D for Humboldt Bay spawn areas. |
| **10** | **NGO Letter** (Continued) | FMP Section 7.7.2 | **10-f.** The Executive Summary (p. ii) and Section 7.7.2 state that complying with the Commission's Forage Species policy is a secondary goal. This prioritization undercuts the Commission's forage policy and implies that other goals are more important. We request that the FMP present all goals equally, including compliance with the Forage Species policy and incorporating ecosystem considerations into Herring management. | The primary management goals as outlined in the Herring FMP are those described in the MLMA, which is the overarching legal framework for fisheries management in California. For this reason, these goals are given primacy in the Herring FMP. However, the Commission's forage species policy played an important role in the development of FMP objectives, as described in the Herring FMP. |

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| **10** | **NGO Letter** (Continued) | FMP Executive Summary, Section 7.6.3 | **10-g.** The Executive Summary (p. iv) indicates that the multi-indicator predictive model is adopted by the FMP. However, Section 7.6.3 makes clear that the spawn deposition surveys are the default for estimating San Francisco Bay SSB until the predictive model has 3 or more years of successful predictive power. The Executive Summary should be clarified consistent with this description in Section 7.6.3. | The Herring FMP adopts the multi-indicator predictive model as an option for estimating Spawning Stock Biomass in the San Francisco Bay management area. The Final Herring FMP Section 7.6.3 has been edited to clarify the requirements for use of the multi-indicator predictive model. Spawn deposition surveys remain the default method for determining Spawning Stock Biomass, and the Executive Summary has been edited to clarify this. |
| **10** | **NGO Letter** (Continued) | FMP Section 7.7.1, Figure 7-2; Appendix F | **10-h.** The FMP should clarify that Figure 7-2 represents the default harvest control rule, which is subject to ecosystem adjustments as indicated by the decision tree. Currently, Appendix F and Figure 7-2 are misleading because they do not reference potential adjustments to catch limits based on ecosystem considerations, therefore implying that these represent the final catch limit. | Chapter 7 has been modified so that the caption for Figure 7-2 clarifies that the black line indicates the unadjusted quota for the season. Section 7.7 describes how the quota may be adjusted for ecosystem considerations. |

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| **10** | **NGO Letter** (Continued) | FMP Executive Summary | **10-i.** Given California's leading role in addressing the climate crisis, the Executive Summary should emphasize and highlight the several areas where climate change is addressed in the FMP, specifically the use of climate indicators in the predictive model, the use of management strategy evaluation to ensure the harvest control rule is robust to future climate change scenarios, and the use of climate indicators as ecosystem considerations. | Adaptive management frameworks based on the best available science and including multiple indicators, such as the framework presented in the Herring FMP, are key tools for promoting climate change resilience in fisheries management, and this is emphasized throughout the document. The Executive Summary has been updated in the Final Herring FMP to better reflect this. |
| **10** | **NGO Letter** (Continued) | FMP Acknowledge-ments | **10-j.** Finally, we request that the Acknowledgments section recognize all cash funding sources for the FMP, specifically the Gordon and Betty Moore Foundation and the National Fish and Wildlife Foundation. | The Gordon and Betty Moore Foundation has been added to the Acknowledgements in the Final Herring FMP. |
| **10** | **NGO Letter** (Continued) | FMP General | **10-k.** For the [several stated] reasons, we support the adoption of the FMP. We request the Commission incorporate the above recommendations on the Draft Herring FMP into the final version and urge the Commission to adopt the Final Herring FMP at its October meeting, as scheduled. | Support for the Herring FMP is appreciated. Comments received have been responded to here and in the Final FMP as appropriate. |

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| 11 | **Anna Weinstein**<br>Audubon California<br>Herring FMP Steering Committee<br>**+3,258 Individual Signatories**<br>Letter dated 7/31/2019 | FMP<br>General | **11-a.** [Signatories and Audubon] support the adoption of the Fishery Management Plan (FMP) for Pacific Herring at your meeting in October 2019, pending specific changes listed. | Support for the Herring FMP is appreciated. Comments received have been responded to here and in the Final FMP as appropriate. |
| 11 | **Anna Weinstein**<br>**+3,258 Individual Signatories**<br>(Continued) | FMP Appendices | **11-b.** All the Appendices should be provided as part of the FMP and organized so they can be readily navigated by the public. | All appendices, including Appendix R (see response to Comment **9-a**), are now available for the public to review, and include appropriate page numbering. Pending adoption, for ease of download, the FMP body and appendices will be made available separately. |

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| 11 | **Anna Weinstein +3,258 Individual Signatories** (Continued) | FMP Section 2.13.2.3, Appendix D | **11-c.** The Department's maps of Herring spawning areal extent and most-used spawning areas for Humboldt Bay should be included in the FMP. | Habitat maps for management areas where no commercial activity occurs at the time of Herring FMP development are presented in Appendix D. However, the Humboldt Bay map in the Draft Herring FMP Appendix D did not include spawn areas. Detailed maps of recent observed spawning locations are available for Humboldt Bay and have been be included in the Final FMP. Section 2.13.2.3 has been edited to refer the reader to Appendix D for Humboldt Bay spawn areas. |
| 11 | **Anna Weinstein +3,258 Individual Signatories** (Continued) | FMP Executive Summary | **11-d.** In the Executive Summary and throughout the FMP, present all FMP goals equally, including compliance with the forage species policy and incorporating ecosystem considerations into Herring management. | The primary management goals as outlined in the FMP are those described in the MLMA, which is the overarching legal framework for fisheries management in California. For this reason, these goals are given primacy in the Herring FMP. However, the Commission's forage species policy played an important role in the development of the FMP objectives, as described in the FMP. |

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| 11 | **Anna Weinstein**<br>Oral comment w/ Nick S. (Commenter 8) at FGC meeting 8/8/2019 | FMP<br>General | **11-e.** General support. Commend and thank involved parties, including FGC. FMP is groundbreaking. | Support for the Herring FMP is appreciated. |
| 11 | **Anna Weinstein**<br>Oral comment w/ Nick S.<br>(Continued) | FMP<br>General | **11-f.** Audubon has provided comment and non-substantive requests to ensure transparency and MLMA compliance (formatting fixes, better assembled appendices on website, tier 2 fishery criteria). | Comments received have been responded to here and in the Final FMP as appropriate. |
| 11 | **Anna Weinstein**<br>Oral comment at FGC meeting<br>10/10/2019 | FMP | **11-g.** Supports action to adopt Herring FMP and regs. Climate-ready framework that protects a very important food source for a variety of predators. Also supports properly sized commercial fleet and allows a generous yet sustainable catch. Really proud of this plan, learned a lot from this process. Grateful for our environmental colleagues. Barnes wisdom helped move us forward early on. Thanked a number of individuals. Also support pursuing a lessons learned that we think could help inform other FMPs. | Support for the Herring FMP is appreciated. The Herring FMP was the result of a great deal of work by many different stakeholders, and the Department hopes to continue future collaborations to benefit the resource. |

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| **12** | **Nils Warnock**<br>Audubon Canyon Ranch (ACR)<br>Letter dated 7/31/2019 | FMP Section 7.8.2.2 | **12-a.** ACR agrees with the Commission's recommendation to reduce the maximum number of permits allowed for Tomales Bay (from 35 to 15 via attrition), but further recommends that no new permits be issued for Tomales Bay (instead of beginning to issue once number of Tomales permits drops below 15). Rather, Tomales Bay would be best left as a protected area for Herring. Cites linked importance of Herring to seabirds, lack of commercial interest in Tomales Bay Fishery, and proximity to SF bay fishery as reasons. | The FMP specifies a management approach for Pacific Herring in Tomales Bay that is compatible with both conservation and fishing goals. Should there be renewed commercial interest in Herring fishing in Tomales Bay, the quota will be set at a small fraction of historical quotas to ensure that the Tomales Bay Herring stock can serve as food for predators as well as support a small commercial fishery, as described in Chapter 7. |
| **12** | **Nils Warnock**<br>(Continued) | FMP Section 7.8.7; Title 14, CCR §28.62 | **12-b.** ACR endorses FMP's recommendation of a recreational bag limit range of 0-100 lbs, equivalent to up to ten gallons, or two 5-gallon buckets of Herring, each containing 260 fish. | Support for the recreational bag limit in the Herring regulations is appreciated. |
| **12** | **Nils Warnock**<br>(Continued) | FMP Chapter 7 - Tomales Bay Spawning Biomass Surveys | **12-c.** As current monitoring data are critical for helping managers steward resources, especially during these times of rapid climate change, ACR encourages the Commission to recommend renewed Herring monitoring in Tomales Bay. | The Herring FMP identifies management areas with active commercial fisheries as the highest priority for monitoring. As described in Chapter 7, an appropriate level of monitoring will resume in Tomales Bay should commercial fishing activity resume there. |

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| **12** | **Nils Warnock** (Continued) | FMP General | **12-d.** With some suggested modifications, Herring FMP will provide strong guidance for the long-term sustainable mgmt. of Pacific Herring in California, including Tomales Bay. | Support for the Herring FMP is appreciated. Comments received have been responded to here and in the Final FMP as appropriate. |
| **13** | **Pam Young** Golden Gate Audubon Society Letter dated 7/31/2019 | FMP General | **13-a.** General support for the Herring FMP, including use of the best available science to support sustainable management. | Support for the Herring FMP is appreciated. |
| **14** | **Morgan Patton**, West Marin Environmental Action Committee (EAC); **Ashley Eagle-Gibbs**, EAC Letter dated 8/1/2019 | FMP Section 7.8.7; Title 14, CCR §28.62 | **14-a.** Consistent with past comments and Audubon Canyon Ranch's comments, EAC supports the Herring FMP's daily bag limit two 5-gallon buckets of Pacific Herring | Support for the recreational bag limit in the Herring regulations is appreciated. |

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| 14 | **Morgan Patton, Ashley Eagle Gibbs** (Continued) | FMP Chapter 7, General | **14-b.** While supportive of the overall management strategy in Chapter 7 of the Herring FMP, recommend full closure of commercial fishery in Tomales Bay, due to a number of factors. These include low Herring numbers, environmental considerations, lack of interest, high operating costs, and poor market conditions. No recent research (other than observations) has been conducted to indicate adequate biomass for the Tomales Bay fishery operation. Recommend CDFW (or other qualified and independent researchers) conduct renewed monitoring of Herring populations in Tomales Bay in order to compare against outdated information that is now 13 years old [limited monitoring conducted during 2006-07 season] to better understand the population dynamics | Support for the Herring FMP's management strategy is appreciated. The Herring FMP specifies a management approach for Pacific Herring in Tomales Bay that is compatible with both conservation and fishing goals. As described in Chapter 7, a precautionary quota is available, and an appropriate level of monitoring shall occur should commercial interest in the Tomales Bay stock resume. |

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| 14 | **Morgan Patton, Ashley Eagle Gibbs** (Continued) | FMP Chapter 7, General | **14-c.** The Tomales Bay Herring fishery should only be open after a comprehensive and scientifically based assessment and analysis is made of the Herring stocks, current and future spawning estimates, biomass, etc. led by Department of Fish and Wildlife staff and/or other trained and independent researchers, with the involvement of multiple stakeholders. EAC requests 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. | Should there be renewed commercial interest in Herring fishing in Tomales Bay, the Herring FMP specifies that the quota will be set at precautionary harvest rate to ensure that the Tomales Bay Herring stock can fulfill its ecological role as forage for predators as well as support a small fishery. This harvest rate can only be increased with additional monitoring demonstrating the population can support additional harvest, including determination of the Spawning Stock Biomass. The Department welcomes the opportunity to collaborate with stakeholders to increase our collective understanding of California's Pacific Herring stocks. |
| 14 | **Morgan Patton, Ashley Eagle Gibbs** EAC Second letter Dated 9/26/2019 | FMP Chapter 7, | **14-d.** Reiterates comments from 8/1/2019 letter, specifically 1) support for the recreational limit, 2) support of overall management goals, which the recommendation that Tomales Bay be closed to commercial take, and 3) commercial take in Tomales Bay should not be allowed until certain research and monitoring is conducted. | See responses above to comments **14-a**, **14-b**, and **14-c**. |

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| **14** | **Morgan Patton, Ashley Eagle Gibbs** (Second letter Continued) | Title 14 CCR §28.60 | **14-e.** Recommends that the recreational take of Herring roe be prohibited in Tomales Bay due to sensitive nature of the ecosystem there. Specifically, waterbird populations in Tomales Bay are in decline, Tomales Bay serves as important marine mammal habitat, and eelgrass in Tomales Bay is important to herring. Furthermore, eelgrass is likely to be mistaken for kelp and taken along with the recreational take of roe, even though this is prohibited. | The daily limit of 25 lb wet weight, including roe and vegetation, is meant to allow for a satisfying recreational experience for individuals while ensuring that total Herring harvest remains sustainable. The Department recognizes the importance of eelgrass and other sensitive habitat types in Tomales Bay, and the prohibition on take of eelgrass is meant to prevent impacts to this important species during recreational fishing activity. |

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| **15** | **Julie Thayer, Ph.D.**<br>Farallon Institute<br>Letter dated 7/31/2019 in attachment to Email dated 8/1/2019 | FMP<br>Chapters 3, 7; Appendices E, F | **15-a.** Work conducted by the Farallon institute as a contractor on FMP development was not accurately represented in the draft FMP. Includes specific description of issues with information presented in Ch 3, Ch 7, and Appendix E, and F. Inaccurate representation of this work led to erroneous conclusions by Peer Review of FMP science. Requests that actual contractor work be presented in the appendices. | The Farallon Institute was subcontracted to assist the Project Management Team with developing scientific advice for the management of Pacific Herring. This work produced a number of valuable contributions to the field of ecosystem-based fishery management, and the parts that were used in the development of the FMP's management framework were provided to the Peer Review, are reproduced in Appendices E and F. However, there were other components of the work produced that were evaluated by the Project Management Team, the Department, and the Steering Committee that were deemed to be not suitable for use in the management framework at this time. The Peer Review committee requested to see, and were provided, additional components from the Farallon Institute's work that were not used in the Herring FMP during the review process. As such, the review committee's final recommendation does take into account these additional components as well. |
| **15** | **Julie Thayer, Ph.D.**<br>(Continued) | FMP Chapter 7, Section 7.6.3 | **15-b.** Chapter 7 incorrectly states that the predictive model needs to be tested before use, though it has already been validated against 27 years of SF Bay biomass. | The Herring FMP adopts the multi-indicator predicted model as an option for estimating Spawning Stock Biomass in the San Francisco Bay management area. The Final Herring FMP Section 7.6.3 has been edited to clarify the requirements for use of |

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| | | | | the multi-indicator predictive model. Specifically, the model's use depends on availability of required data and its continued predictive skill. |
| **15** | **Julie Thayer, Ph.D.** (Continued) | FMP Appendix E | **15-c.** Appendix E summarizes a draft report of the SSB forecasting model submitted by Farallon Institute early in the FMP development process, instead of the final publication of this work which included key revisions to the original draft | The information summarized in appendices E and F includes the portions of the work produced by the Farallon Institute under subcontract by the Project Management Team that were included in the Herring FMP. The final publication referred to (Sydeman and others, 2018) does not include the multi-indicator predictive model adopted by the Herring FMP. However, this publication is referenced in the FMP, including in Appendix E, as appropriate. |

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| 15 | **Julie Thayer, Ph.D.** (Continued) | FMP Chapter 9, Appendix R | **15-d.** Considerations for future research and management should include the importance of making ecosystem-based catch adjustments more meaningful. Re-instate appendix R, allow wider discretion on quota adjustment bounds in HCR framework. | Appendix R was drafted, but omitted from the May-dated Draft FMP in error (see response to Comment **9-a**). It has been included in the Final FMP and contains information on the development of the Harvest Control Rule framework, as well as guidance for amending the Decision Tree as the field of ecosystem-based fishery management develops. Any increase in the bounds on ecosystem-based quota adjustment beyond those indicated in Chapter 7 (Figure 7-3) and Appendix R (Figure R-3) will require FMP amendment. |
| 15 | **Julie Thayer, Ph.D.** (Continued) | FMP Sections 2.4, 5.6, Chapter 8 | **15-e.** Importance of temporal variability in spawning should be explicitly stated in the FMP (w/ specific recommendations for Sections 2.4, 5.6, and Chapter 8). | The observed temporal variability in Herring spawning is stated a number of times throughout the Herring FMP. In particular, Section 2.4 and Figure 2-4 describe the available information on this variability. Section 8.6 also flags changes in observed spawning habitat over time as a key uncertainty and avenue for future research. |

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| 15 | **Julie Thayer, Ph.D.**<br>(Continued) | FMP Appendices | **15-f.** The FMP is prohibitively large and difficult to navigate due to myriad of appendices, both current and historical information. Suggest final document only include immediately-relevant supplemental material such as formulas and decision trees, w/ clear page numbering. Historical info should be separated into distinct files that can be downloaded separately, and are also clearly referenced. | California's Herring fishery is complex, with a long history of management. The FMP serves as a central repository for all of the available information on Pacific Herring and its management in California. Pending adoption, for ease of download, the FMP body and appendices will be made available separately. |
| 16 | **Jennifer Fearing**<br>Fearless Advocacy<br>Oral comment at FGC meeting<br>8/8/2019 | FMP<br>General | **16-a.** Strong support for adoption in October. The FMP is a tremendous step forward for Ecosystem-Based Management. Appreciate CDFW incorporating Appendix R | Support for the Herring FMP is appreciated. Appendix R was drafted but was omitted in error (see response to Comment **9-a**). It has been included in an updated draft of the FMP and is available for review. |

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| **16** | **Jennifer Fearing**<br>(Continued) | FMP Section 7.5.3 | **16-b.** As per NGO Letter (see Commenter 9), recommendations to strengthen MLMA compliance w/out altering timeline for adoption, request Fish and Game Commission direct CDFW to address those recommendations prior to adoption. | Section 7.5.3 has been amended in the Final Herring FMP to include criteria for determining when a given management area's spawning stock biomass is considered overfished or otherwise depressed under Tier 2. If the stocks drops below these limits, the quotas will be set to zero to promote stock rebuilding. This brings the management plan into compliance with the MLMA, which states that FMPs must specify overfishing limits and rebuilding plans. |

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| 17 | **Geoff Shester**<br>Oceana<br>FMP Steering Committee<br>**+3,091 California Residents**<br>Letter dated 9/24/2019 | FMP and Regulations<br>General | **17-a.** General support for Herring FMP and associated implementing regulations. Discussion of importance of Herring's ecosystem role, stresses importance of precautionary management for Herring. Commends Fish and Game Commission and Department of Fish and Wildlife for precautionary management, describes FMP in historic terms due to ecosystem adjustments. Points out that adoption of FMP and implementing regulations will advance implementation of Commission's forage species policy and ensure responsible fishery management moving forward. Requests that Commissioners please protect Herring and adopt the FMP. | The Department appreciates support for the FMP and the description of its various benefits to Herring and the California Current Ecosystem, as well as the future of responsible fishery management in California. |

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| **17** | **Geoff Shester**<br>Oral Comment at FGC Meeting<br>10/10/2019 | FMP | **17-b.** Adoption is long-time coming, asking FGC to adopt as is without any further changes. Long road, including starting with forage species policy in 2012, then sat down with industry and Audubon to see what this could look like, raised money, and helped reviewed content along the entire way. Support CDFW, have brought all sides together for a very controversial issue where both sides were fighting adamantly for their views, compromised and think this does result in a number of positive aspects (including ecosystem based quota adjustments and tiered mgt.), been a valuable experience and ask Commission to adopt. Moving forward would be good to have a lessons learned, but think we have something we can all be proud of. | Support for the Herring FMP is appreciated. The FMP had valuable input from a variety of interested parties and the financial support from contributors was essential to its completion. |
| **17** | **Geoff Shester**<br>(continued) | Implementing Regulations | **17-d** Ask FGC to adopt implementing regs package for FMP. | Support for adoption of the implementing regulations package is appreciated. |

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| 17 | **Geoff Shester** (continued) | Implementing Regulations | **17-e** Support CDFW's proposal to do a follow up package for HEOK comments. | The Department has committed to working to resolve some of the concerns with the proposed HEOK regulations, including meeting the HEOK representative at a Marine Resources Committee meeting on November 5, 2019 and the possibility of a follow up rulemaking package in 2020 to address the remaining HEOK issues. |
| 17 | **Geoff Shester** (continued) | Implementing Regulations | **17-f** Hoped the regs would apply this season, but learned they will not go into effect until next season. Latest biomass estimate presented at the DHAC was ~ 8k tons which is well below the threshold and if the FMP was implemented it would be considered a depleted state. | The spawning stock biomass estimate of 8,030 is one of the lowest on record, however existing regulations establish a 750 ton gillnet quota during the 2019-20 season. This quota allows for a gillnet-sector target harvest rate (this year's quota as a percentage of last year's biomass) of 9.3%, which the Department considers to be precautionary. |
| 17 | **Geoff Shester** (continued) | Implementing Regulations | **17-g** Consider the current stock of the population for the rec bag limit considerations. Do support rec bag limit. | The Fish and Game Commission selected a ten-gallon recreational bag limit from the 0-10 gallon range provided by the Department. |

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| 18 | **Dan Yoakum**<br>Commercial Participant<br>Letter dated 9/24/2019 Attached to Email dated 10/02/2019 | FMP and Regulations<br>General | **18-a.** The Department did not adequately incorporate recommendations from the HEOK sector into the FMP's rulemaking package. As a result, proposed regs create potential for violations when trying to conduct normal HEOK operations. Several specific issues are identified as (comments **18-b** through **18-h**), and Mr. Yoakum requests that the Department work with him to resolve these issues. | Department staff engaged with Mr. Yoakum, in his capacity as the HEOK-sector representative, by way of multiple, formal, in-person meetings, as well as numerous phone calls, regarding the proposed regulations. The Department has committed to working with Mr. Yoakum to resolve some of the concerns with the proposed HEOK regulations mentioned in his letter, including meeting at a Marine Resources Committee meeting on November 5, 2019 and the possibility of a follow-up rulemaking in 2020 to address the remaining HEOK issues. Regarding specific issues identified by Mr. Yoakum with this regulatory package, see responses to comments **18-b** through **18-h** below. |

| Commenter Number | Commenter Name, Organization If Applicable, Comment Format, and Date | Herring FMP Section or New Title 14, CCR (Implementing Regulations) Section Referenced | Comment Summary | Response |
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| **18** | **Dan Yoakum** (continued) | FMP Section 7.8.1.1, Title 14 CCR §55.02(d) | **18-b.** Doing away with permit quotas will result in increased competition, reduced cooperation, inferior quality product, and will be inconsistent with HEOK regulations in Canada, Alaska, and Washington. | Proposed regulations in §55.02(d) state that the Director of the Department shall sat quotas for all sectors according to Chapter 7 of the FMP. Under the FMP, HEOK permits are separate from Herring gillnet permits. Section 7.8.1.1 of the FMP's Chapter 7 describes HEOK quota as being set to a product weight equivalent to approximately 1% of the total quantity of eggs produced by the most recent SSB. The permit quotas under regulation prior to the FMP were derived from a system that subtracts HEOK quota from the total gillnet quota, despite the HEOK sector not taking any adult fish. The rationale for setting HEOK quotas at 1% of the most recent SSB's egg deposition is addressed in Appendix N of the Herring FMP.<br><br>Department staff will work with Mr. Yoakum to incorporate allocation of the HEOK quota to individual permittees in a follow-up rulemaking in 2020 (see response to comment **18-a**). |

| Commenter Number | Commenter Name, Organization If Applicable, Comment Format, and Date | Herring FMP Section or New Title 14, CCR (Implementing Regulations) Section Referenced | Comment Summary | Response |
|---|---|---|---|---|
| **18** | **Dan Yoakum** (continued) | Title 14 CCR §164(h)(4) | **18-c.** Prohibiting weekend landings will negatively affect the quality of product, and effectively reduce fishable time by 1/3, since HEOK must be harvested and landed immediately after spawn on the kelp, and participants cannot control when fish spawn. | As described in the Necessity and Rationale for this regulatory change, the intent of this requirement was to improve the Department's ability to track the catch relative to the quota and determine when the quota has been reached. Quota managed fisheries, like the HEOK fishery, require staff to be able to track landings in near-real time, and it is difficult for Department staff to track landings at night and/or during the weekend. However, in light of points made by Mr. Yoakum's comment, the Department will work to address this issue in a follow-up rulemaking in 2020 (see response to comment **18-a**). |
| **18** | **Dan Yoakum** (continued) | Title 14 CCR §164(a)(3) | **18-d.** The definition of "processing" omits washing/rinsing, which needs to be included. | The Department will address this issue in a follow-up rulemaking in 2020 (see response to comment **18-a**). |

| Commenter Number | Commenter Name, Organization If Applicable, Comment Format, and Date | Herring FMP Section or New Title 14, CCR (Implementing Regulations) Section Referenced | Comment Summary | Response |
|---|---|---|---|---|
| **18** | **Dan Yoakum** (continued) | Title 14 CCR §164(g) | **18-e.** Proposed regulations prohibit marine mammal deterrent devices during HEOK fishing in San Francisco Bay. | The HEOK sector is a high-visibility fishery in San Francisco Bay. Department program staff worked closely with Law Enforcement Division staff on this requirement, and it was made clear to Mr. Yoakum that he would not be allowed to harass seals and/or sea lions in San Francisco Bay. An experimental fishery permit is an available option to HEOK participants who would like to develop seal-exclusion gear that does not harass marine mammals. |
| **18** | **Dan Yoakum** (continued) | Title 14 CCR §164(d)(1)(E) and (F) | **18-f.** Gear requirements for the allowable length of corklines and their marking requirements ignore that lines must be broken down into smaller segments in order to be operated. | Department program staff worked with Law Enforcement Division to develop this requirement, the intent of which is that any line engaged in fishing be 1,200 feet in length or less and adequately marked at each end. |
| **18** | **Dan Yoakum** (continued) | Title 14 CCR §164(f) | **18-g.** The noise rule in 164(f) is unnecessary, as the HEOK sector is quiet by nature. Including this rule leaves HEOK participants open to harassment. | This requirement has always applied to all Herring permittees in §163 (including HEOK) prior to FMP-implementing regulations. Under FMP-implementing regulations, harvest of HEOK is addressed in §164, including noise reduction requirements. |

| Commenter Number | Commenter Name, Organization If Applicable, Comment Format, and Date | Herring FMP Section or New Title 14, CCR (Implementing Regulations) Section Referenced | Comment Summary | Response |
|---|---|---|---|---|
| 18 | **Dan Yoakum**<br>(continued) | Title 14 CCR §163(e)(3)(B) | **18-h.** The requirement that the HEOK permittee be aboard any vessel engaged in harvesting, processing, or transporting herring eggs is not workable, as kelp is not hung aboard the vessel. Dan recommends that the requirement be changed to 'in the vicinity' of the vessel, so that permittees may be allowed to work from, for example, their raft(s). | Department program staff worked with Law Enforcement Division to develop this requirement, the intent of which is that the permittee be present during harvest, processing, or transporting of HEOK product. Language such as "in the vicinity" is vague, and could potentially be interpreted in such a way that no permittee need be present during these operations, which is not sufficient from an enforcement standpoint. However, the Department will clarify this requirement in a follow-up rulemaking in 2020 (see response to comment **18-a**). |
| 18 | **Dan Yoakum**<br>Oral comment at FGC meeting 10/10/2019 | FMP and Regulations General | **18-i.** There are many problems with the regs and the HEOK fishery that came about because CDFW took recommendations but did not reach out to review them, just kept pushing it off and never talked about the changes they made. | See responses above to comment **18-a.** The Department has committed to working with Mr. Yoakum to resolve some of the concerns with the proposed HEOK regulations mentioned in this letter, including meeting at a Marine Resources Committee meeting on November 5, 2019 and the possibility of a follow up rulemaking in 2020 to address the remaining HEOK issues. |

| Commenter Number | Commenter Name, Organization If Applicable, Comment Format, and Date | Herring FMP Section or New Title 14, CCR (Implementing Regulations) Section Referenced | Comment Summary | Response |
|---|---|---|---|---|
| 18 | **Dan Yoakum**<br>(continued) | FMP and Regulations<br>(Reiterated) | **18-j.** Reiterated comments from 9/24/2019 letter, specifically 1) maintain individual quotas. 2) Continue to allow weekend landings. And 3) to fish HEOK, you have to be able to get off the vessel while fishing HEOK. | See responses above to comment **18-b**, **18-c**, and **18-h**. |
| 19 | **Neha Ram**<br>Student<br>Scripps Institute of Oceanography<br>Oral comment<br>at FGC meeting<br>10/10/2019 | Herring FMP | **19-a.** Support for Herring FMP along with some concerns. 1) pushing not only for more research on climate change effects, but also concrete mitigation measures using scientific information produced, 2) whale entanglement – collaboration, 3) mitigation measures to protect marine mammals, birds and large fish. | Support for the Herring FMP is appreciated, and the Department welcomes the opportunity to collaborate with stakeholders and researchers to increase our collective understanding of California's Pacific Herring stocks. Due to the small mesh size of the gillnets used and the nearshore fishing locations, whale entanglement is not likely in this fishery. Close tending of nets reduces the chance of entangling other marine mammals, birds and large fish. |

Table S-2. Summary of minor corrections and changes to the Draft Herring FMP.

| Document Section | Page Number | Correction |
|---|---|---|
| Title page | *NA* | **~~Draft~~ California Pacific Herring Fishery Management Plan**<br>**~~Draft~~**<br>~~August 08, 2019~~<br>October 25, 2019 |
| Executive Summary | ii | 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:<br>(…)<br>• describe the effects of climate change on California's Herring stocks, and identify environmental and ecosystem indicators that can inform effective management, |
| Executive Summary | iv | ~~The currently used method is available as a backup should data be unavailable or should environmental changes compromise the predictive power of the model.~~ The FMP adopts this multi-indicator predictive model as an option for estimating the coming year's SSB in the San Francisco Bay management area, contingent upon availability of necessary input data and continued predictive power by the model. Spawn deposition surveys remain the default method for determining SSB. |

| Document Section | Page Number | Correction |
|---|---|---|
| Acknowledgements | xxii | Finally, the Gordon and Betty Moore Foundation and 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. |
| 2.8, Figure 2-5 caption | 2-10 | Figure 2-5. ~~Observed age distribution of the research catch in San Francisco Bay~~, Percent at age, by number, of ripe fish for the San Francisco Bay spawning stock biomass. Based on age composition of the research catch (excluding age-1 fish), 1982-83 through 2017-18 seasons. Note that ~~no sampling was conducted in~~ final age composition was not determined for the 1990-91 and 2002-03 seasons. |
| 2.8 | 2-10 | …the North Pacific Marine Heatwave (~~Chapter~~ Section 3.2). |
| 2.13.2.3 | 2-26 | 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. Maximum spawning extents observed during the 2014-15 through 2017-18 seasons are presented in Appendix D. |
| 4.2, Figure 4-2 caption | 4-3 | 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). The commercial fishery was closed for the 2009-10 season. Note that this figure does not include landings from the ocean waters fishery (Monterey Bay). |
| 4.7.2 | 4-16 | In 2014, the ~~SFBHRA~~ San Francisco Herring Association, a group of commercial Herring fishermen, filed a lawsuit against Pacific Gas and Electric (PG&E) for contamination of the San Francisco Bay waterfront. |

| Document Section | Page Number | Correction |
|---|---|---|
| 4.7.3, Table 4-2 caption | 4-18 | ~~2017~~ Commercial landings and ex-vessel value for the <u>five most valuable fisheries each in the</u> San Francisco, Tomales, Eureka, and Crescent City ports <u>in 2017</u>. |
| 5.6.1, Table 5-2 caption | 5-12 | Table 5-2. California Herring fishery season dates <u>prior to the implementation of this FMP</u>. |
| 5.6.2.2 | 5-13 | ~~Currently, Herring offloading only takes place at Pier 45 on the San Francisco waterfront.~~ *Remove sentence as unnecessary and potentially inaccurate in the future. Section is titled "Nighttime Restrictions on Unloading", and content functions just fine without this sentence.* |
| 6.2.1 | 6-12 | 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, <u>at the time of FMP development,</u> no commercial fishing has occurred… |
| 7.4 | 7-6 | The Tier 1 quota for Crescent City Harbor is set at ~~12~~ <u>11</u> tons (~~11~~<u>10</u> metric tons), which is 50% of the average historic<u>al</u> landings and a ~~60%~~<u>63%</u> decrease from the quota prior to the adoption of this FMP. |

| Document Section | Page Number | Correction |
|---|---|---|
| 7.5.3 | 7-8 | Conversely, under a Tier 2 monitoring protocol, the quota shall be reduced to zero as a rebuilding provision in years where either the employed Rapid Spawn Assessment indicates poor spawning behavior, or spawn deposition survey-derived SSB estimates indicate an SSB ~~too small to support fishing~~ that is overfished or otherwise depressed. For San Francisco Bay, the stock is considered overfished or otherwise depressed at SSB estimates below the 15,000-ton cutoff established by the HCR (see Section 7.7.1). For Tomales Bay and Humboldt Bay, the stock is considered overfished or otherwise depressed at stock sizes that are less than 20% of the long-term average biomass (including historical and contemporary SSB estimates) for each respective management area. For Crescent City Harbor, the stock is considered overfished or otherwise depressed at SSB estimates less than 66 tons, which is approximately three times the average historical catch in that management area. |
| 7.6.2.1 | 7-10 | All necessary data ~~are~~ may be available by the end of September each year, and prior to the beginning of the fishing season, which begins in December. |

| Document Section | Page Number | Correction |
|---|---|---|
| 7.6.3 | 7-12 | 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 model's use depends on availability of required data and the model's continued predictive skill (see Section 7.6.2.1, Appendix E). When these two requirements are met, the Department may decide to use the predictive model in yearly quota setting. |
| 7.7.1, Figure 7-2 caption | 7-13 | ~~HCR~~ Harvest Control Rule describing the relationship between estimated SSB and unadjusted quota for subsequent season of the San Francisco Bay Herring commercial fishery. |
| 7.7.2.3 | 7-21 | 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~~ the target harvest rate may be reduced by up to 1% (Figure 7-3). |
| 7.7.2.3 | 7-22 | Conversely, if an increase is warranted, ~~a 300 ton increase to the quota should be applied~~ the target harvest rate may be increased by up to 1% (Figure 7-3). |
| 9.2 | 9-4 | 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~~ Section 7.7.2.3, provided the supporting science is clearly documented (see Appendix R). |
| All appendices | *multiple* | *Insert incomplete and/or missing page numbers into all pages of all appendices* |

| Document Section | Page Number | Correction |
|---|---|---|
| Appendix D, Figure D3 and caption | D-3 | *Include recent ('14-'15 thru '17-'18 seasons) spawn areas in Humboldt Bay map;* Figure D3. Eelgrass and other habitat types in Humboldt Bay (from Schlosser and Eicher, 2012) and Herring spawn coverage. |
| Appendix D, Figure D6 | D-6 | *Include Noyo Harbor eelgrass map; update figure numbers in appendix.* |
| Appendix E | E-7 | 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$_{yr-1}$. T~~ the three-factor models~~, including the current model used by the Department~~ out-performed simpler one- and two-factor models by a large margin (improved r2 = 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~~69% compared to 77% to 119%) (Sydeman and others, 2018; Table E-3). The three-factor model that provided the best prediction for the current year SSB included: SSB$_{yr-1}$, YOY$_{yr-3}$ and SST$_{(Jul-Sep)\ yr-1}$. Notably, current Department fishing quotas are based on SSB$_{yr-1}$. |
| Appendix R | *multiple* | *Included Appendix R in response to public comment (see Table S-1).* |
| Appendix S | *multiple* | *Add Appendix S, including summary of public comments received and responses (Table S-1), and summary of changes to the FMP (Tables S-2 and S-3).* |
| Chapter 11. Works Cited | 11-10 | Merkel & Associates. 2016. Noyo River and Harbor Maintenance Dredging Pre-dredge Eelgrass Survey Results Transmittal. Prepared for U.S. Army Corps of Engineers San Francisco District, September 2016. |

| Document Section | Page Number | Correction |
|---|---|---|
| All | *multiple* | *Various corrections to capitalization, spacing, spelling, punctuation, font, nomenclature, and formatting.* |

Table S-3. Summary of minor corrections and changes to the Final Draft Herring FMP as adopted.

| Document Section | Page Number | Correction |
|---|---|---|
| Executive Summary | vi | *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~~ establishing a daily bag limit through regulation. ~~This~~The established bag limit ~~is~~ should be easily enforceable and provide~~s~~ for a satisfying and sustainable recreational experience while deterring illegal commercialization of the fishery. |
| 7.8.7 | 7-28 | This FMP establishes that a daily bag limit for recreational fishing be adopted through regulation. ~~This~~The FMP recommends a ~~range between 0 and 100 lb (45-kg)~~ daily bag limit be established at ~~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~~The possession limit ~~is also~~ should also be designed to be clear and easily enforceable. For reference, two 5-gallon buckets of Herring are equivalent to 100 lb of herring, or, approximately 260 Herring per bucket. Currently, there are no estimates of the recreational catch available, but ~~this~~ a 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. |
| 10.5.1 | 10-11 | Deleted Section 10.5.1. |
| 10.5.2 | 10-11 | Renumbered Section 10.5.2 as Section 10.5.1. |

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