Committee Staff Summary for September 12, 2024 WRC Meeting

2. Periodic Regulation Changes

Today's Item **Information ☐** **Action ☒**

Discussion and potential recommendations for 2025-26 seasons:

(A) Inland sport fishing

- I. Striped bass slot limits (discussion only)
- II. Other recommended changes (discussion only)

(B) Upland (resident) game bird hunting (potential recommendation)

(C) Mammal hunting (potential recommendation)

Summary of Previous/Future Actions

• Initial vetting	May 16, 2024; WRC
• **Today's discussion and potential recommendations**	**September 19, 2024**

Background

Today the Wildlife Resources Committee (WRC) will hear and discuss Department recommendations for regulation changes on a number of topics, and potentially make recommendations (except for inland sport fishing) to the Commission.

(A) Inland sport fishing

- I. *Striped bass slot limits:* This item was referred to WRC as a result of the Commission granting Petition 2020-005, regarding striped bass slot limits. The Department has completed its analysis of the petition's request and will make a recommendation to WRC (see exhibits A1 through A3). WRC is seeking public input on the recommendation and striped bass slot limits in general. In turn, WRC may make a recommendation to the Commission.
- II. *Other recommended changes:* This is an initial opportunity for interested parties to make suggestions to the Department and WRC regarding potential regulation changes for inland sport fishing. The Department will make its initial recommendations to WRC (Exhibit A4). The second opportunity to discuss ideas with WRC will be its January 2025 meeting, when WRC is expected to make recommendations to the Commission.

(B) Discussion and potential recommendation for upland (resident) game bird hunting (2025-26) for various resident upland game bird species, which includes California quail, pheasant, wild turkey, and mourning dove.

(C) Discussion and potential recommendation for mammal hunting (2025-26) for various big game mammals, including deer, Nelson bighorn sheep, pronghorn antelope, and elk (Exhibit C1).

Given the Commission's current regulatory staffing limitations, any recommendations made today for regulation changes necessarily will include a caveat from staff that timing for developing rulemaking materials to implement the recommendations will be dependent upon staff capacity. Staff appreciates input from WRC and stakeholders on the relative importance of different proposed actions.

Significant Public Comments

A hunter proposes several ideas and asks questions with respect to many aspects of mammal hunting, including elk tag allocations (archery tags, the Tehachapi Hunt Zone, and the Marble Mountains Elk Management Unit), the Department Shared Habitat Alliance for Recreational Enhancement Program, black bear hunting, the Department Private Lands Management Program, and chronic wasting disease (Exhibit C2).

Recommendation

Commission staff: Based on the Department's presentation and today's discussion, recommend the Commission support future rulemakings regarding striped bass slot limits and mammal hunting.

Department: Support future rulemakings regarding striped bass slot limits and mammal hunting.

Exhibits

- A1. Department striped bass presentation
- A2. Department report, *California Department of Fish and Wildlife Valuation of Regulation Change Petition 2022–12: Proposed 20–30–Inch Harvest Slot Limit for Striped Bass (*Morone saxatilis*)*, received August 29, 2024
- A3. Department report, *California Department of Fish and Wildlife Valuation of Nor-Cal Guides and Sportsmen's Association (NCGASA) Proposed 20-30 Inch Harvest Slot Limit for Striped Bass Appendices*, received August 29, 2024
- A4. Department inland sport fishing presentation
- C1. Department mammal hunting presentation (to be distributed separately)
- C2. Email from Mike Costello, received August 20, 2024

Committee Direction/Recommendation

The Wildlife Resources Committee recommends that the Commission support future rulemakings regarding striped bass slot limits and mammal hunting based on the Department's recommendation and today's discussion.

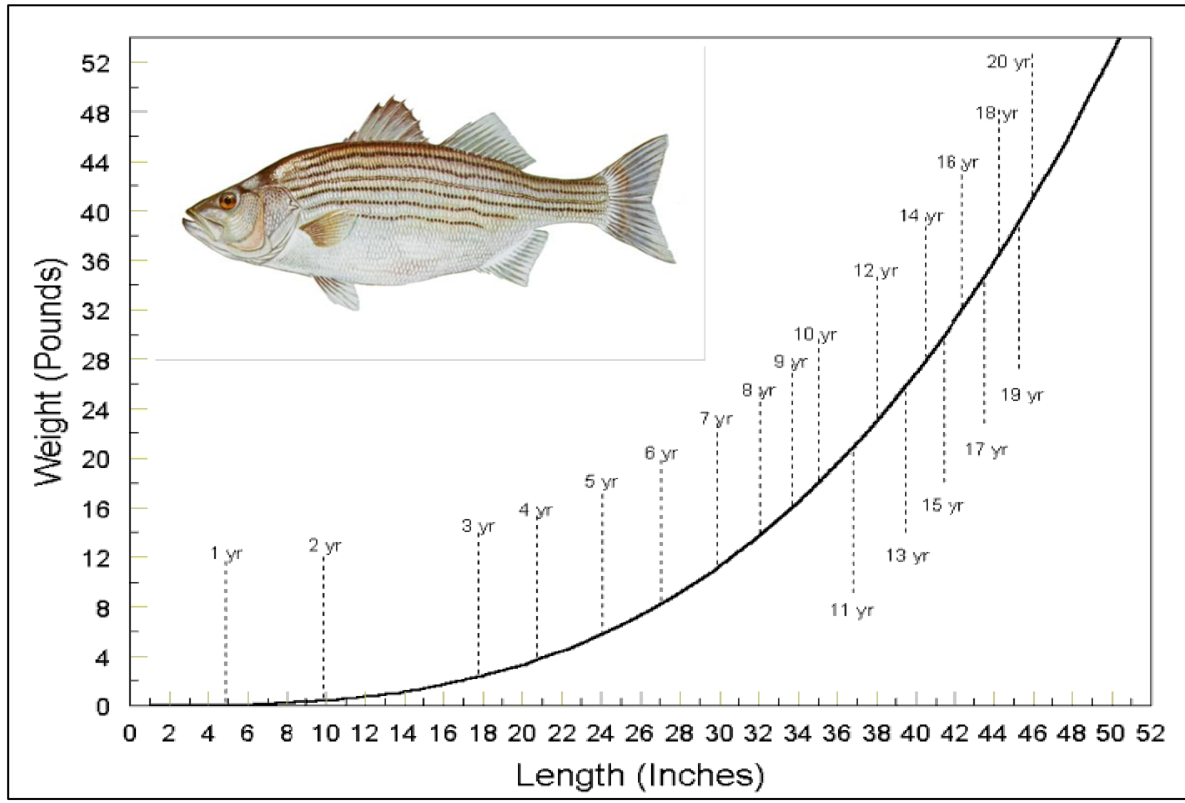
California Department of Fish and Wildlife Regulation Petition Evaluation 20-30 Inch Striped Bass Slot Limit

Erin Ferguson
Senior Environmental Scientist
CDFW Fisheries Branch

Wildlife Resources Committee Meeting
September 12, 2024

Striped Bass (*Morone saxatilis*)

- Native to East Coast
- Long-lived
  - Up to 30 years
- Anadromous
  - Highly migratory
- Maturation
  - Females: age 4-5 (22-24 inches)
- Broadcast spawners
- Opportunistic predators
  - insects, fishes, and crustaceans
  - cannibalistic



Wildlife.ca.gov – Striped Bass Fishing Map

Petition Background

- **Who** - Petitioner is the Nor-Cal Guides and Sportsmen's Association (NCGASA)
- **What** - Restrict the harvest of Striped Bass (SB) to a harvest slot limit (HSL) of 20-30 inches for inland anadromous and marine waters
- **Why** - NCGASA stated goal:
  - To protect the species by increasing the minimum length to allow more fish to mature and successfully spawn prior to harvest and
  - To protect the larger fish that tend to be the most prolific spawners and are becoming increasingly rare in the fishery
- **Current regulations**- 18-inch minimum length limit, 2 fish daily bag limit

FGC Striped Bass Policy

The Department of Fish and Wildlife shall…

- Ensure, enhance, & prevent loss of sport fishing opportunities
- Aim to maintain a self-sustaining Striped Bass population in support of a robust recreational fishery *while adhering to the Department's long-term mission related to threatened, endangered species, and other species of greatest conservation need*
- Work with relevant stakeholders, organizations, and the public to develop appropriate objectives to achieve these broad aims

CDFW Evaluation Contents

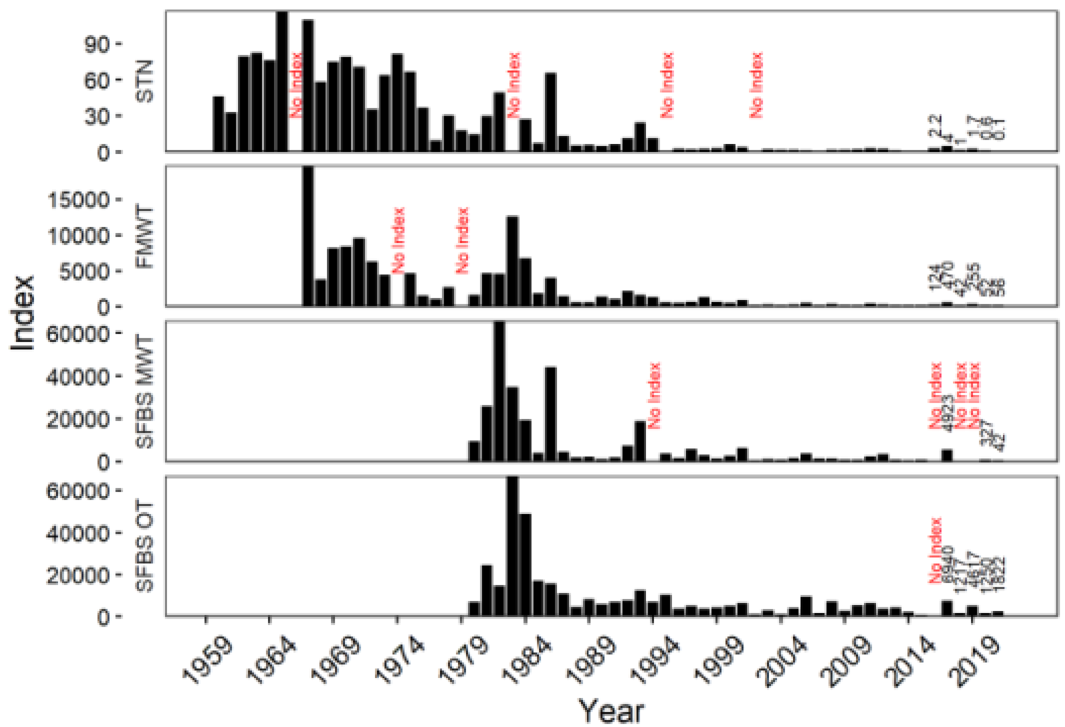
- Population and Fishery Trends:
  - Existing fisheries monitoring data
  - Marine and Inland Creel survey data
- Public Input*
- Population and fishery impacts of regulatory changes*
- Atlantic States SB regulations
- Predation impacts*

**Additional information included in Appendices*

Population Trends

Juvenile abundance surveys
(fishery independent surveys)

- Indicate some level of decline in catch of age-0 or young SB
    - Potential lateral shift in habitat usage by SB not well captured by survey methods

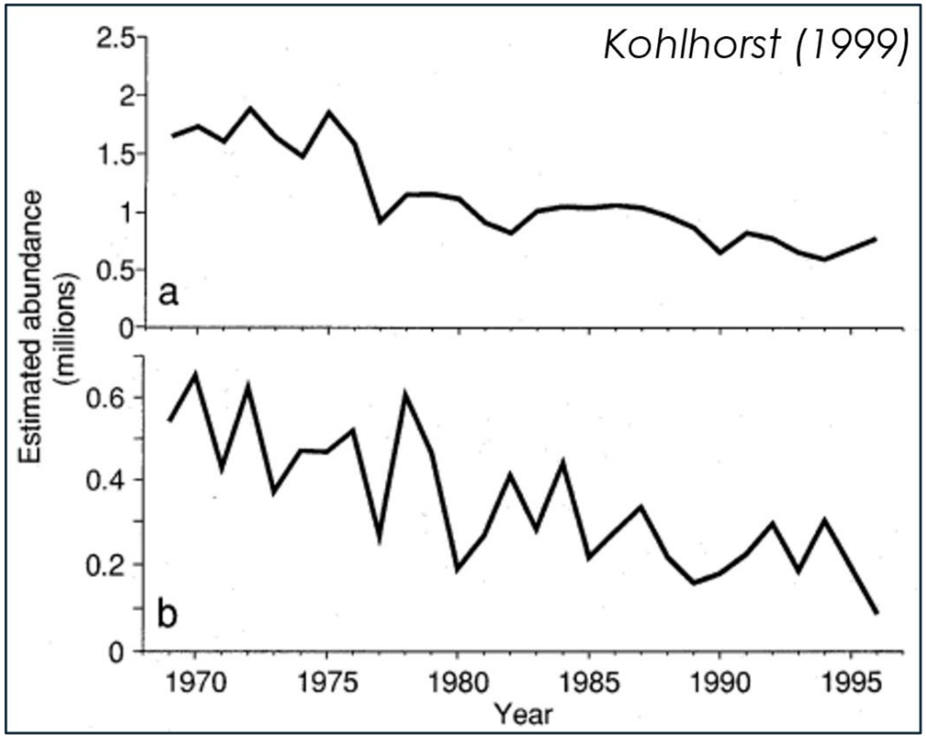


Malinich et al. 2022

Population Trends Cont.

Adult population monitoring
(fishery dependent data)

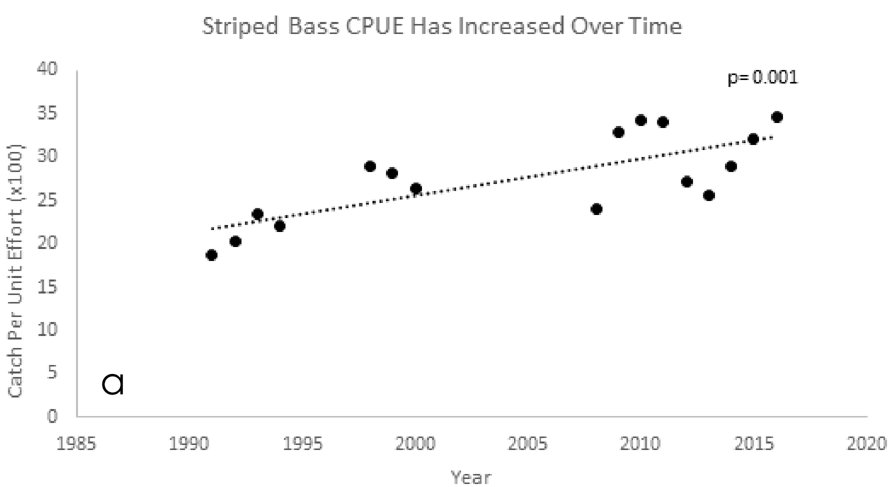
- Mark-recapture (Lincoln-Petersen Estimator):
  - Adult population numbers (**a**) and age-3 abundance (**b**) have declined from historical levels, but overall appear stable (**a**)
- Harvest and harvest rate (Lincoln-Harvest estimator):
  - ~1,157,275 > 18 inches TL (average, 2011-2016)

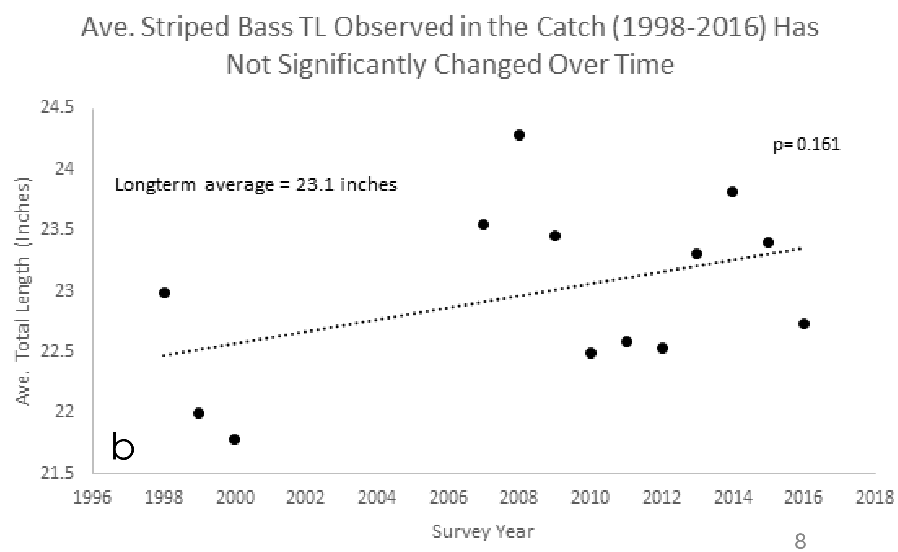


Fishery Trends

1991-2022 Creel Data (fishery dependent surveys)

- Angling effort targeting Striped Bass **has not** significantly changed
- Catch and Catch-per-unit-effort (CPUE, Fig. a) **have** significantly increased
- Harvest **has not** significantly changed over time
- Number of SB released over time **has** significantly increased
- Mean size of SB harvested **has not** significantly changed (~23 in; Fig. b)





Public Input

Joint Public Town Hall Meeting (August 24, 2022)

- Purpose – discuss the NCGASA regulation change petition and CDFW's evaluation plan
- Well Attended with 50 in-person and100 virtual participants
- Majority of commenters (40/45) supported 20-30-inch HSL

Angler Preference Questionnaire (July 26, 2022 – October 31, 2022)

- Purpose – Better understand anglers' sentiments about the SB fishery
- Distributed through email and social media
- Available in 7 languages (English, Spanish, Tagalog, Traditional Chinese, Simplified Chinese, Russian, Vietnamese)
- Questionnaire vetted for bias and leading language

Questionnaire Results

26,410 Total responses

- 18,751 respondents fish for SB
- 7,659 did not fish for SB

Brief results

- 71% of Striped Bass anglers support the current minimum size limit (MSL)
- If given the option
  - 54% of respondents would not change the MSL
  - 28% would either lower or no limit at all
- Trophy fish
  - 64% of respondents were in favor of catch-and-release trophy fishery
  - 30 inches (26%), 36 inches (15%), ≥ 40 inches (21%)

Photo credit: Erin Ferguson

Predicting the Impact of Regulatory Changes

Goal: Understand potential population and fishery tradeoffs resulting from proposed regulatory changes

Approach: Developed a sex-specific, age and size-structured population model for West Coast Striped Bass following methods in Gwinn et al. (2013)

FISH and FISHERIES

Original Article

Rethinking length-based fisheries regulations: the value of protecting old and large fish with harvest slots

Daniel C Gwinn, Micheal S Allen, Fiona D Johnston, Paul Brown, Charles R Todd, Robert Arlinghaus

First published: 07 September 2013 | https://doi.org/10.1111/faf.12053 | Citations: 134

Abstract

Managing fisheries using length-based harvest regulations is common, but such policies often create trade-offs among conservation (e.g. maintaining natural age-structure or spawning stock biomass) and fishery objectives (e.g. maximizing yield or harvest numbers). By focusing harvest on the larger (older) fish, minimum-length limits are thought to maximize biomass yield, but at the potential cost of severe age and size truncation at high fishing mortality. Harvest-slot-length limits (harvest slots) restrict harvest to intermediate lengths (ages), which may contribute to maintaining high harvest numbers and a more natural age-structure. However, an evaluation of minimum-length limits vs. harvest slots for jointly meeting fisheries and conservation objectives across a range of fish life-history strategies is currently lacking. We present a general age- and size-structured population model calibrated to several recreationally important fish

Predicting the Impact of Regulatory Changes Cont.

Approach: Evaluated how the following metrics would change in response to implementing a 20-30-inch HSL (proposed), 18-30-inch HSL (alternative), or 28-35-inch HSL (conservative) regulation:

- Stock Conservation:
  - Probability of recruitment overfishing (exploitation at a rate beyond stock replacement)
  - Proportion of fecundity contribution from older females (>10 years)
- Fishery:
  - Total catch, total harvest, and Trophy-size (> 30 inches) catch

Data: Input parameter data informed by multiple data sources, published values, and life-history theory

Model Results

Relative to the current 18-inch MLL:

- Probability of recruitment overfishing decreased under evaluated HSLs vs current 18-inch MLL
    - 20-30-inch HSL: ↓ 19%
    - 18-30-inch HSL: ↓ 14%
    - 28-35- inch HSL: ↓ 32%
- Reproductive contributions from older (thus larger) females increase under evaluated HSL vs MLL
- Increase in catch and trophy catch under evaluated HSLs
- Decrease in total harvest under evaluated
    - 20-30-inch HSL: ↓ 21%
    - 18-30-inch HSL: ↓ 8%
    - 28-35-inch HSL: ↓ 73%

Model Take-aways

- More favorable outcomes for nearly all management priorities (stock conservation and fishery) under evaluated HSLs compared to the currently enforced 18-inch MLL.
- Largest improvements were to the risk of recruitment overfishing [decreased] and catch of trophy-sized fish [increased]
- HSL Tradeoff: harvest numbers
- Effectiveness of HSLs can differ based on management priority:
    - Harvest: best supported by current MLL, or wide HSL
    - Population conservation: restrictive HSL to protect mature size-classes
    - Angler experience: HSLs that balance harvest and conservation

CDFW Does Not Support Increasing Lower Limit

CDFW does not support increasing the MLL from 18 inches to 20 inches

- Stock Conservation:
  - Similar gains in recruitment under 20-inch vs 18-inch lower slot limit (paired with 30-inch upper limit)
  - Greatest potential recruitment gains come from 30-inch harvest cap, not from shifting lower limit size
- Harvest:
  - Greater loss of harvest opportunity
    - 21% decrease in harvest under an 20-30-inch HSL vs an 8% decrease in under an 18-30-inch HSL
  - 18 and 19-inch Striped Bass represent ~ 20% of the harvest (creel surveys)
  - Harvest loss disproportionately affects disadvantaged communities
  - Increasing the lower limit will likely increase discard mortality

CDFW Does Not Support Increasing Lower Limit (cont.)

CDFW does not support increasing the MLL from 18 inches to 20 inches

- Predation considerations
  - Increased abundance of juvenile SB (which are more likely to consume smaller prey items such as salmonids at certain times of year) may increase predation on native and non-native species
- Angler Preference Questionnaire results indicate low support
  - 71% (11,981 out of 16,875) of respondents support the current minimum size retention at 18 inches
  - If given the option:
    - 54% (8,975 out of 16,621) of respondents did not support changing the minimum size limit from 18 inches
    - 28% (4,653 out of 16,621) supported lowering the minimum size or no minimum size at all

CDFW Could Support Implementing a 30-inch Upper Slot Limit

- **Benefit to anglers**
  - Create trophy fishery
  - Predicted to increase total catch
  - 18-30-inch HSL resulted in less impact to current harvest levels (8% predicted loss) compared to a 20-30-inch HSL (21% predicted loss)
- **Population benefits**
  - Decreases risk of recruitment overfishing compared to MLL
  - Predicted to increase egg contribution from older fish to total fecundity
    - Performs similarly to 20–30-inch HSL

Photo credit: Central Valley Angler Survey

Uncertainties and Additional Considerations

- It is unknown how environmental conditions (flow, temperature, water quality, etc.) constrain the Striped Bass population growth
- Implementing a slot limit will require modification to spear fishing regulations, which includes restricting as a method of take
- Discard mortality may increase as a result of a HSL regulation change
- Unknown effects of Striped Bass predation
- Lack of funding prevents current Striped Bass adult population monitoring to measure the effectiveness or impact of a regulation change

CDFW Conclusions

Petition Evaluation Biological Conclusion

- The added protection of raising the lower harvest limit to 20 inches is unlikely to provide the intended benefits of increased recruitment due to spawning of early-maturing females, as stated by petitioners.
- A 30-inch upper slot limit is more likely to provide stock conservation benefits through increased recruitment resulting from protections for older, larger spawning females.

Slot Limit Support

- While adult population and creel survey data suggest that the Striped Bass population is relatively stable in recent decades, *CDFW could support a slot limit to:*
  1) improve population resiliency to environmental stochasticity/perturbations
  2) improve the angling experience
     - Catch-and-release trophy fishery
     - Angler Preference Questionnaire showed general support for an upper limit

CDFW could support either "no change" or an 18-30-inch HSL

Questions?

Thank you!

California Department of Fish and Wildlife
StripedBass@wildlife.ca.gov

CALIFORNIA DEPARTMENT OF FISH AND WILDLIFE EVALUATION OF REGULATION CHANGE PETITION 2022–12: PROPOSED 20–30–INCH HARVEST SLOT LIMIT FOR STRIPED BASS (*MORONE SAXATILIS*)

Petition submitted August 1, 2022 by Nor–Cal Guides and Sportsmen's Association (NCGASA)

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Acknowledgements

We would like to acknowledge the invaluable intellectual contribution of Dr. Daniel Gwinn to the population modeling conducted in this evaluation. Additionally, we would like to thank John Kelly, Jim Hobbs, Dan Kratville, Steve Tsao, Kristen Ramey and Jay Rowan for their input, reviews, and contributions to the content of this evaluation.

Striped Bass Fishery Background

Native to the East and Gulf Coasts of North America, Striped Bass (*Morone saxatilis*) were introduced to Pacific waters in 1879 when 132 individuals were planted in San Francisco Bay (Scofield 1930). After one additional fish transfer in 1882 (Smith 1895), a commercial fishery was established in the San Francisco Bay area by the late 1880s (Hart 1973). To protect the increasingly popular sport fishery, the commercial Striped Bass fishery closed in 1935. Prior to 1956, fishing regulations generally included a 12–inch minimum length limit (MLL) and a five fish daily bag limit. From 1956–1981 the MLL increased to 16 inches with a daily bag limit reduction to three fish (Stevens and Kohlhorst 2001). In response to declines in legal–size Striped Bass in the 1970's (Kohlhorst 1999) and at the request of anglers, the California legislature established a short–lived Striped Bass Management program in 1981, which included stocking Striped Bass in California rivers using private and state–run hatcheries. In the same year, Striped Bass regulations were further restricted to an 18–inch MLL and a daily bag limit of two fish, (14 CCR 5.75; 14 CCR 27.85) which remain in effect today.

The Striped Bass Management Plan was terminated in 2004 due to observed increases in the Striped Bass population and growing concern over the impact of Striped Bass predation on native fish species (SB 692, 2003). In 2020, the Fish and Game Commission unanimously adopted an amendment to the Striped Bass policy that eliminated a numeric target for population size and replaced it with a broader commitment to sustain Striped Bass populations in support of a robust and self-sustaining recreational fishery (FGC 2020).

Summary of Proposed Regulation Change Petition

The Nor–Cal Guides and Sportsmen's Association (NCGASA) submitted a regulation change proposal to the Fish and Game Commission on August 1, 2022 (Tracking number [TN] 2022–12). The proposed regulation change would impose a slot limit within anadromous and marine waters whereby only Striped Bass from 20 to 30 inches would be available for harvest in the sport fishery, with no proposed change to the bag limit. Currently, any Striped Bass 18 inches or greater may be harvested within anadromous and marine waters with a daily bag limit of two fish. The NCGASA–proposed Striped Bass regulation change did not consider or propose any changes to the current bag limit, season, or geographic range.

The NCGASA stated need for the proposed shift from 18 to 20–inch minimum harvest length:

"This will allow more opportunity (at least one more year) for females to spawn after initial maturity (which is around 18 inches). It would also protect any unripe Striped Bass (male or female) that fall between 18 to 20 inches from harvest." (M. Smith, personal communication, November 1, 2022).

The NCGASA stated need for the proposed 30–inch maximum harvest length:

"This will allow protection to the most fecund female spawners and contributes to increased spawning success of the population." (M. Smith, personal communication, November 1, 2022).

Communication between NCGASA and the California Department of Fish and Wildlife (Department)

Since petition TN 2022-12 was submitted, the Department has met with NCGASA and their scientific advisors multiple times. The meetings and email correspondences helped to clarify desired short- and long-term Striped Bass fishery outcomes and share available data so that the Department could fairly and accurately evaluate the contents of the petition on its face, as well as the intent of the petitioner. Through those discussions the Department also tracked these additional comments from the petitioner.

Additional comments from NCGASA:

- *"The Striped Bass population is in desperate trouble at each life stage. The population is collapsing and is no longer viable," (Page 2, TN 2022–12).*
- *"Current regulations allow for the removal of female Striped Bass before they reach sexual maturity as well as removal of the largest females from the system," (Page 3, TN 2022–12).*
- *"20 inches may not be ideal for protecting reproductive females (that would be 24 or 26 inches) but it is an initial starting point that balances at least one more year toward maturity and maintains recreational angler opportunity. We are open to adjusting the lower slot upwards in a phased approach as populations sizes gradually increase."* (M. Smith, personal communication, November 1, 2022).

- *“20–30 inches was what the majority of the Striped Bass fishing organizations and angling community contacted by NCGASA from Monterey to Yuba City were in agreement to for socio economics and food for fishing families.”* (J. Stone, personal communication, November 1, 2022).

Evaluation Summary

The Department received and evaluated a regulation change petition (TN 2022–12), whereby if implemented, would impose a Harvest Slot Limit (HSL) of 20–30 inches on Striped Bass in marine and anadromous waters. The Department evaluated if the Striped Bass population warrants further protection through changes to current angling regulations, and if the proposed HSL would produce the biological and fisheries improvements desired by the petitioners.

Within Striped Bass native ranges, Atlantic states have adopted various combinations of regulatory practices to meet their management goals (Figure 15, ASMFC 2022). Examples include various harvest slot ranges, split slot limits, seasonal and geographic regulations, changes to bag limits, gear restrictions, and others. The petition only requested a specific HSL and did not include alternative HSL options or other considerations such as changes to season, bag limit, or geographic range; therefore the Department’s evaluation is focused on the proposed 20–30–inch HSL and does not include evaluation of these other factors. The Department gathered available data from inland and marine creel surveys, juvenile and adult abundance surveys, and a Striped Bass Angler Preference Questionnaire. Additionally, modeled population and fishery responses under the current 18–inch MLL regulation were compared to the proposed 20–30–inch HSL and an alternative 18–30–inch HSL that maintains the current 18–inch MLL.

The Department could support a regulation change for Striped Bass, including a HSL, if it were determined that the population warranted further regulatory protections or that regulatory protections would improve the angler experience.

Harvest slot limits can provide effective population and fisheries benefits such as increased productivity, population growth, reduced overfishing, and trophy fisheries. Harvest slot limits are best determined using species–specific biological metrics, population dynamics, consideration of environmental influences, impacts to fisheries participants, and management goals and objectives.

Relative to the current MLL, a HSL is estimated to decrease the risk of recruitment overfishing, defined as exploitation at a rate beyond stock replacement (Goodyear 1980, Mace and Sissenwine 1993) (Figure 13a). Therefore, implementation of an HSL may result in increased Striped Bass population growth if carrying capacity is not constrained. Population model simulations resulted in a 53% probability of recruitment overfishing (i.e., probability of a spawner potential ratio [SPR] < 0.35; Figure 13a) under the current 18–inch MLL, suggesting that the current regulation may not be adequate for long–term population sustainability and growth. Under an 18–30–inch and 20–30–inch HSL, model simulations resulted in a decreased risk of recruitment overfishing by 14% and 19%, respectively (Figure 13a), indicating that a harvest slot may improve recruitment success.

Population model simulations resulted in a higher proportion of fecundity contribution from older (age 10+) females under HSLs compared to the current MLL (Figure 13b), which may have positive implications on recruitment for Striped Bass. However, there was *no difference* in this metric between the 18–30–inch HSL and the 20–30–inch HSL. Thus, it is unlikely that raising the lower limit from 18 to 20-inch (while maintaining the 30–inch upper limit) will have substantial impacts on reproductive output.

Relative to the current MLL, the evaluated 18–30 inch and 20–30–inch HSL regulations resulted in similar improvements to catch and trophy–sized catch (Figure13e-f), but harvest was substantially lower under the 20–30–inch slot (21%; Figure 13d). Population model simulations resulted in 13% lower harvest under the proposed 20–30–inch HSL compared to the 18–30–inch HSL.

Prioritizing harvest numbers above other fishery objectives (e.g., increased catch, size of catch, fishing opportunities, angler satisfaction, etc.) is best supported by the current 18–inch MLL or implementing a wide harvest slot that encompasses the majority of sizes that are vulnerable to catch modeled for the recreational fishery. If the management objective is to enhance recreational fishing opportunities in the form of catch numbers, HSLs better achieve this goal compared to the current MLL. Possibly the most realized benefit of HSLs in terms of catch comes in the form of catch size, as HSLs produced substantially higher numbers of trophy–sized catch compared to the current MLL (Figure 13f). Thus, HSLs can provide multiple benefits to the angler experience, including higher catch rates and improved quality of catch (as defined by fish size). If the fishery objective is to be more protective and increase spawning opportunity, then the HSL needs to be set to minimize harvest of the most abundant spawning size classes, which will inherently decrease harvest opportunity.

As stated above, the focus of this evaluation was to determine if (1) the population warrants further protection through changes to current angling regulations and (2) to assess if the proposed HSL would produce the biological and fisheries improvements desired by the petitioners. While the Department is in support of an HSL for the Striped Bass fishery as a concept, available monitoring data suggest that the adult population is relatively stable and further protections to the population in the form of regulatory changes may not be warranted at this time; however, regulatory changes in the form of a slot limit could enhance recreational fishing opportunities in both catch numbers and catch size.

Declines in recruitment to age–0 in the Delta (Figure 8) suggests some level of reduced spawning and/or recruitment success, though recent abundance estimates (2011–2016) imply relative stability in the adult (> 18 inches TL) population.

Recent abundance estimates calculated using the combined inland and marine harvest estimated from the Central Valley Angler Survey (CVAS) and the California Recreational Fisheries Survey (CRFS) creel surveys, as well as harvest rate from tag returns, resulted in an average of 1,157,275 legal–sized (> 18–inches TL) Striped Bass estimated from 2011–2016. Relative measures of angler catch/harvest of adult Striped Bass collected in the CVAS also suggest stability in the adult (> 18 inches) population. Angler effort targeting Striped Bass has not significantly changed during 1991–2016, however, angler catch-per-unit-effort (CPUE) has increased significantly over the same period (Figure 2). Data collected from Commercial Passenger Fishing Vessels (CPFV) during 1995–2020 also indicate that CPUE has significantly increased over time (Figure 3). The average size of Striped Bass harvested by anglers has not changed significantly over time (Figure 5). However, length data on fish released was not historically recorded, and thus it is possible that the size of fish released in the fishery has changed over time.

Despite evidence of stability in the adult population, the Department is not opposed to implementing a HSL to benefit the angling experience. However, our evaluation has concluded that a 20–30–inch HSL, as proposed by petitioners, may not be adequate in meeting the petitioner's stated fishery and population objectives.

The Department does not support increasing the MLL from 18 to 20 inches because it would likely not produce the biological or fisheries responses described in the petition.

One of the stated desires of the petitioners is to protect the earliest spawners. The Department has determined that increasing the current MLL from 18 to 20 inches fails to provide sufficient protections to sexually mature female Striped Bass and would not provide the fisheries response sought. The potential for increased population fecundity contributed by mature females between 18 and 20 inches is negligible based on the percentage of female maturity in that size and age range. Females are roughly 3 years old at 18–20 inches. Literature on the fecundity and maturity of Striped Bass on the West Coast suggests that most females mature between ages 4 and 5 when they are around 22–24 inches, and nearly all females are mature by age 6 when they are approximately 27 inches (Collins 1982, Raney 1989, Scofield 1930). In Atlantic stocks, recent studies have found less than 10% of individuals mature at age 3 (Brown et al. 2024), and stock assessments for Atlantic Striped Bass use a sexual maturity of 0% for age–3 females in population models (ASMFC 2014, ASMFC 2022).

To incorporate natural variation in age–at–maturation in our population model of West Coast Striped Bass, we set the mean length at maturation for females at 22.8 inches with a 95% probability between ~ 20–26 inches (Appendix A2f). There was no difference in the proportion of fecundity contributed by older females when comparing the model simulations between the proposed 20–30–inch HSL inch to the alternative 18–30–inch HSL (Fig. 13b). In other words, increasing the lower limit from 18 to 20 inches does not translate into an increase in egg contribution by older fish. This is important for population persistence considering energy investment into individual offspring changes with female size, such that larger fish produce offspring that are greater in size and number compared to smaller fish (Lim et al. 2014). This can have implications on recruitment success, as larger offspring are less vulnerable to size–dependent mortality and therefore typically experience higher survival rates (Conover and Schultz 1997). The difference in the probability of recruitment overfishing (probability of SPR < 0.35) under an 18–30–inch HSL vs 20–30–inch HSL was relatively small (5%; Figure 13a), suggesting that recruitment gains under each lower limit are similar.

It is estimated that harvest would decrease by 21% under a 20–30–inch HSL compared to the current 18-inch MLL (Fig. 13d). This may have an outsized impact on disadvantaged communities that utilize Striped Bass for sustenance. Additionally, increasing the MLL to 20 inches is not supported by the angling public contacted through an electronic questionnaire distributed by CDFW (n = 18,751). The Striped Bass Angler Preference Questionnaire indicated that 71% supported the current 18–inch MLL. Data from inland and marine creel surveys indicate that Striped Bass CPUE, size of the catch, and harvest have been stable for decades, and both fisheries have seen an increase in the number of released Striped Bass.

Increasing the MLL from 18 to 20 inches will likely minimize potential population benefits due to an increase in discard mortality. Discard mortality (i.e., release mortality) can be high (Table 2.3), especially during unfavorable environmental conditions such as elevated water temperatures, which are common as climate change increases the severity and frequency of drought conditions in California. Discard mortality rates for California Striped Bass fisheries are not currently monitored; however, the Department's Central Valley Angler Survey qualitatively observes an increase in moribund Striped Bass during late–spring through summer when water temperatures are elevated. Mortality rates of discarded Striped Bass are well documented in Atlantic Coast recreational fisheries (see Appendix 2.1.2).

CDFW is supportive of an upper HSL to support a trophy fishery but has not determined if 30 inches is the most appropriate size.

The upper 30–inch HSL proposed by the petitioner was not determined based on biological evidence or supporting scientific data, but instead informed by angler preference in the Striped Bass fishing organizations and angling communities contacted by petitioners. The narrow focus of the current evaluation precluded additional analysis of what the most biologically appropriate HSL, or combination of regulatory strategies (as observed in the East Coast regulations), would be best to meet the goals of both the Department and the petitioners.

While it would be prudent to compare additional HSLs, the Department could support an upper HSL of 30 inches (as proposed by petitioners) to create opportunity for a trophy fishery. Results from the Striped Bass Angler Preference Questionnaire indicate that 63% of respondents were supportive of a catch–and–release trophy Striped Bass fishery. 'Trophy' size was also defined as ≥ 30 inches by most respondents in that survey). Based on the creel surveys, a 30–inch upper HSL would likely not have substantial impacts on harvest patterns. Creel data indicate that reported harvest of fish > 30 inches is low and many anglers informally report to creel clerks that they currently release larger fish for various reasons. Based on model results, implementing an upper slot limit of 30 inches with the current 18–inch MLL only decreased estimated harvest by approximately 8% (Figure 13d).

In concept, an upper HSL of 30 inches could be more protective of the female spawning biomass and may contribute to increased recruitment. Model simulations resulted in an 8.1% increase in the proportion of fecundity contributed by older fish under both evaluated HSLs (20-30 and 18–30 inch) compared to the current 18–inch MLL (Fig. 12b). However, a number of factors could minimize the expected recruitment response resulting from a 30-inch HSL. Anglers harvest a very low proportion of > 30–inch fish (< 6%; Figure 6 and Figure 7), and the Department lacks the data necessary to determine if this observation is driven by (1) anglers choosing to release larger fish, (2) low abundance of > 30–inch fish in the population, (3) larger fish being less vulnerable to catch in the fishery (see Appendix section 2.1.3), or (4) a combination of these factors.

Decreasing the upper slot limit (< 30 inches) may be necessary to be more protective of the greatest proportion of the female spawning biomass. Regardless, for significant spawning and recruitment gains to be realized, the benefit would likely come at the cost of harvest opportunity. With these considerations in mind, additional analysis would be necessary to determine if 30 inches is the most efficient upper HSL in terms of maximizing stock conservation gains while minimizing impacts to the fishery (i.e., loss of catch or harvest opportunity).

Implementation of a harvest slot may necessitate removal of spearfishing as a method of take for Striped Bass.

It is common to allow spearfishing for fish species with MLLs based on the assumption that anglers can visually estimate if a fish is larger than the minimum size. It becomes extremely difficult, if not impossible, for an angler to accurately visually estimate the size of a fish that has a minimum and maximum size limit. In addition, the lethal nature of a speargun would make it impossible to release a fish in good condition if outside the harvest slot. This can result in illegal harvest if retained and put the angler at risk; or the angler releases a moribund fish that can no longer contribute to future spawning and catch, which is counter to the purpose of the HSL. Additionally, the release of a moribund fish is considered wanton waste of fish by definition in regulation. California currently does not allow spearfishing take for any species with a harvest slot limit, however, a few regions on the East Coast allow take by spear where Striped Bass have slot limits (Figure 15).

Based on available data in California, there is insufficient evidence to support that Striped Bass predation is a primary contributor to declining salmonid and smelt populations.

Observations of salmonids in Striped Bass stomachs vary by life stage and season, but overall remains relatively low (Stevens 1966, Michel et al. 2018, Stompe et al. 2020, Peterson et al. 2020, Brandl et al. 2021). An extensive review of literature pertaining to Striped Bass predation in the Sacramento– San Joaquin River Delta suggests that sub–adult size classes are more likely to encounter and consume native fish due to their longer Delta and freshwater residency and more optimal predator–to–prey ratio (PPR) (see Appendix 3).

While older (larger) Striped Bass consume more prey on an individual basis, total consumption is often greater for sub–adults compared to adults due to a higher abundance of younger (smaller) fish (Loboschefsky et al. 2012). It is likely that smaller sub–adult Striped Bass (ages 1 and 2) that are present year–round and have a wide geographic distribution in the Delta and Central Valley rivers have more opportunity to contact native fish species. A shift in MLL from 18 to 20 inches may contribute to an increase or shift in predation habits for Striped Bass between 18 and 20 inches.

The majority of larger Striped Bass (> 21 inches, Dorazio et al. 1994) are migratory, spend less time in the freshwater environment, and are less likely to target smaller sized prey due to PPR. There may also be a contingent of large Striped Bass that are freshwater residents, posing some constant, yet unquantified, level of predation pressure. Establishing an upper HSL at 30 inches will not likely have a noticeable impact on predation of juvenile salmonids and smelt due to (1) PPR, (2) high variation in the size of prey consumed, and (3) little evidence of prey specialization.

Department Recommendation

The Department does not recommend a 20–30–inch HSL as proposed in the petition. The Department recommends maintaining the current 18–inch MLL regulation and is supportive of establishing an upper HSL. Modeling suggests a 30-inch upper limit could result in decreased risk of recruitment overfishing (and thus stock conservation benefits) and increased catch and trophy fishing opportunity, but it cannot confirm if 30 inches is the most appropriate size due to the narrow scope of the current analysis. While there is public support for maintaining the 18–inch MLL (71% or respondents) and establishing a catch–and–release trophy fishery (64% of respondents), the highest percentage of respondents supported no change in harvest regulations (54% of respondents) in the Striped Bass Angler Preference Questionnaire. Creel data suggest that the Striped Bass fishery in California is currently stable, and the current regulations are not contributing to perceived population declines; however, modeling results suggest that the current 18-inch MLL on its own may not be adequate for long-term population stability and growth.

The Department will continue to support harvest opportunity for anglers as long as the available data reflect trends that are in line with the guidance laid out in the Fish and Game Commission Striped Bass Policy. In the absence of additional funding, monitoring, and staffing that would be necessary to conduct a more comprehensive, multifaceted approach to determine the most effective angling regulation, the Department believes there could be some benefit to the Striped Bass fishery by implementing a HSL and could support a HSL of 18-30 inches.

Scientific Evaluation of Striped Bass Fishery

Evaluation of the health and performance of a fishery includes understanding angler usage and participation, appropriate regulatory tools to control the impact of recreational angling on fish stocks, biological fisheries metrics, and how these factors relate to management objectives and realized fisheries responses. In order for regulatory tools, such as daily bag and size limits, to be effective, responses in angler effort must be reliably estimated relative to regulatory adjustment or management objectives. However, predicting angler effort responses to regulatory adjustment is difficult because responses depend on many factors, including the structure of prevailing and proposed regulations and the drivers of angler behavior (Carr–Harris and Steinback 2020). While quantitatively accounting for angler effort responses in fishery outcomes was beyond the scope of this evaluation, data on angler preference and sentiment regarding the current fishery and alternative regulations were considered alongside biological fisheries metrics.

Female spawning stock biomass is a metric of stock performance that is often relied on in fisheries management. Understanding the biological consequences of alternative harvest size restrictions such as minimum length limits, harvest bag limits, harvest slots (minimum and maximum length limits), and protected harvest slots is important in preventing recruitment overfishing, a condition in which the spawning stock is depleted to a level at which future recruitment declines strongly (Allen et al. 2013). In practice, harvest slot policies have been proposed as alternatives to minimum length regulations in some recreational fisheries because they are more likely to preserve natural age structures, positively affect spawning and recruitment potential, increase total harvest and trophy catch numbers, and reduce risk of population decline (Arlinghaus et al., 2010, Koehn and Todd, 2012, Ayllón et al., 2019). The Department must evaluate if the Striped

Bass population is at risk of recruitment overfishing under current regulations, as well as weigh stock conservation outcomes against fishery objectives under alternative length–based harvest scenarios.

The Department's scientific evaluation of the Striped Bass fishery contains a summary of the Department's public outreach efforts in the form of results from the Striped Bass Angler Preference Questionnaire, proceedings from a town hall meeting, Striped Bass angling regulations from their native range of the Eastern United States, and assessments of available Department data sets (inland and marine creel surveys and juvenile and adult abundance monitoring). Additionally, the Department has leveraged current and historic data, literature, and life history modeling tools to inform an age and size–structured population model to evaluate potential fishery tradeoffs resulting from changes in harvest regulations. Lastly, considerations for how changing the current Striped Bass fishing regulations may impact native species is reviewed. This information was used to inform the Department's assessment of the necessity, effectiveness, and feasibility of implementing a 20–30–inch slot limit in the Striped Bass fishery.

Public Input

Understanding angler usage and participation is key to evaluating the health and performance of a fishery, as failing to consider angler effort responses can result in regulations that are insufficient in meeting intended objectives. (Carr–Harris and Steinback 2020). In response to the NCGASA proposal, the Department developed a Striped Bass Angler Preference Questionnaire and hosted a public Town Hall to gather information from the Striped Bass angling community on their thoughts about the overall fishery and determine if there was a general desire for changes to the Striped Bass fishery.

Striped Bass Angler Preference Questionnaire

The questionnaire was sent out electronically to ~1 million angling license holders and was available in 7[1] languages. Prior to distribution, the questionnaire was

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[1] The initial Striped Bass Angler Preference Questionnaire (APQ) was only distributed in English due to the timing aligned with the change of the State of California fiscal year (July 1) and the need for renewal of the translation services contract. Upon contract renewal, the survey was redistributed (through email and social media posts) in Spanish, Tagalog, Vietnamese, Russian, Simplified Chinese, and Traditional Chinese.

reviewed by Fisheries Branch managers, the Human Dimensions Unit (who reviewed content for bias, leading language, etc.), and final approval was given by the Office of Communication and Outreach Branch (OCEO). There were 26,410 responses to the questionnaire, of which 18,751 indicated they do fish for Striped Bass and 7,659 did not. Briefly, results show that ~71% of Striped Bass anglers (11,981 out of 16,875) support the current minimum size for retention at 18 inches. When offered options for changing the minimum size limit, 54% of responses (8,975 out of 16,621) did not support increasing the minimum size from 18 inches while ~28% (4,653 out of 16,621) supported either lowering the minimum or no minimum at all (Table 1). However, 64% of responses (10,750 out of 16,797) supported a catch–and–release fishery for trophy sized Striped Bass even if it would require setting a maximum size limit (in effect a slot limit) on Striped Bass that could be harvested (Table 2). The definition of a trophy Striped Bass varied widely between responses, with 30, 36, and >40 inches reported most frequently (Figure 1). Complete results can be found in Appendix 1.

Table 1. Results from Question 4 in the 2022 Striped Bass Angler Preference Questionnaire. Results reflect responses to the question "Would you like to see the minimum size limit for harvest of Striped Bass".

No change (%)	No minimum size (%)	Lower than 18 inches (%)	Higher than 18 inches (%)	Number of Responses
54	8	20	18	16,621

Table 2. Results from Question 6 in the 2022 Striped Bass Angler Preference Questionnaire. Results reflect responses to the question "Would you support a catch and release fishery for trophy sized Striped Bass? This would require setting a maximum size/slot limit on Striped Bass".

Yes (%)	No (%)	Number of Responses
64	36	16,797

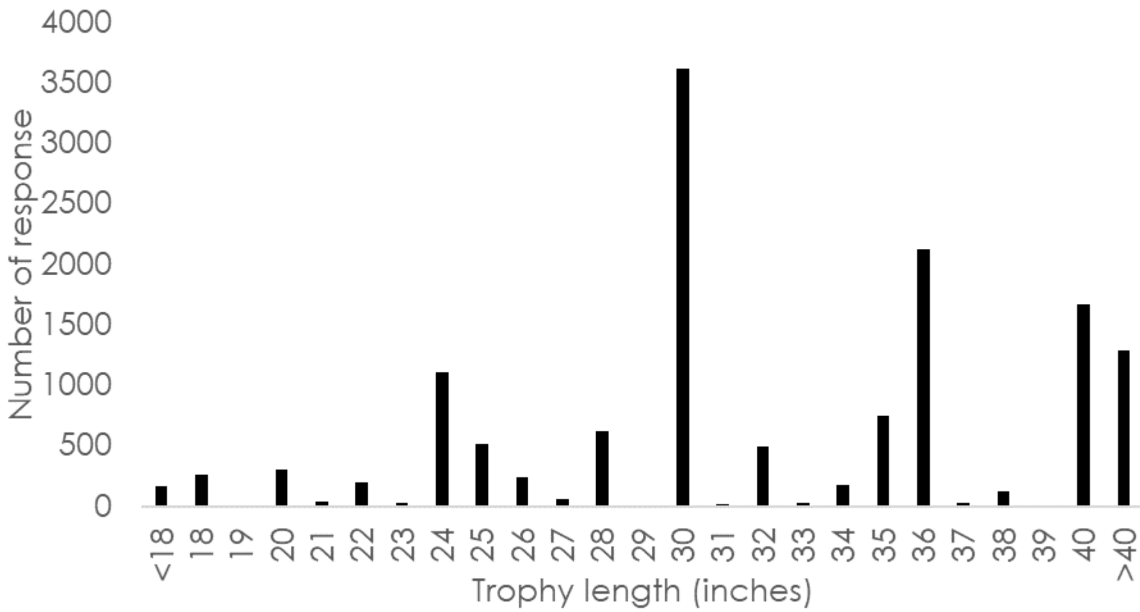


Figure 1. Figure 1.2 in Appendix 1, 2022 Striped Bass Angler Preference Questionnaire Results Summary. Fill–in–the blank responses to what size Striped Bass anglers considered a trophy. Data source: 2022 Striped Bass Angler Preference Questionnaire.

Joint Town Hall Meeting

The Department hosted a joint public town hall meeting with the NCGASA on August 24, 2022. The meeting platform was hybrid with the option to attend in–person at the Fisheries Branch headquarters in West Sacramento or virtually via Zoom. The purpose of the meeting was to discuss the regulation change petition brought forth by the NCGASA, the Department's evaluation of the petition to date, and allow public questions and comments to the NCGASA and the Department.

The meeting was well attended with approximately 50 members of the public in attendance and 100 more attending virtually. Forty–five public comments were made at the meeting with 40 commenters supporting the proposed slot limit (20–30 inches TL), two commenters opposing the proposed slot limit, and three commenters who were neutral on the issue.

CDFW Monitoring Studies

Angler Derived Fishery Data: Creel Surveys

There is limited monitoring data for Striped Bass in California, restricting the Department's ability to accurately estimate population and size class abundance. The Department's primary sources of recreational angling data are collected by our Inland (Central Valley Angler Survey) and Marine (California Recreational Fisheries Survey) creel programs. From these programs, fishery metrics such as effort, catch, harvest, and size of the catch can be estimated; however, the size ranges observed in the fishery may not be reflective of the size class distribution or abundance in the population.

CPUE as a relative measure of abundance, for the purpose of monitoring trends in the Striped Bass fishery, can be used when absolute population estimates do not exist (Hilborn and Walters 1992, Quinn and Deriso 1999). However, these measures are best used in conjunction with population estimates to better understand CPUE trends in a broader context (Ward et al. 2013). Hyperstability is the "illusion of plenty", where CPUE is not linearly related to fish density. This often occurs when fisheries target aggregations of fish. Catch rates can remain stable, while abundance of the population declines (Erisman et al. 2011). Hyperstability has been documented in many commercial fisheries and a few recreational fisheries (Shuter et al. 1998, Rose and Kulka 1999, Erisman et al. 2011), and is often attributed to fish aggregations and changes in gear efficiency in commercial fisheries. However, the mechanisms driving hyperstability in recreational fisheries can be attributed to improved fishing techniques (technology, gear, and bait) and information sharing (social media, etc.).

Department creel surveys try to account for sampling factors that could contribute to hyperstability through their study designs. Sampling occurs over a large geographic area, year–round, and applies other randomly selected factors (start times, launch locations/ports, sample day, etc.). Building random stratification into the study design captures variability in angler effort (spatially and temporally), fish distribution and/or seasonality, and the range of angler experience (catchability).

Based on The Department's Central Valley Angler Survey (CVAS) data, angler effort (total angler hours) targeting Striped Bass has not significantly changed during 1991–2016, however angler CPUE has increased significantly over the same period (Figure 2). Similarly, data collected from Commercial Passenger

Fishing Vessels (CPFV) during 1995–2020 also indicate that Striped Bass CPUE has significantly increased over time (Figure 3), providing evidence that fishery performance is improving in both fresh and marine waters.

While CPUE from angler–based surveys have remained relatively stable or even increased over time (potential hyperstability), recruitment to age–0 has precipitously declined in the Delta (see Juvenile and Adult Monitoring section below). However, recruitment to age 3 (size of entry to the fishery) has been shown to be strongly density dependent (Figure 4, Kimmerer et al. 2000). This may buffer changes in fishable sized Striped Bass from the decline in recruitment of age–0 fish.

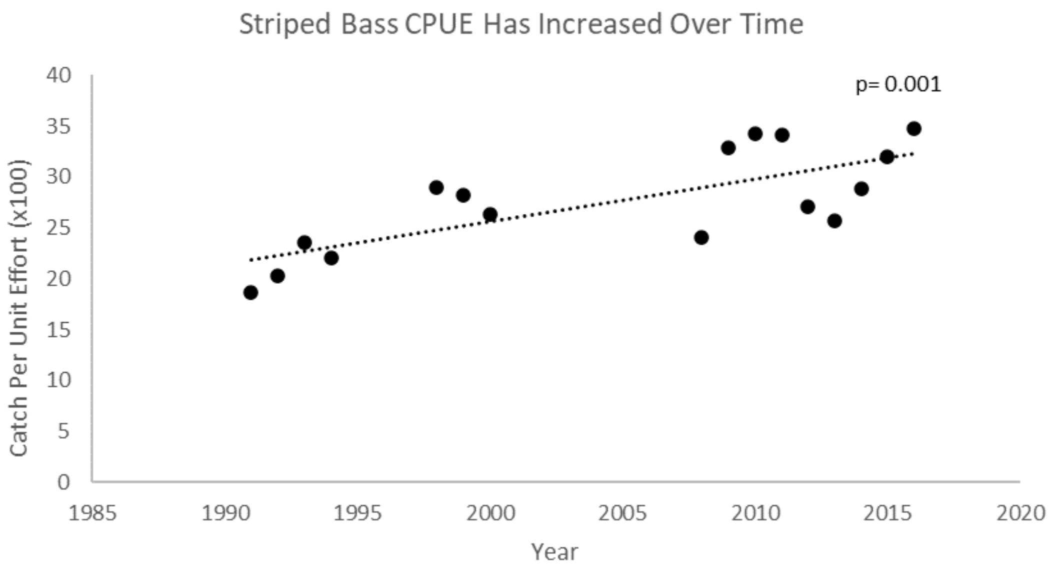


Figure 2. Average catch of Striped Bass per angler hour. Striped Bass CPUE has significantly increased over time (p = 0.001). Data source: CVAS data.

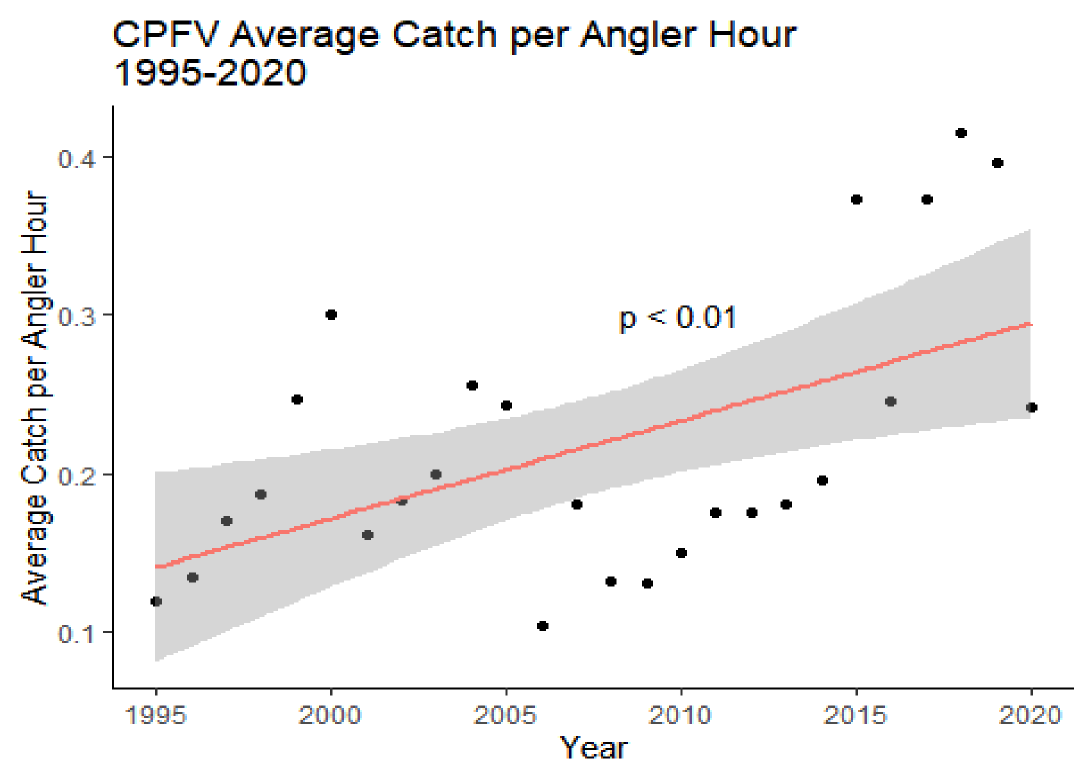


Figure 3. Average catch of Striped Bass per angler hour. Data source: CPFV Logs.

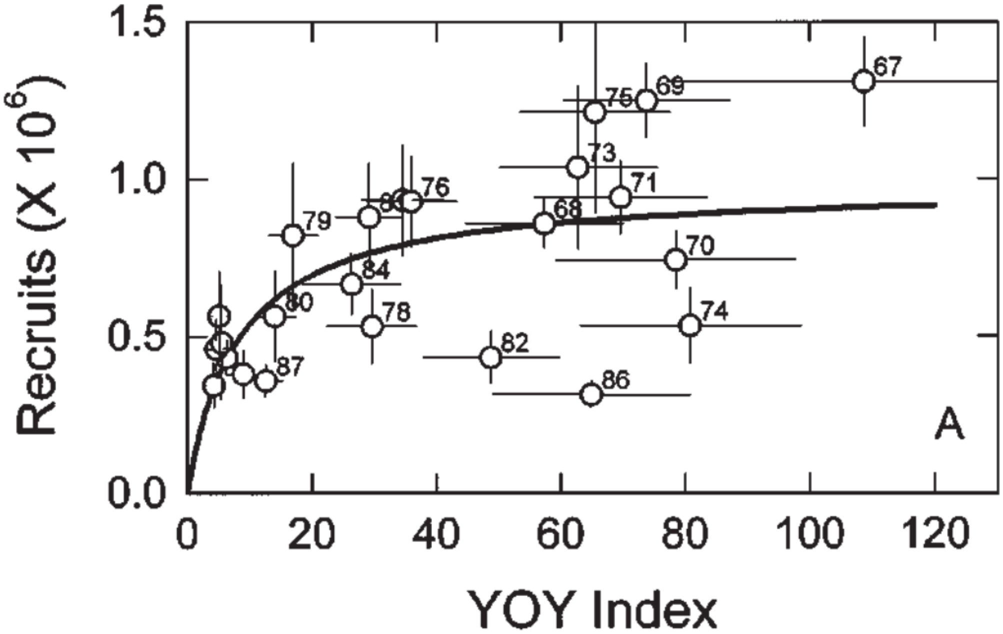


Figure 4. From Kimmerer et al. 2000 Fig 5(A). Young–of–the–year (YOY) index was estimated from a combination of Summer Townet Survey, Fall Midwater Trawl Survey and the San Francisco Bay Study. Recruits refers to abundance estimates of age–3 fish in the Adult Striped Bass Study.

Catch-per-unit-effort is one metric which is often used to evaluate fisheries stability. A declining CPUE may be an indication of overexploitation by recreational anglers. While an increasing CPUE may result from improvements in fishing technology (lures, fish finders, etc.) that increase anglers' ability to locate and catch fish, and/or may be an indication of an increasing Striped Bass population, particularly of sub–adults that are sub–legal size (<18 inches) for harvest in the fishery. Evidence of the latter comes from the significant increase in numbers of Striped Bass reported as released in both the inland and ocean/bay fisheries. Anglers typically report releasing Striped Bass because they are 1) practicing catch–and–release fishing, 2) the fish is larger than they find desirable, and most commonly 3) because the fish is smaller than what they can either legally keep or want to keep. However, angler catch data alone cannot be used to assess the status and trends of the Striped Bass population; fishery–independent population studies and assessments are also needed to address these questions.

Another metric that can be evaluated for fisheries performance is fish size. An indication that a fishery may be in decline is a significant decrease in the size of fish harvested. The average size of Striped Bass harvested by anglers has not changed significantly over time (Figure 5). Inland harvest from 1998–2016 has remained around 23 inches total length (average), while Striped Bass harvested in the ocean/bay from 2010–2021 averages around 22 inches. Unfortunately, neither inland nor ocean surveys have historically collected size data on fish that are reported as released, thus it is possible that the size of fish released in the fishery has declined over time. Additionally, creel surveys do not monitor the nighttime Striped Bass fishery, so it is possible that there may be a difference in the size of Striped Bass harvested during the day when compared to what is harvested at night. Currently the Department does not have data to address these questions.

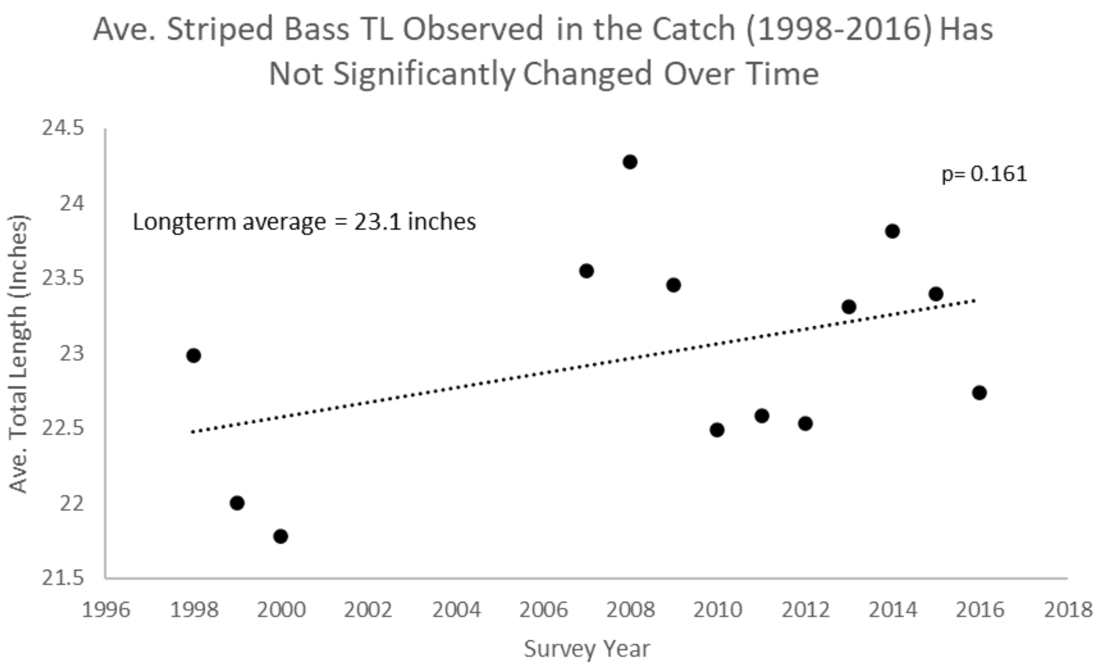


Figure 5. The average size of Striped Bass observed in angler catch by the Survey. The slope of the trend line is not significantly different than 0 ($p = 0.161$) over the sampling period 1998–2016. Data source: CVAS.

Changes to Striped Bass fishing regulations may have unintended consequences, such as decreased harvest opportunity. For example, an increase to the minimum size for retention may decrease harvest opportunities for all anglers and may disproportionately impact disadvantaged communities that rely on recreational harvest for food security. In a survey commissioned by the California Department of Water Resources (DWR) (Ag. Innovations 2021), 90% of disadvantaged community (DAC) respondents indicated that they or their families consume fish from the Delta four to five times per week. Striped Bass comprised 33% of the catch that DAC anglers reportedly harvested. Currently, Striped Bass harvested in the < 20–inch category represents ~20% of the inland harvest (as reported by CVAS), and ~9% of the ocean/bay harvest (as reported by CRFS). This indicates that Striped Bass anglers are willing to keep smaller fish and may already struggle to catch legal–sized Striped Bass (Figures 6 and 7).

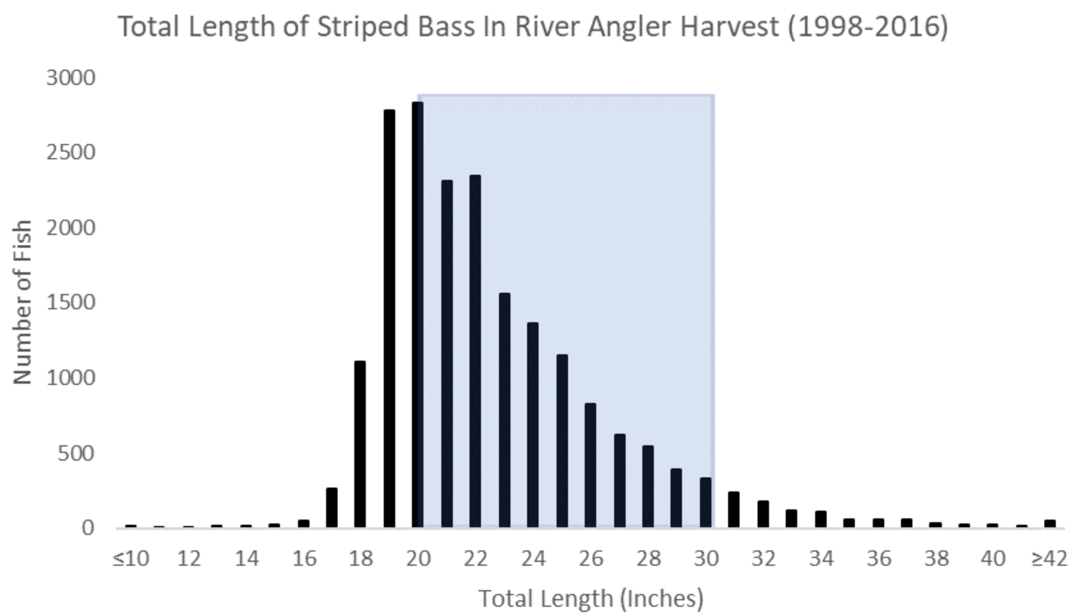


Figure 6. Length–frequency distribution of Striped Bass observed in angler harvest for Central Valley during 1998–2016. Proposed NCGASA slot limit highlighted in blue (74% of reported harvest falls within this range). Data Source: CVAS.

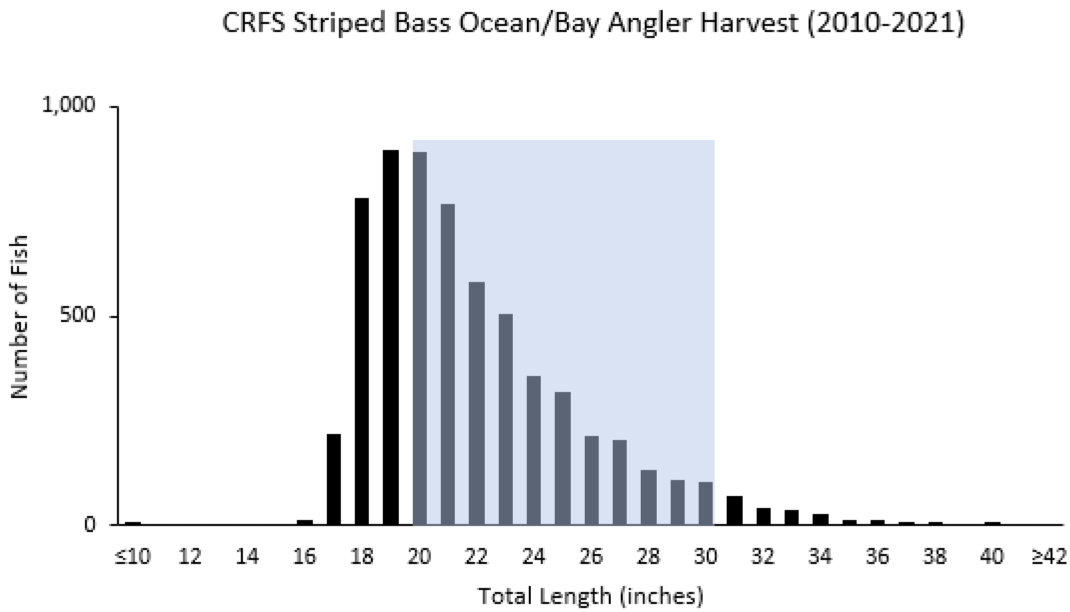


Figure 7. Length–frequency distribution of Striped Bass observed in angler harvest for Ocean/Bay during 2010–2021. Proposed NCGASA slot limit highlighted in blue (87% of reported harvest falls within this range). Data source: RecFIN (CRFS).

Juvenile Abundance Indices

Juvenile abundance for Striped Bass inhabiting the Sacramento–San Joaquin Delta have been indexed using data collected during the Summer Townet Survey (STN, since 1959) and the Fall Midwater Trawl Survey (FMWT, since 1967). These surveys sample the pelagic, open–water habitats of the Delta through San Pablo Bay and target primarily age–0 fish. Age–0 Striped Bass abundance has also been indexed from the San Francisco Bay Study otter and midwater trawls (since 1980), which sample benthic and pelagic open–water habitats from the confluence of the Sacramento–San Joaquin Rivers to South San Francisco Bay. Finally, the UC Davis Suisun Marsh Fish Study (since 1980) also provides a long–term metric of juvenile abundance for Striped Bass inhabiting the sloughs of Suisun Marsh (data available upon request to UC Davis).

All the above–mentioned surveys have documented some level of decline in catch of age–0 or young Striped Bass over their operating history (Figures 8 and 9). These declines are most drastic in the open water surveys (STN, FMWT, SF Bay Study), while the Suisun Marsh Fish Study does not show as steep of a decline (Figure 9). The scale of the decline in the open water surveys may be partially explained by a lateral shift in distribution away from channel habitats to shoal habitats, which are generally not as well surveyed by the STN, FMWT, and San Francisco Bay Study (Sommer et al. 2011). Regardless, the decline in abundance amongst all surveys to some degree indicates reduced spawning success and recruitment to age–0.

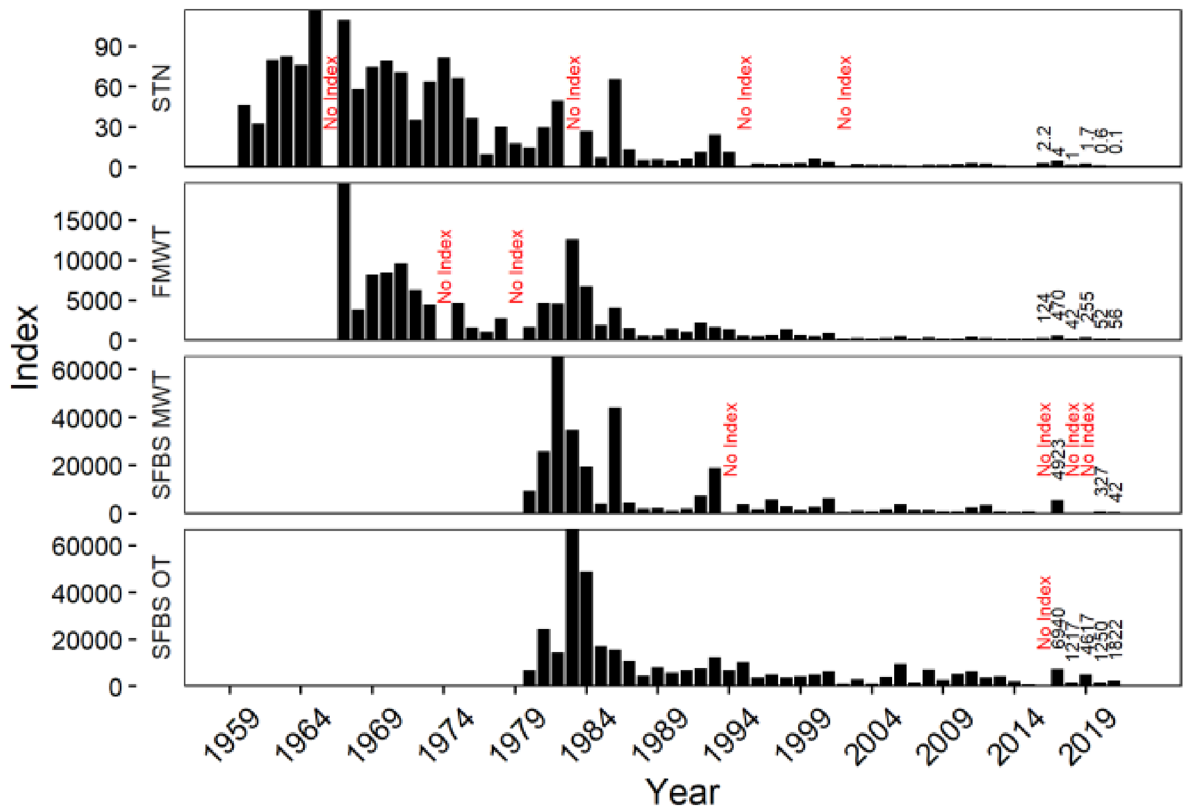


Figure 8. Figure 13 in Malinich et al. 2022. Index values for age–0+ (STN, FMWT) and age–0 Striped Bass (SFBS MWT, SFBS OT) from the Summer Townet Survey (STN), Fall Midwater Trawl (FMWT) and San Francisco Bay Study (SFBS) midwater trawl (MWT) and otter trawl (OT). See Malinich et al. (2022) for description of index values.

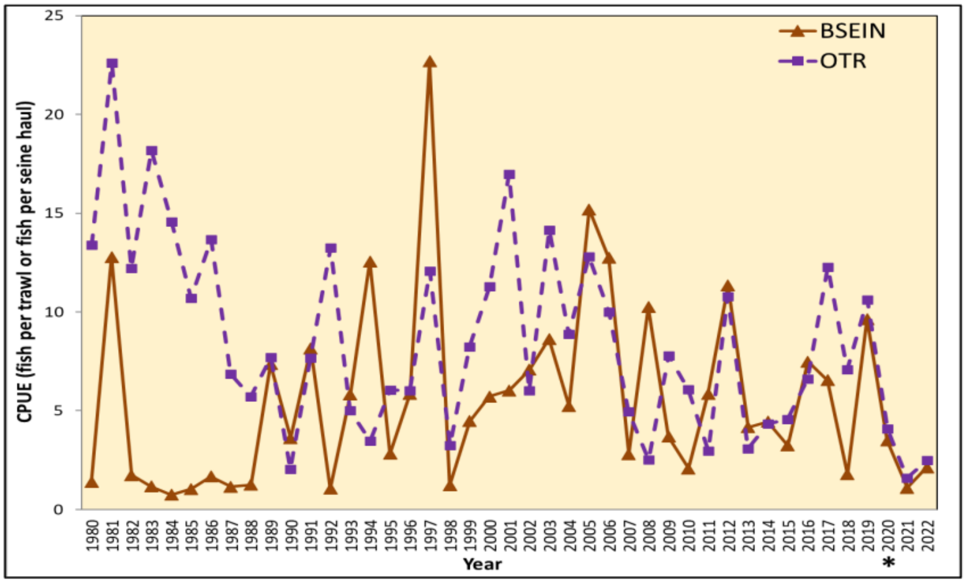


Figure 9. Figure 22 from O'Rear et al. (2022). Catch per unit effort (CPUE) of Striped Bass from the Suisun Marsh Fish Study beach seine (BSEIN) and otter trawl (OTR) surveys. See O'Rear et al. (2022) for description of CPUE calculations.

Adult Population Monitoring

Adult abundance was first estimated in 1969 and continued through the early 2000s. These estimates relied on tagging and subsequent recapture of tagged individuals to generate Lincoln–Petersen population estimates. Estimates show a decline from 1.5–2 million adults in the 1960s and 1970s to fewer than 1 million adults by the late 1990s (Figure 10a). Similarly, age–3 Striped Bass declined from over 600,000 to approximately 100,000 during the same time period (Figure 10b). Harvest rates have also been generated as a product of the adult mark–recapture program. Using high–reward tags and angler tag returns, harvest rates can be calculated from 2011 to 2022. During this time period, harvest rates averaged 12%, with a low of approximately 4% in 2015 and a high of 29% in 2017 (Figure 11). Decreased funding and an associated reduction in the number of tags released and recovered resulted in the inability to reliably calculate abundance estimates using mark–recapture methods after the early 2000s. However, recent abundance estimates calculated using the combined inland and marine harvest estimated from CVAS and CRFS creel surveys, as well as harvest rate from tag returns, resulted in an average of 1,157,275 legal–sized (> 18–inches TL) Striped Bass estimated from 2011–2016. Abundance estimates during this period ranged from 604,695 legal–sized Striped Bass in 2013 to 2,252,748 in 2015. Abundance estimates using harvest and harvest rate are restricted to this time period due to year–round sampling limitations by CVAS. Additionally, these estimates do not account for harvest in the night fishery or from those fish harvested outside of the CVAS survey area and are therefore biased low.

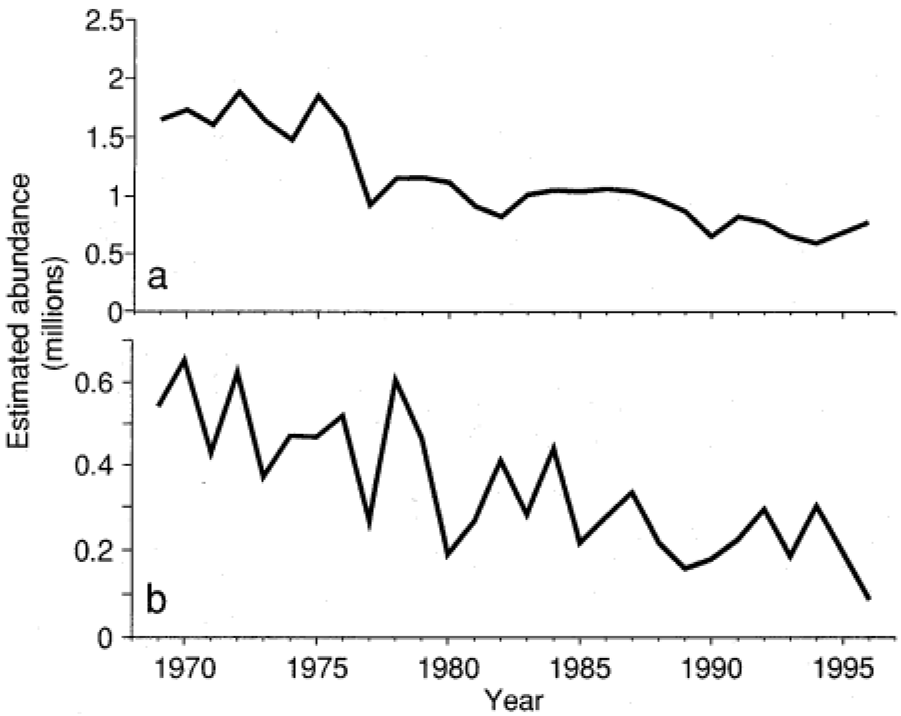


Figure 10. Estimated abundance of a) legal sized Striped Bass (≥ 18inches total length) and b) age–3 Striped Bass in the Sacramento–San Joaquin Watershed from 1969–1996. Figure from Kohlhorst (1999).

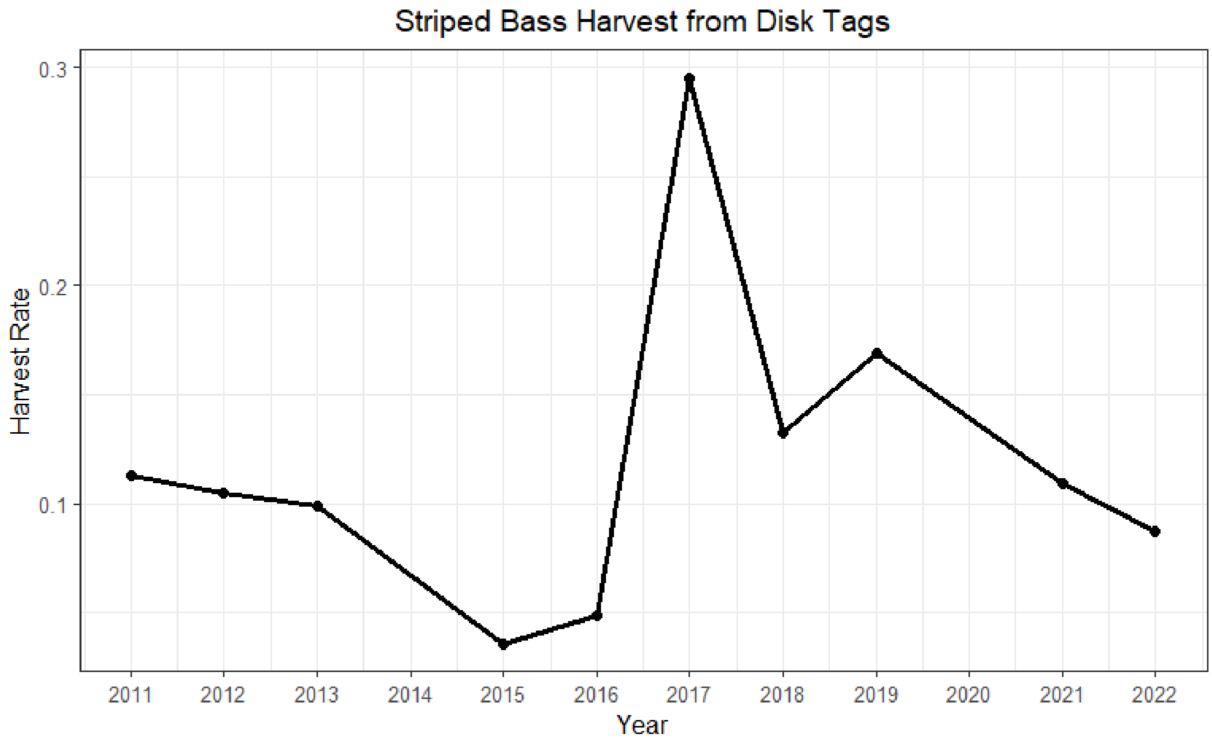


Figure 11. Estimated harvest rate of Striped Bass in the Sacramento–San Joaquin Watershed from 2011–2022.

Population Model

Model overview

To understand potential fishery tradeoffs resulting from proposed regulatory changes to the Striped Bass (*Morone saxatilis*) recreational fishery, we developed a sex–specific age and size–structured population model. The model predicts the sex–specific abundance of growth–type groups for each age at equilibrium as a function of density–dependent recruitment, natural mortality, harvest mortality, and discard mortality. The model accounts for differences in the impact of length–based harvest on females and males by modelling their abundance independently with different average growth rates and contributions to the total fecundity of the stock. Multiple growth–type groups were modelled for each sex to account for inherent variation in fish growth and the cumulative effects of size–selective harvest on the size structure of the stock. We applied the model to evaluate the relative performance of a range of length–based harvest restrictions with a focus on the current MLL and a recently proposed harvest–slot limit (HSL) at meeting fisheries and conservation management objectives. To account for uncertainty in life history, recruitment, and fishery inputs, we simulated the distribution of plausible model outcomes using a Monte Carlo simulation approach. With this approach we evaluated four management priorities, including stock conservation, total harvest, catch of trophy–sized fish, and total catch.

Methods

Model Formulation

We model the number of fish of each sex and growth–type–group recruiting to age–1 at equilibrium ($R_{g,s}$) with a Botsford–modified Beverton–Holt stock–recruitment function (Beverton and Holt 1957, Botsford and Wickham 1979, Botsford 1981a, Botsford 1981b) as,

Equation (Eq.) 1

$$R_{g,s} = \dot{p}_s p_g R_0 \left(\frac{CR - \phi_0/\phi_f}{CR - 1} \right),$$

where CR is the Goodyear recruitment compensation ratio (Goodyear 1977, 1980) that describes the maximum relative increase in juvenile survival as the total fecundity is reduced from the unfished biomass to near zero (Walter and Martell 2004). The parameters ϕ_0 and ϕ_f are the per–recruit fecundity of the unexploited stock and the exploited stock, respectively. The parameter R_0 is the average number of juvenile fish recruiting to age–1 in the unfished stock, which is analogous to the carrying capacity of the stock. The parameter p_g is a vector of fixed proportions that apportion the number of recruits each year to each growth–type–group (g). By apportioning recruits in fixed proportions, the assumption that variation in growth is a non–heritable trait is made explicit. The parameter $\dot{p}_s$ is a fixed sex ratio of recruits.

The fecundity per recruit of the stock in the fished (ϕ_f) and unfished (ϕ_0) condition was calculated as,

Eq. 2

$$\phi = \sum_a \sum_g p_{g,s=f} S_{a,g,s=f} f_{a,g,s=f} \left(1 - e^{-\theta * p_{male}}\right),$$

where $S_{a,g,s=f}$ is finite survival rate for females, and $f_{a,g,s=f}$ is the reproductive biomass of females at age a in growth–type–group g. The term $(1-e^{-\theta * p_{male}})$ modifies the fecundity based on the ratio of reproductive males to females –per Heppel et al. (2006), where the parameter p_{male} represents the per–recruit proportion of mature males in the fished condition and θ represents the relative contribution of male to female reproductive biomass in the reproductive process. This modification to the per–recruit fecundity calculation formalizes the assumption that females are the primary contributors to the annual fecundity of the stock while accounting for the influence of altered sex ratios due to differential effects of size–selective harvest on the male and female components of the stock. The reproductive biomass $f_{a,g,s}$ for both sexes was approximated as the difference between the weight and weight–at–maturation for each age, growth–type–group, and sex.

For each sex and growth–type–group, survivorship S to age a was calculated recursively as,

Eq. 3

$$S_{a,g,s} = S_{a-1,g,s} e^{-M_{a-1,g,s}} (1 - \dot{V}_{a-1,g,s} V_{a-1,g,s} U)(1 - (\dot{V}_{a-1,g,s} \dot{U} - \dot{V}_{a-1,g,s} V_{a-1,g,s} U) D),$$

where $S_{a-1,g,s}$ is the finite annual natural survival rate (i.e., $S_{a,g,s} = e^{-M_{a,g,s}}$) that models the proportion of fish surviving from deaths due to natural causes. The parameter $M_{a,g,s}$ is the instantaneous annual natural mortality rate, and the terms $\dot{V}_{a,g,s}$ and $V_{a,g,s}$ are the length–based vulnerabilities of fish to capture and harvest (respectively). The parameter D models discard mortality rate, which represents the proportion of caught and released fish that die due to the capture and handling process, and $\dot{U}$ and U represent capture and harvest rate, respectively.

We modeled the instantaneous annual natural mortality rate $M_{a,g,s}$ as inversely proportional to fish length per Lorenzen (2000) as,

Eq. 4

$$M_{a,g,s} = M_{ref} \left(\frac{L_{ref}}{L_{a,g,s}} \right),$$

where L_{ref} is a reference length where the natural mortality rate is known to be a given value (i.e., M_{ref}). This formulation describes natural mortality as higher for smaller, younger fish and lower for larger, older fish, which is a pattern that is consistent across fish species (Lorenzen 2000) and is important when determining length–based harvest regulations (Ahrens et al. 2020).

The vulnerability of each sex, age and growth–type–group to capture ($\dot{V}_{a,g,s}$ in Eq. 3) was described as a dome shape with a double logistic model to describe reduced vulnerability of smaller and larger fish relative to moderate sizes as,

Eq. 5

$$\dot{V}_{a,g,s} = \left(\frac{1}{1 + e^{-\left(\frac{L_{a,g,s} - L_{low}}{\sigma * L_{a,g,s}}\right)}} - \frac{1}{1 + e^{-\left(\frac{L_{a,g,s} - L_{high}}{\sigma * L_{a,g,s}}\right)}} \right),$$

where $L_{a,g,s}$ is the length of fish at age a in growth–type–group g for sex s; L_{low} is the lower total length at which fish are 50% vulnerable to capture; L_{high} is the upper total length at 50% vulnerability to capture; and σ approximates the standard deviation of the logistic distribution. The left terms in Eq. 5 model increasing vulnerability to angling with length, and the right terms models declining vulnerability to angling with length. Values of σ specify the steepness of each side of the dome–shaped vulnerability curve.

The vulnerability of each sex, age and growth–type–group to harvest was modeled as Boolean variables where a value of 1 indicated that fish of age a in growth–type–group g were of size legal to harvest (i.e., within range given the MLL or HSL evaluated) and a value of 0 indicated that they were not. Thus, we specified vulnerability to harvest with a logical test as,

Eq. 6

$$V_{a,g,s} = 1, \text{ when } L_{min} < L_{a,g,s} < L_{max}$$

$$V_{a,g,s} = 0, \text{ when } L_{min} > L_{a,g,s} \text{ or } L_{max} < L_{a,g,s}$$

Where specified values of L_{min} and L_{max} represent the length–based harvest regulation, with L_{min} as the lower and L_{max} as the upper legal length for harvest.

We modelled the growth of males and female fish in each growth–type–group independently with a standard Bertalanffy (1938) growth model as,

Eq. 7

$$L_{a,g,s} = L_{\infty,g,s}\left(1 - e^{-k(a-t_0)}\right),$$

where $L_{\infty,g,s}$ is the asymptotic (maximum) size of growth–type–group g for sex s, k is the metabolic parameter that determines the rate that $L_{\infty,g,s}$ is attained, and t_0 is the theoretical age at length equal to zero. We simulated variability in growth by assigning each growth–type–group a unique $L_{\infty,g,s}$ based on a range between ± 20% of an average annual asymptotic length $\bar{L}_{\infty,s}$ (Walters and Martell 2004). The weight of fish was calculated with a standard weight/length relationship as:

Eq. 8

$$w_{a,g,s} = aL_{a,g,s}{}^{b},$$

where a is the scaling parameter and b is the allometric parameter that modifies the relationship between length and weight.

Simulation Process

We ran our model as a Monte Carlo simulation in three main steps by, 1) defining a set of MLL and HSL regulations to be evaluated, 2) generating a random sample of input parameter values, and 3) running the model iteratively for the full combination of regulations and inputs to produce a sample of predicted outcomes for each regulation. We defined a set of length–based regulations as the combination of a range of minimum (L_{min}) and maximum (L_{max}) legal–size limits. We achieved this by creating vectors for L_{min} and L_{max} in 1 cm increments from 30 cm to a maximum legal length L_{max}(set at 182 cm, i.e., + 20% the maximum value of $\bar{L}_{\infty}$). The vector for L_{max} ranged from the minimum value of the L_{min} vector +1 (i.e., 31 cm) to 182 cm. All regulations with $L_{max} = 182\ \mathrm{cm}$ and $L_{min} < 182\ \mathrm{cm}$ represent MLL regulations while all regulations with $L_{min} < L_{max} < 182\ \mathrm{cm}$ represent HSL regulations. All regulations with $L_{min} > L_{max}$ were excluded from the process.

All additional input parameters were either fixed values or drawn randomly from sampling distributions to account for fishery and biological uncertainty. Distributions for randomly drawn inputs were specified such that the central tendency and variation in parameter values were plausible based on multiple data sources, published values, and life–history theory. The uncertainty associated with key life history and stock recruitment inputs including the density–dependent compensation ratio CR, the average asymptotic length $\overline{L}_{\infty}$, the metabolic growth parameter k, the instantaneous natural mortality rate M_{ref}, and the length at maturation L_{mat} were obtained using the R package *Fishlife* (Thorson et al. 2017, Thorson 2019, Thorson 2022). The R package *Fishlife* was created to provide life history and stock recruitment parameters with measures of uncertainty important for determining sustainable regulations for data–limited fisheries. The package utilizes data from over 10,000 fish populations contained in the Fishbase database (Froese and Pauly 2017) in a hierarchical multivariate generalized linear mixed model to predict mean parameter values and a covariance matrix based on taxonomic relationships. To further inform the estimation process, we used parameter values available in the literature with the model updating feature provided in the package to produce the covariance matrix used for generating these input parameters (e.g., Rudd et al. 2019). All input parameters of the model, mean values, and sampling distributions are defined in Tables 3 and 4, and fully justified in Appendix 2.

Table 3. Average life history and biological parameter input values used for population simulations of Striped Bass.

Parameter	Description	Male Value	Female Value	Sampling Distribution
R_0 [2]	Beverton-Holt Stock Recruitment: Average annual unfished recruitment	1	1	Fixed
CR [2]	Beverton-Holt Stock Recruitment: Compensation ratio	11.6	11.6	$CR \sim \mathrm{MvN}(\mu, \Sigma)$
θ [2]	Sex ratio: Fertility function parameter	-	50.4	$\theta \sim \mathrm{U}(a = 20, b = 8($
$L_{\infty,min}$ [3]	Growth: Minimum asymptotic length (cm)	96.8	106.3	Derived
$L_{\infty,max}$ [3]	Growth: Maximum asymptotic length (cm)	145.2	159.5	Derived
$\overline{L}_\infty$ [4]	Growth: Average asymptotic length (cm)	121	132.9	$\overline{L}_\infty \sim \mathrm{MvN}(\mu, \Sigma)$
k [4]	Growth: Von Bertalanffy growth coefficient (yr^{-1})	0.1	0.1	$k \sim \mathrm{MvN}(\mu, \Sigma)$
t_0 [4]	Growth: Theoretical age at length 0 (years)	-1.4	-1.4	Fixed
L_{mat} [4]	Maturation: Length (cm) at maturation (years)	35.1	58	$L_{mat} \sim \mathrm{MvN}(\mu, \Sigma)$
A_{max}	Mortality: Maximum age (years)	30	30	Fixed
M_{ref} [5]	Mortality: Natural mortality rate at L_{ref} (yr^{-1})	0.15	0.15	$M_{ref} \sim \mathrm{MvN}(\mu, \Sigma)$
L_{ref} [5]	Mortality: Reference length where $M = M_{ref}$ (cm)	90	90	Fixed
a [6]	Length-weight: scaling parameter	4.8×10^{-5}	2.7×10^{-5}	Fixed
b [6]	Length-weight: allometric parameter	2.7	2.8	Fixed

[2] Appendix 2.2.5

[3] Appendix 2.2.1

[4] Appendix 2.2.3

[5] Appendix 2.2.4

[6] Appendix 2.2.2

Table 4. Average fishery parameter input values used for population simulations of Striped Bass.

Parameter	Description	Mean Value	Sampling Distribution
L_{troph}	Minimum TL of trophy-size fish (cm)	76	Fixed
D [7]	Discard Mortality rate	0.29	$D \sim B(\alpha = 3.75, \beta = 9.25)$
U [8]	Harvest rate	0.14	$U \sim B(\alpha = 5 , \beta = 30)$
$\dot{U}$ [8]	Catch rate	0.35	$U/(1 - r_{rate})$
δ [8]	Release rate	0.58	$\delta \sim B(\alpha = 70 , \beta = 50)$
L_{low} [9]	Lower bound of length that is 50% vulnerable to capture (cm)	48	$N(\mu = 60, \sigma = 3)$
L_{high} [9]	Upper bound of length that is 50% vulnerable to capture (cm)	79	L_{low} + Δ, $\Delta \sim logN(\mu = \ln(5)$, $\sigma = 1)$

Model Outputs

We defined a set of model outputs as management performance metrics relevant to four primary objectives for the Striped Bass fishery. These objectives include three fisheries objectives to 1) maximize harvest, 2) maximize total catch, and 3) maximize catch of trophy–sized fish, and the objective to 4) provide stock conservation. Because the true value of the average number of fish recruiting to age–1 in the unfished condition is unknown, we specified management performance metrics for the fisheries objectives relative to the predicted values for the current MLL. These metrics included the percent change in harvest, total catch, and catch of trophy–sized fish between the

[7] Appendix 2.1.2
[8] Appendix 2.1.1
[9] Appendix 2.1.3

evaluated regulation and the current MLL. We calculated harvest, total catch, and catch of trophy–sized fish as,

Eq. 9

$$H = U \sum_{a} \sum_{g} \sum_{s} N_{a,g,s} \dot{V}_{a,g,s} V_{a,g,s}$$

Eq. 10

$$C = \dot{U} \sum_{a} \sum_{g} \sum_{s} N_{a,g,s} \dot{V}_{a,g,s}$$

Eq. 11

$$T = \dot{U} \sum_{a} \sum_{g} \sum_{s} N_{a,g,s} t_{a,g,s} \dot{V}_{a,g,s}$$

where $N_{a,g,s}$ is the predicted abundance of fish for each age, growth–type–group and sex. The parameter $t_{a,g,s}$ in Eq. 11 is a Boolean variable that takes the value of one when $L_{a,g,s}$ (Eq. 7) is greater than or equal to trophy size (L_{troph}, Table 4). The abundance of each sex at age for each growth–type–group was calculated as,

Eq. 12

$$N_{a,g,s} = R_{g,s} S_{a,g,s}$$

where $R_{g,s}$ is the number of fish recruiting to age–1 for each growth–type–group and sex (Eq. 1) and $S_{a,g,s}$ is their survival to each age (Eq. 3).

We used three performance metrics to evaluate the ability of regulations to conserve important components of the reproductive process as measures of stock conservation, which included,1) spawning stock biomass, 2) mature stock sex ratio, and 3) reproduction by older female fish. The conservation of spawning stock biomass was represented as the probability of each regulation resulting in a spawning potential ratio (SPR) ≥ 0.35. The spawning potential ratio is defined as the ratio of fished to unfished stock fecundity and is commonly used to indicate the risk of recruitment overfishing (i.e., exploitation at a rate beyond stock replacement; Goodyear 1990, Mace and Sissenwine 1993). Minimum values of SPR required for stock persistence vary in the literature from values of

0.3 to 0.5 (Walters and Martelle 2004). We adopted the value of SPR ≥ 0.35 from the 2022 Albemarle Sound–Roanoke River Striped Bass stock assessment (Lee et al., 2022) as an indication of spawning stock biomass conservation and calculated the probability of each regulation meeting this criterion as,

Eq. 13

$$SPR_{prob} = \sum_{I} \left(\frac{R\phi_f}{R_0\phi_0} \geq 0.35 \right) / I_{total},$$

where R is recruitment at equilibrium in the fished condition (Eq. 1), ϕ_0 and ϕ_f is the per–recruit fecundity of the unexploited and exploited stock (respectively, Eq. 2), R_0 is the average number of juvenile fish recruiting to age–1 in the unexploited stock (Table 3), I indicates each model iteration, and I_{total} is the total number of model iterations.

We chose the percent change in mature male sex ratio (r_{male}) between the current and evaluated harvest regulations to account for potential influence of the interaction between variable growth and maturation rates of male and female Striped Bass and length–based vulnerabilities to capture and harvest that may alter the sex ratio (McCleave and Jellyman 2004). In the case of Striped Bass, where females grow and mature at faster rates than males, increased harvest pressure on larger fish may impact the reproductive capacity of the population if exploitation results in disproportionate removal of females. Furthermore, population resilience to exploitation or unfavorable environmental conditions may increase with higher fecundity contribution from larger females. While it is assumed that fecundity scales linearly with body size in individual fishes (i.e. isometric relationship; Walters and Martell, 2004), many marine species demonstrate disproportionately higher reproductive output with body size (i.e. hyperallometric relationship; Barneche et al. 2018). Larger female Striped Bass have been reported to produce larger eggs, larger newly hatched larvae (Monteleone and Houde 1990) and may have higher hatching success than younger females (Zastrow et al. 1990). To capture the impact of regulations on age–specific reproductive output, we used the percent change in the fecundity contribution of females aged ≥ 10 years to the total fecundity of the population between the current and evaluated harvest regulations, calculated as,

Eq. 14

$$\gamma = \frac{\sum_{a\geq 10}\sum_{g} N_{a,g,s=f} f_{a,g,s=f}}{\sum_{a}\sum_{g} N_{a,g,s=f} f_{a,g,s=f}},$$

where $N_{a,g,s=f}$ is the is the predicted abundance (Eq. 12) and $f_{a,g,s=f}$ is the reproductive biomass for females within each age and growth–type–group.

We compared the following three alternative regulations to the results of the current (a) 46–cm TL MLL regulation: (b) 51–76–cm TL HSL, (c) 46–76–cm TL HSL and (d) 70–90–cm TL (Table 5). Regulations (b) and (c) serve as two candidate regulations under consideration as alternatives to the current MLL: (b) was proposed by NCGASA with the goal of increasing opportunities for mature females to spawn before entering the fishery (by increasing the minimum harvest length), and providing protection for older, more fecund females that escape the fishery (see *Introduction* for more details). Additionally, this regulation has the added benefit of creating a trophy fishery by limiting the maximum harvest size to 76–cm TL. Regulation (c) represents an alternative to regulation (b) to allow for continued harvest at the current MLL while establishing a trophy fishery by limiting the maximum harvest size to 76–cm TL. Lastly, we measure the outcome of the current 46–cm TL MLL against (d) East Coast Striped Bass regulations to compare results to a conservation–focused management strategy that is currently implemented for Atlantic stocks (Table 5).

Table 5. Current regulations and proposed and alternate slot limit ranges in consideration for the Striped Bass (*Morone saxatilis*, Moronidae) fishery in California.

Regulation	Description
(a) 46 cm (~18 inches) TL MLL	Current Striped Bass regulation in California
(b) 51-76 cm (~20-30 inches) TL HSL	Slot limit proposed by NCGASA
(c) 46 - 76 cm (~18-30 inches) TL HSL	Current MLL with upper HSL proposed by NCGASA
(d) 70-90 cm (~28- 35 inches) TL HSL	East coast regulations (for comparison)

Model Results

Conditions that affect overfishing.

The probability that length–based harvest regulations resulted in overfishing for Striped Bass varied across several fishery and population conditions (Figure 12). The probability of the model resulting in an SPR < 0.35 (i.e., overfishing) increased as harvest rate (U), catch rate ($\dot{U}$), and discard mortality (D) increased (Figure 12a–f). The probability of overfishing was more variable at high discard mortality rates, likely because (1) these scenarios occurred less frequently in the simulation and (2) high discard mortality conditions that resulted in low probabilities of overfishing included below average values for catch rate (13%) and harvest rate (5%). The probability of overfished conditions occurring declined as the ratio of fecundity contribution of females age ≥10 years (γ) increased (Figure 12i–j), suggesting a relationship between fecundity contribution from larger females and population sustainability. Overfishing was also less likely to occur as release rate (δ) increased (Figure 12g–h), but values never reached zero due to some level of discard mortality present.

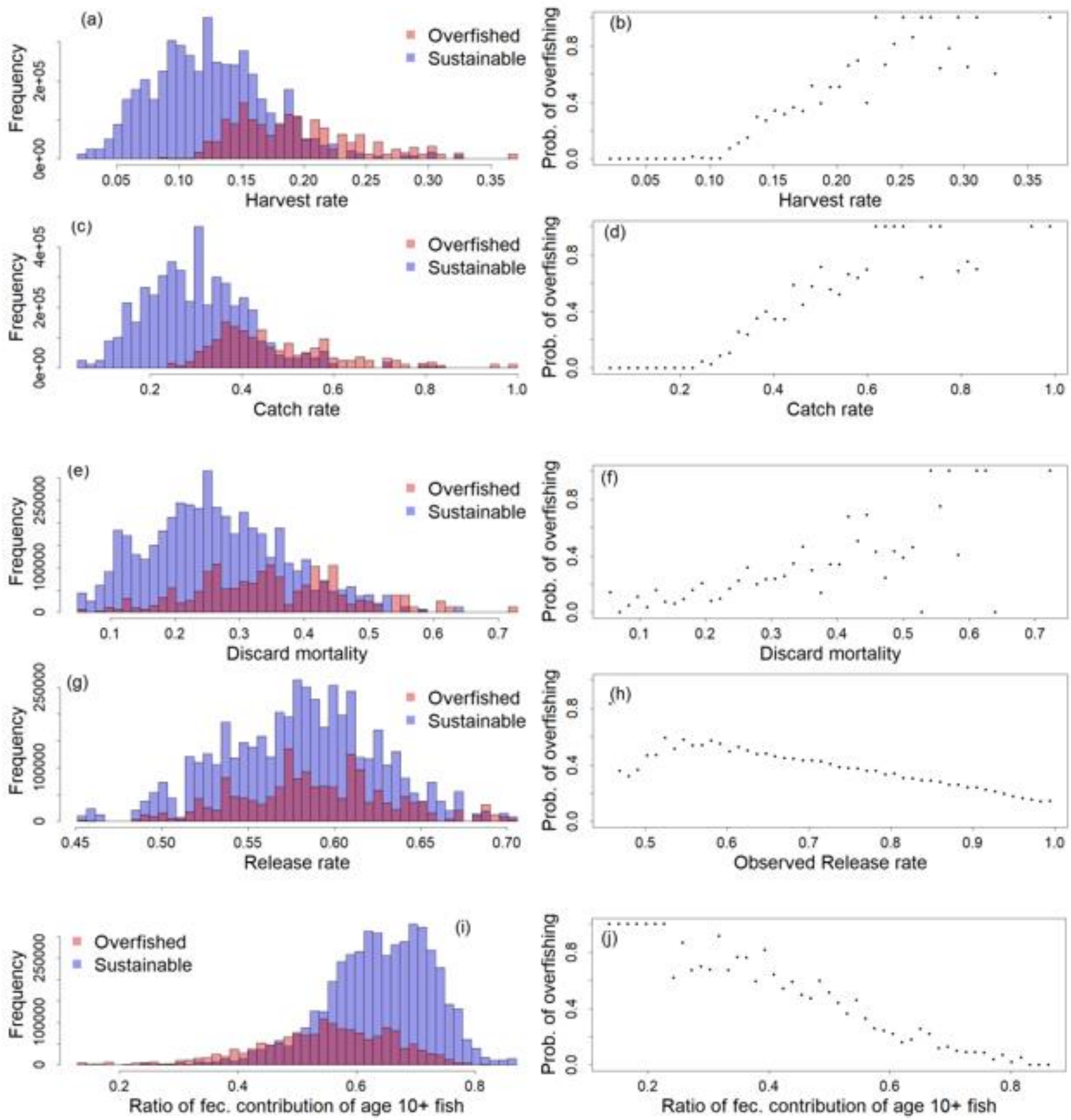


Figure 12. Histograms (left) and scatter plots (right) of simulated values for harvest rate (U, a–b), catch rate ($\dot{U}$, c–d), discard mortality (D, e–f), release rate (δ, g–h), and outputs for fecundity contribution of older (age 10+) fish (γ, i–j) that result in SPR values representing overfished (SPR < 0.35) and sustainable (SPR ≥ 0.35) conditions.

Performance of MLLs and HSLs for fishery objectives

Except for harvest, candidate HSLs outperformed the current MLL for all fishery objectives. The probability of meeting conservation thresholds (SPR ≥ 0.35) under the current 46–cm TL MLL regulation was 47%, compared to 61% and 66% for a HSL with the current MLL 46–76–cm TL and the NCGASA–proposed 51–76–cm TL HSL, respectively. This probability increased to 79% under East Coast regulations (70–90–cm TL HSL) (Figure 13a). The fecundity contribution of older (≥ age 10) fish was higher under HSLs relative to the current MLL, but no differences resulted between the HSLs of interest (Figure 13b). Fecundity contribution of older fish was 6.5% higher than the current MLL under the East Coast HSL, and 8.1% higher under both candidate HSLs (46–76–cm and 51–76–cm) (Figure 13b). Differences in the estimated proportion of mature males in the population between the current and evaluated regulations were minimal, ranging from 1.5–4.5% lower than the current MLL (Figure 13c).

Compared to the three evaluated HSLs (Table 5), the current MLL resulted in the highest harvest per–recruit estimates (Figure 13d). However, the 46–76–cm HSL performed similarly, with harvest only 7.7% lower than that under the current MLL. Harvest estimates decreased by 21.1% under the candidate 51–76–cm HSL and were 73% lower than the current MLL under the East Coast HSL (70–90 cm) (Figure 13d). However, the East Coast HSL resulted in the largest percent increase in catch compared to the current MLL (30.3%), followed by the two candidate HSLs (Figure 13e). Evaluated HSLs performed similarly to each other, resulting in an estimated 8.5% and 13.1% increase in catch per–recruit under the 46–76–cm and 51–76–cm HSL, respectively. Relative to the current MLL, estimates of trophy catch per–recruit was 19% and 24.2% higher under the 46–76– cm and 51–76–cm HSLs (respectively) and 54.6% higher under the East Coast regulation (Figure 13f).

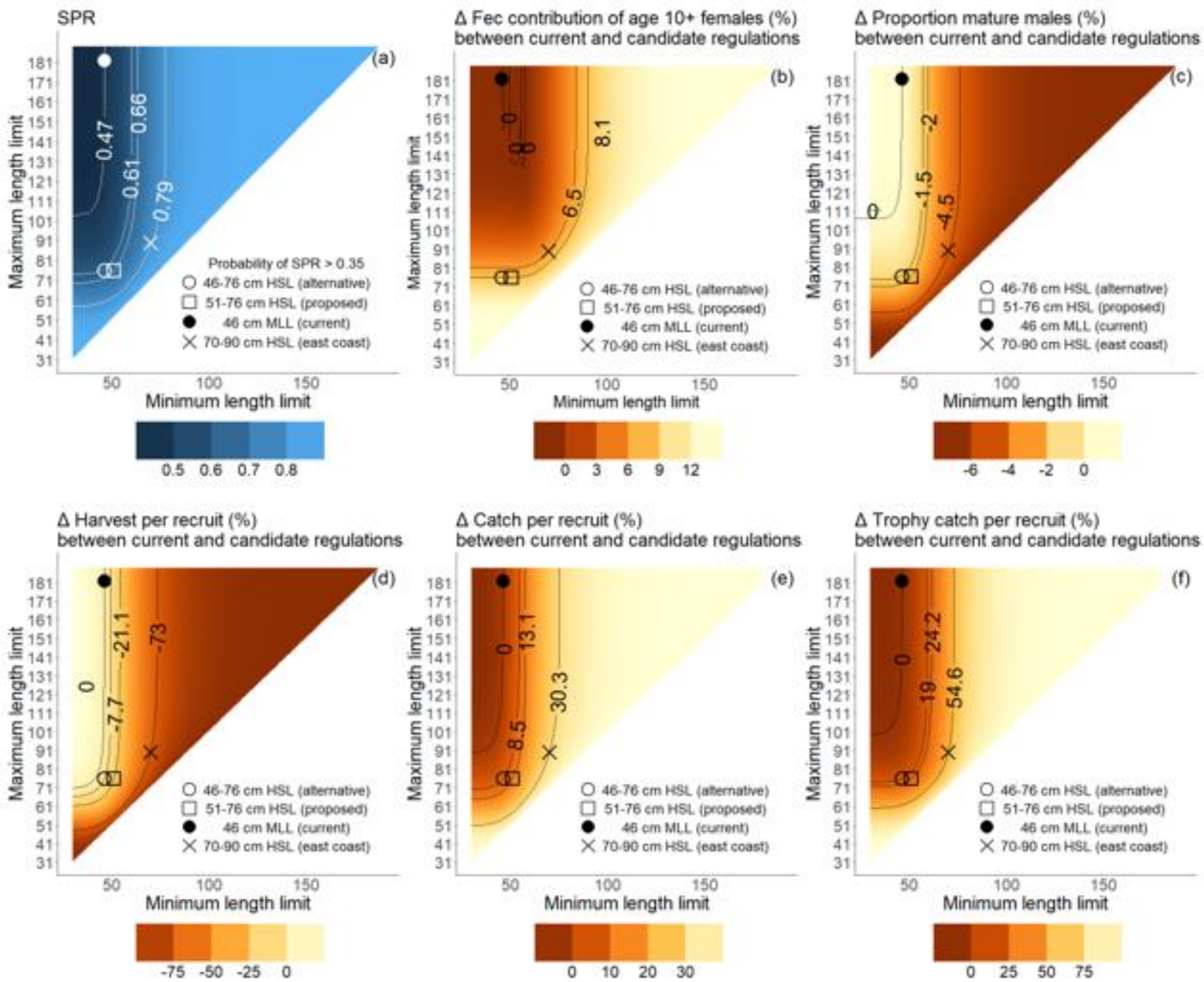


Figure 13. Model results describing (a) the probability of regulations resulting in an SPR ≥ 0.35 and the percent difference in (b) the ratio of fecundity contribution of age 10+ females, (c) the proportion of mature males in the population, (d) harvest per recruit, (e) total catch per recruit, and (f) catch of trophy–sized fish per recruit between current regulations (46–cm MLL) and a continuous range of MLLs and HSLs. The four evaluated regulations (Table 5) are denoted by symbols.

Model Discussion

Our simulation procedure produced more favorable outcomes for nearly all management priorities under HSLs compared to the currently enforced 46–cm MLL. The evaluated HSL regulations produced the greatest improvements to the catch of trophy fish and SPR but represented a trade off in harvest numbers.

HSLs produced more modest improvements to the total catch, the sex ratio and fecundity contribution of older females. These improvements were similar between the two evaluated HSL regulations; however, the harvest tradeoff was greatest for 51–76–cm HSL compared to 46–76–cm HSL.

These results corroborate a growing body of literature that indicate HSLs as an effective alternative to more common MLLs for promoting stock conservation while maintaining catch and harvest opportunities. For example, Gwinn et al. (2015) demonstrated that protecting both immature and large fish from harvest results in a better compromise among management objectives including harvest, trophy–catch, and stock conservation for both short and long–lived species. Ahrens et al. (2020) advanced this work by accounting for the impacts of density and size–dependent growth, mortality, and fecundity on optimal harvest schedules, finding that harvest slots typically outperformed minimum length limits for harvest and catch–related objectives. This work also highlighted the importance of low discard mortality rates for the benefits of HSLs to be realized. Similarly, the benefits for HSLs have been predicted for individual fisheries such as Murray Cod (*Maccullochella peelii*, Koehn and Tood 2012), Northern Pike (*Esox lucius*, Arlinghaus et al., 2010), Gulf of Mexico Red Snapper (Bohaboy et al., 2022), Gag Grouper (Tetzlaf et al., 2013), as well as East Coast Striped Bass (Carr–Harris and Steinback 2020). This body of literature, including this study, suggests that in the recreational fisheries context, HSLs can provide a better outcome for meeting diverse fisheries objectives.

The efficacy of each HSL of interest ultimately depends on the Department's management plan for Striped Bass, which is currently defined by broad goals for the fishery as opposed to quantitative measures. A management goal primarily focused on conservation of the species may consider HSLs closer to East Coast regulations (70–90–cm HSL) to ensure harvest policies result in > 75% probability of population sustainability (Figure 13a). However, these more restrictive regulations conflict with The Department's (CDFW) responsibility to preserve recreational opportunities in the form of harvest, which would decrease by 73% relative to current levels (Figure 13d). Prioritizing harvest numbers above other fishery objectives is best supported by the current MLL, or a wide harvest slot that encompasses most sizes that are vulnerable to catch modeled for the recreational fishery (~46 –100 cm). If the management objective is to enhance recreational fishing opportunities in the form of catch numbers, HSLs better achieve this goal compared to the current MLL. Possibly the most realized benefit of HSLs in terms of catch comes in the form of catch size, as the evaluated HSLs produced substantially higher (19–54%, Figure 13f) numbers of trophy–sized catch compared to the current MLL. Thus, HSLs provide multiple benefits to the angler experience, including higher catch rates and improved quality of catch (as defined by fish size).

Pursuant to section 703 of the California Fish and Game Code, it is the policy of the Fish and Game Commission that the Department takes actions to promote a self–sustaining Striped Bass population in support of a robust recreational fishery while considering the potential impacts of Striped Bass population growth on native species (FGC 2020). Therefore, regulations that balance stock persistence and recreational catch and harvest opportunities are of primary interest to the Department. Based on model results, the current 46 cm MLL may not be sufficient to ensure the long–term sustainability of the population. Model simulations resulted in a 53% probability of recruitment overfishing (SPR < 0.35) under this regulation, versus a 34–39% probability under the evaluated HSLs (51–76–cm and 46–76–cm HSL, respectively) (Figure 13a). While the probability of meeting a SPR target of ≥ 0.35 relative to the current MLL is marginally higher (5%) under a 51–76–cm HSL, this small improvement comes at the cost of harvest opportunities. Harvest was estimated to decrease by about 21% relative to current levels under a 51–76–cm HSL compared to only a ~8% decrease under a 46–76–cm HSL (Figure 13d). These results align with data collected by creel surveys, which show that Striped Bass harvested in the <20–inch category represent ~20% of the inland harvest (CVAS) and ~9% of the ocean/bay harvest (CRFS) (Figures 6 and 7). Thus, when compared to the proposed 51–76–cm HSL, the 46–76–cm HSL results in a more optimal balance between population sustainability and harvest opportunities.

Evaluated HSLs resulted in higher total catch relative to the current MLL, however, improvements were moderate (8.5% and 13.1% increase under 46–76 and 51–76–cm HSL, respectively) and only reached a maximum of ~40% higher under the most restrictive harvest regulations (Figure 13e). This is most likely due to constraints placed on catch by the highly dome–shaped length selectivity curve used in the model (Figure 2.3). This curve was informed by length selectivity estimated for Atlantic Striped Bass caught in the recreational fishery (Carr–Harris and Steinback 2020) and is supported by the strong dome–shaped selectivity of other large–bodied recreational fish species reported in the literature (see Appendix 2.1.3). The modeled selectivity curve renders larger fish less vulnerable to catch, thus decreasing the risk of fishery mortality from harvest or discard. The dome–shaped vulnerability curve may also moderate the results of trophy catch (Figure 13f) under the candidate HSLs, as a more asymptotic length selectivity curve would have yielded in higher differences in these outcomes relative to the current MLL. While trophy catch (relative to the current MLL) is 5.2% higher under a 51–76–cm HSL compared to a 46–76–cm HSL (Figure 13f), this gain may not be worth the ~13% loss in harvest opportunities that results from increasing the lower HSL from 46 to 51 cm (Figure 13d). Furthermore, higher abundance of trophy–sized fish resulting from the 51–76–cm HSL compared to the 46–76–cm HSL may not be enough to produce differences in the proportion of fecundity contribution from older (age 10+) females (γ) between the two regulations (Figure 13b). In other words, increasing the lower HSL from 46 to 51 cm does not translate into an increase in the proportion of total fecundity that is contributed by older fish.

While modest (8.1%), candidate HSLs improved γ relative to the current MLL (Figure 13b), which may have positive implications on recruitment success and stock conservation for Striped Bass. Lim et al. (2014) found positive correlations between maternal size and offspring size and number within species across a range of taxa, suggesting that energy investment into individual offspring changes with female size. This can have substantial impacts on recruitment, as larger offspring are less vulnerable to size–dependent mortality and therefore typically experience higher survival rates (Conover and Schultz 1997). The importance of preserving large females by way of HSLs is evident in Le Bris et al. (2015), who demonstrated that population resilience to and recovery from perturbations (i.e. exploitation) was most impacted by the relationship between female size and fecundity. They found that preservation of large fish that possessed non–linear mass–fecundity relationships, as suggested for Striped Bass (Zastrow et al. 1990, Cowan and Rose 1991), increased the ability of the population to withstand and recover from high fishing pressure. Therefore, using HSLs to increase the proportion of total fecundity contributed by larger females may help buffer Striped Bass populations against fluctuations resulting from high exploitation rates and environmental stochasticity.

Our results suggest that the performance of the length–based regulations evaluated are highly sensitive to the catch, harvest, and discard mortality rates of the fishery. This finding is consistent with the literature for both MLLs (Coggins et al. 2007) and HSLs (Gwinn et al. 2015, Ahrens et al. 2020). For HSLs to be effective at preventing overfishing and improving trophy fisheries, the cumulative mortality from discards and harvest must be low enough to allow a proportion of legal fish to grow out of the slot and into larger protected size classes. Higher rates of these sources of mortality will require narrower harvest slots to achieve fishery benefits. This highlights the importance of understanding these rates when designing HSL regulations. Considering data limitations on discard mortality for the CA Striped Bass fishery, we ran our simulations with a broad range of values. This uncertainty results in lower resolution for predicting differences in the outcomes among competing regulations. A more refined understanding of this parameter for this fishery would increase the ability to distinguish among regulation performances.

Predation Considerations

With the potential to increase Striped Bass population abundance from regulation changes (which requires California Environmental Quality Act [CEQA] permitting), we must consider the impact these changes may have on California Endangered Species Act (CESA) and Federal Endangered Species Act (ESA)–listed prey species the Department is also tasked with managing.

While Striped Bass are known opportunistic predators on salmonid and smelt species, their diets have been found to primarily consist of macroinvertebrates, crayfish, lamprey, and other non–native predator and prey species in aquatic and estuarine habitats (Raney 1952, Callahan et al. 1989, Grossman 2016, Michel et al. 2018, Stompe et al. 2020, Young et al. 2022). Fish become a more important prey item for Striped Bass in the spring and summer (Nobriga and Feyrer 2007, Zeug et al. 2017, Young et al. 2022), which coincides with the seaward migration of salmonids from freshwater habitats.

Observations of salmonids in Striped Bass stomachs vary by life stage and season, but overall remains relatively low (Stevens 1966, Michel et al. 2018, Stompe et al. 2020, Peterson et al. 2020, Brandl et al. 2021). While predation on listed species does occur, there is not enough evidence to support the assertion that Striped Bass predation is the primary contributor to declining salmonid and smelt populations based on available piscivorous predation data in California. Instead, Striped Bass predation impacts should be considered within the broader context of environmental stressors on native fishes, and not necessarily singled out as a significant contributor to salmonid declines.

Striped Bass consume a wide variety of prey species and do not tend to specialize on certain prey items (Zeug et al. 2017, Brandl et al. 2021); however, predation of salmonids and smelt species may be more prevalent in specific size classes of the Striped Bass population based on abundance and spatial/temporal distribution. The profitable prey size for Striped Bass is related to the prey–to–predator size ratio (PPR), where capture success decreases as the

PPR ratio increases (Hartman 2000). Fish are unimportant in the diets of YOY Striped Bass, as diet during this life stage is primarily driven by plankton abundance (Heubach 1963). In a diet composition study of large Atlantic Striped Bass, Walter and Austin (2003) found significant relationships between Striped Bass total length and prey length ($p < 0.05$), indicating that larger and older Striped Bass ate larger prey. Poor regression fit (r2 = 0.26) indicated that large fish also consumed small prey, supporting the argument that larger Striped Bass consume a greater size range of prey. Smaller Striped Bass in this study (458–710 mm [~ 18–28 inches]) consumed prey that approached 40% of their total length; however, most prey consumed by all sizes of Striped Bass were smaller, young–of–the–year fishes. This finding is corroborated by Overton (2002), who predicted an optimal prey size to be 21% of the Striped Bass length.

If similar predator–prey dynamics hold true for Striped Bass in California, smolts (ranging from 70–140 mm), as classified by Sturrock et al. (2019) may represent optimal prey size for smaller Striped Bass (13–27 inches). CDFW Fyke trap data show that Striped Bass entering the Sacramento River in the spring are generally < 28 inches (Figure 14), and therefore may exhibit similar feeding patterns to the 'small' Striped Bass in Walter and Austin (2003). Furthermore, Loboshefsky et al. (2012) found that while individual consumption of adult Striped Bass was higher than sub–adults, population total consumption of sub–adults was similar to adults due to greater abundance of sub–adults in the system. A harvest slot may shift the population structure to increase the abundance of older, large fish, yet this still may not have a noticeable impact on salmonid predation due to (1) PPR, (2) high variation in the size of prey consumed, and (3) little evidence of prey specialization. Increasing the minimum length limit from 18–20 inches may have a more noticeable impact on salmonid consumption, however, as this protects a size class of Striped Bass more likely to encounter and consume smolt–sized fishes due to (1) potentially higher delta and freshwater residency of smaller Striped Bass compared to larger, more migratory fish (Dorazio et al. 1994) and (2) more optimal PPR between this size class and smolts.

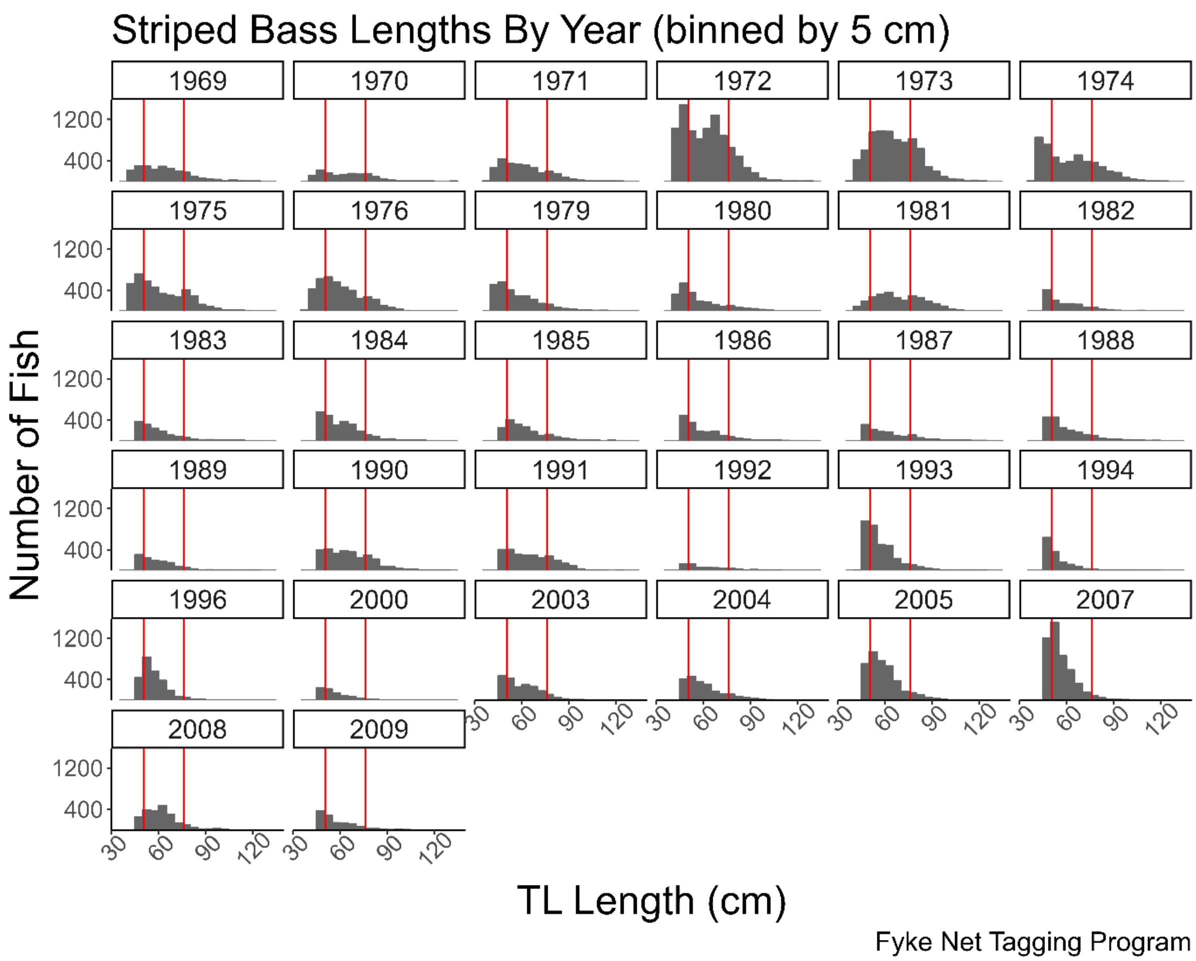


Figure 14. Length–frequency histograms for Striped Bass sampled from fyke nets. Parallel vertical red lines indicate the NCGASA–proposed 20–30 inch total length (51 – 76 cm) slot limit. Note that effort is not accounted for in catch. Data Source: Adult Striped Bass Population Study.

Despite these considerations, most of the literature reviewed suggests that Striped Bass consumption of salmonids and smelts is relatively low compared to other prey items. That said, Striped Bass are widespread, highly opportunistic, generalist predators that display aggregatory feeding behavior, particularly near manmade structures and habitat pinch–points (Tucker et al. 1998; Sabal et al. 2016). Thus, temporal overlap between Striped Bass and salmonids is an important factor to consider. Decreased precipitation and associated warming water temperatures could elicit earlier Striped Bass spawning migrations, increasing temporal overlap between Striped Bass and out–migrating juvenile salmonids in the Sacramento River system (Goertler et al. 2021). Climate change and the environmental conditions of an increasingly degraded Delta may continue to increase contact between Striped Bass and listed species, and it is difficult to predict the role that protective harvest regulations will play on the predatory impact of Striped Bass in this context. The completed CDFW Predation Literature Review document can be found in Appendix 3.

Informing Broader Management Strategies from East Coast Regulations

When designing fishing regulations, management objectives are generally set as the target. The Department's management goals are guided by the California Fish and Game Commission's Striped Bass Policy (FGC 2020), which states that the Department shall "...emphasize programs that ensure, enhance, and prevent the loss of sport fishing opportunities" and "…strive to maintain a healthy, self–sustaining Striped Bass population in support of a robust recreational fishery." The intended goal of the NCGASA–proposed 20–30–inch harvest slot limit is to increase abundance of Striped Bass as well as protect larger Striped Bass in the population. This desire is consistent with the California Fish and Game Commission's policy, as the policy also supports actions to increase Striped Bass abundance if the actions are consistent with the Department's long–term mission and public trust responsibilities.

For the purposes of this regulation change petition (TN 2022–12) evaluation, the Department evaluated four regulation options for comparison of the NCGASA proposed 20–30–inch slot limit (Table 5). Because the petition requested only one specific HSL and did not include alternative HSL options or other considerations such as changes to season, bag limit, geographic range, the Department's evaluation specifically focused on the proposed 20–30–inch HSL. If the Department had independently determined that the status and trends observed in the Striped Bass fishery warranted regulatory changes to preserve and improve the fishery, multiple regulatory strategies beyond a pre–defined HSL would have been evaluated to determine which strategy, or combination of strategies, would be the most effective to determine or maintain biological and management objectives.

Within Striped Bass native ranges, Atlantic states have adopted various regulatory practices to meet their management goals (Figure 15, ASMFC 2022). In many states, freshwater (rivers) and marine environments have different regulations to protect migratory and spawning Striped Bass while also providing fishing opportunity. The majority of the Atlantic states' coastlines, as well as the ocean, have a 28–35–inch HSL. However, several areas (particularly in producer areas) enforce slot limits or smaller minimum sizes that allow the harvest of smaller Striped Bass, starting at 18–20 inches depending on the state. There are no regions that include a 20–30–inch slot limit comparable to the NCGASA proposal (K. Drew, ASMFC, personal communication, January 23, 2023).

Atlantic States management (regulations) are based on female spawning stock biomass and fishing mortality targets for the migratory stock complex, which represent the best available scientific information. There are a number of different combinations of size limits and harvest levels that would allow them to achieve the desired spawning stock biomass target and management objectives, and stakeholder needs are considered when they set the size limits and other regulations (ASMFC 2019). The coastal/ocean minimum size limit of 28 inches represents the size at full maturity for Atlantic coast Striped Bass, and therefore fisheries with lower size limits are harvesting immature fish. Those fisheries occur in the producer areas where mature Striped Bass are only available during the spawning season. The Atlantic States Marine Fisheries Commission (ASMFC 2022) allows harvest of those smaller fish and forgoes yield of larger fish in order to create more equitable access to the resource between stakeholders in the ocean region and stakeholders in the producer areas, based on historical fishing patterns (K. Drew, ASMFC, personal communication, January 23, 2023).

In response to the 2015 mandate by the ASMFC to decrease harvest, many coastal and Chesapeake Bay states decreased the recreational bag limit from two to one fish, ≥ 28 inches TL (ASMFC 2014). While these changes successfully hit coast–wide harvest reductions goals, they failed to translate into improvements in the female spawning stock biomass (ASMFC 2016b, ASMFC 2017, NEFSC 2019).

To understand the immediate economic and biological trade–offs resulting from harvest restrictions that favor larger Striped Bass, Carr–Harris and Steinback (2020) evaluated the effect of 36 alternative recreational Striped Bass fishing policies (Table 6 *in* Carr–Harris and Steinback 2020) on (1) expected angler welfare (measured as the level of compensation required to hold anglers' expected utility constant after a policy–induced change in fishing trip quality), (2) total recreational removals, and (3) mature female recreational removals relative to the simulated outcome of the actual 2015 policy of one fish, ≥ 28–inches TL. Simulations revealed that policies that decreased the baseline minimum from 28 to 20 or 24 inches (thus directing harvest toward frequently encountered yet lower–valued smaller Striped Bass) while constraining harvest of rarely encountered yet higher–valued large Striped Bass resulted in increases of recreational harvest that were incommensurate with concurrent welfare gains (Carr–Harris and Steinback 2020. The one fish 28–36–inches TL HSL regulation was the sole policy analyzed that resulted in a non–trivial reduction in recreational removals relative to the actual 2015 MLL policy (one fish ≥ 28–inches TL). This policy resulted in only a slight reduction in angler welfare due to the relatively low frequency at which Striped Bass ≥ 36 inches are encountered in the fishery (Carr–Harris and Steinback 2020.

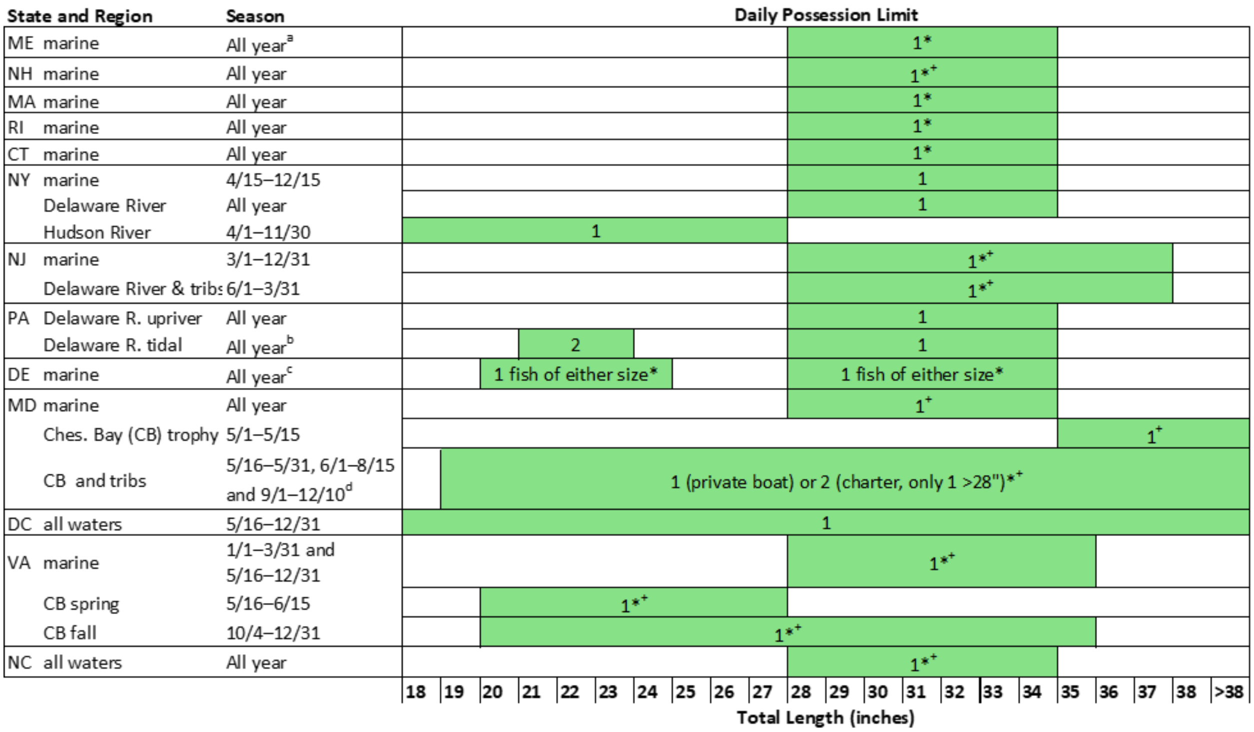
While the effect of length–based regulation changes on angler welfare was not incorporated into the Striped Bass population model presented here, we interpret angler harvest opportunity as a proxy for angler satisfaction. Results from the Striped Bass Angler Preference Questionnaire indicate that 51% of respondents fish for Striped Bass to catch and eat (Question 10, Appendix 1). Furthermore, an Environmental Justice Community Survey conducted for the California Department of Water Resources showed that the overwhelming majority (90%) of the self–identified disadvantaged community (DAC) members surveyed eat fish from the Delta four or more times per week (Ag. Innovations 2021). Aside from those that chose 'other or not specified' (35%), the majority of DAC respondents (51%) indicated that they catch Striped Bass (Ag. Innovations 2021). These results suggest that Striped Bass is an important food source for California anglers, and that failing to maintain harvest opportunities may present an issue for the communities that depend on this resource as a part of their diet.

Compared to the proposed 20–30–inch HSL, our model of the California Striped Bass population estimated that an 18–30–inch HSL would result in a smaller decrease in total harvest relative to current regulations while maintaining the same fecundity contribution of older females in the population (see Population Model section). As with the 'most efficient' regulation of one 28–36–inch fish identified in Carr–Harris and Steinback (2020), an 18–30–inch HSL maintains the lower length limit at the status quo while only excluding harvest opportunity for size classes infrequently encountered in the fishery (see Figure 6 and Figure 7). Thus, we can infer that this regulation may have a similarly low impact on angler welfare as estimated in Carr–Harris and Steinback (2020).

As observed on the East Coast, there are several combinations of harvest size and bag limits that, in concept, could be implemented in California to be more protective of the female spawning biomass and may contribute to increased spawning success compared to the current regulations. However, increasing

Striped Bass abundance and size of fish may not be possible through changes to angling regulations alone due to environmental constraints, carrying capacity, and/or other factors. Examples of management strategies observed on the East Coast (Figure 15) that could be applied to the California Striped Bass fishery (if deemed appropriate) include, but are not limited to:

- Harvest slot limits (as evaluated in this petition)
- Lower or higher minimum size limits
- Split slot limit(s)
- Seasonal closures / Seasonal regulation changes
- Geographic closures (seasonal and/or permanent)
- Increased or decreased bag limits
- Gear Restrictions
- Regulations specific to marine and/or freshwater locations
- Regulations specific to charter boats and private boats
- Combination of more than one option



* Non-offset circle hooks required when fishing bait

\+ Spearfishing permitted, all other size and take limits apply

[a] Spawning areas closed 12/1–4/30 and C&R only 5/1–6/30

[b] The 21-24" slot is only open 4/1–5/31

[c] Spawning areas C&R only 4/1–5/31. 20-25" slot is only open 7/1–8/31 in Delaware River, Bay, and tribs

[d] C&R only 1/1–3/31, 12/11–12/31, additional area closures apply

Figure 15. Overview of 2022 recreational Striped Bass fishing regulations in Atlantic coast states. Additional geographic and gear restrictions apply in many of the fisheries. Figure adapted from Table 6 in ASMFC 2022.

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CALIFORNIA DEPARTMENT OF FISH AND WILDLIFE EVALUATION OF NOR-CAL GUIDES AND SPORTSMEN'S ASSOCIATION (NCGASA) PROPOSED 20-30 INCH HARVEST SLOT LIMIT FOR STRIPED BASS APPENDICES

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APPENDIX 1: 2022 STRIPED BASS ANGLER PREFERENCE QUESTIONNAIRE RESULTS SUMMARY

1.1 Questionnaire Purpose

In the Fall of 2020, the Nor-Cal Guides and Sportsman's Association (NCGASA) submitted a regulation change petition to the Fish and Game Commission. The proposed regulation change would restrict the harvest of Striped Bass to a "slot limit" between 20 and 30 inches for inland anadromous waters. In the summer of 2022, the NCGASA submitted a second petition which would apply the 20-to-30-inch harvest slot limit to Striped Bass caught in marine (ocean and bay) waters as well. The NCGASA petition stated that the regulation change would protect the earliest spawners as well as the largest most fecund individuals, which would then eventually increase the population size of Striped Bass. The NCGASA also stated that they had polled their membership and that there was overwhelming support for a 20-to-30-inch slot limit.

The California Department of Fish and Wildlife (CDFW) is in the process of evaluating the proposals to determine how this proposed change may affect the Striped Bass fishery, including harvest opportunities and biological processes. The Striped Bass fishery is one of the largest fisheries in California. This is because Striped Bass have a wide-spread distribution, fishing methods to target and catch Striped Bass are diverse, and anglers can fish for and catch Striped Bass year-round. Because of the popularity of the fishery, any changes to Striped Bass fishing regulations would impact many thousands of California anglers.

Part of the evaluation process included understanding and documenting anglers' general satisfaction with the Striped Bass fishery, as well as gaging angler interest in changing Striped Bass fishing regulations. To reach California's Striped Bass anglers, the CDFW developed and conducted Striped Bass Angler Preference Questionnaires (APQ) first through opportunistic in-person interviews, and then through expanded electronic questionnaires. Altogether, CDFW contacted more than 960,000 licensed anglers and assessed the data from approximately 26,000 respondents. This summary describes the data collection process and results.

1.2 In-person Striped Bass Angler Preference Questionnaire

Initial in-person interviews began in November 2021 and occurred during randomly scheduled Central Valley Angler Survey (CVAS) surveys. Willing participants in the questionnaire were told that CDFW was soliciting angler input on the current Striped Bass fishery. They were not informed of the Nor-Cal Guides and Sportsman's Association (NCGASA) petition as not to bias the responses. Respondent questions were answered after the questionnaire was completed unless it was for clarification. Questionnaires consisted of nine questions, listed below. The in-person questionnaire took place between November 2021 and July 2022. A total of 211 anglers were interviewed and the results in questions 2-9 reflect the responses of 204 self-identified Striped Bass anglers.

1.2.1 In-person Striped Bass APQ questions and results.

1. Do you fish for Striped Bass?
    - Yes
    - No
2. Do you support the current minimum size and bag limit?
    - Yes
    - No
3. Would you like to see the minimum size limit lower?
    - Yes
    - No
4. Would you like to see the minimum size limit higher?
    - Yes
    - No
5. Would you like to see a maximum size limit applied?
    - Yes
    - No
6. Do you support a catch and release fishery for trophy Striped Bass?
    - Yes
    - No

7. Are you associated with any professional fishing associations?
    - Yes
    - No
8. Are you associated with any state natural resource agency?
    - Yes
    - No
9. What method do you use to catch Striped Bass?
    - Any
    - Bait
    - Lure
    - Fly
    - Spear

1.3 In-person Striped Bass Angler Preference Questionnaire Results by Question

1.3.1 Question 1. Do you fish for Striped Bass?

Yes (%)	No (%)	Number of Responses
97	3	211

Anglers contacted (i.e., respondents) overwhelmingly answered that they fished for Striped Bass. If an angler answered "no" to Question 1, the questionnaire ended. If an angler answered "yes", they moved on to Question 2. Seven respondents ended the questionnaire at Question 1.

1.3.2 Question 2. Do you support the current minimum size and bag limit?

Yes (%)	No (%)	Number of Responses
64	36	204

The majority of respondents answered that they support the current minimum size limit of 18 inches and bag limit of two fish per day (64%).

1.3.3 Question 3. Would you like to see the minimum size limit lower?

Yes (%)	No (%)	Number of Responses
30	70	204

The majority of respondents answered that they would not want to lower the minimum size limit for harvestable Striped Bass (70%).

1.3.4 Question 4. Would you like to see the minimum size limit higher?

Yes (%)	No (%)	Number of Responses
19	81	204

Most respondents answered that they would not want to raise the minimum size limit for harvestable Striped Bass (81%).

1.3.5 Question 5. Would you like to see a maximum size limit applied?

Yes (%)	No (%)	Number of Responses
51	49	204

Respondents were almost evenly split on whether they would want to see an upper size limit applied to the Striped Bass fishery.

1.3.6 Question 6. Do you support a catch and release fishery for trophy Striped Bass?

Yes (%)	No (%)	Number of Responses
60	40	204

However, respondents were generally in-favor of a catch-and-release trophy Striped Bass fishery even though that meant a maximum size limit would need to be applied.

1.3.7 Question 7. Are you a member of any professional fishing association?

Yes (%)	No (%)	Number of Responses
10	90	204

1.3.8 Question 8. Are you associated with any state natural resource agency?

Yes (%)	No (%)	Number of Responses
3	97	204

To evaluate whether the questionnaire was reaching a broad fishing community, and not just those anglers represented by professional fishing associations or natural resource agencies, anglers were asked Questions 7 and 8. In both cases, 10% or less of respondents represented the aforementioned groups, demonstrating that the questionnaire was successful in reaching a broad fishing community.

1.3.9 Question 9. What method do you use to catch Striped Bass?

Artificial lure (%)	Bait (%)	Fly (%)	Spear (%)	Other (%)	Total Responses
32	64	1	2	1	204

Respondents were asked their primary preferred method for catching Striped Bass. They were not able to answer more than one method though it was clear that anglers often used more than one method and that this question needed to be edited. Respondents reported artificial lures as the most preferred method followed by bait, and less often fly and spear.

Results of the questionnaire indicated that the Striped Bass anglers that were interviewed by CVAS staff generally supported the current minimum size limit of 18 inches total length and did not support changing the minimum size either lower or higher than 18 inches (Questions 2-4, Section1.2.1). Anglers were neutral on whether they wanted to see a maximum size, with respondents split nearly 50-50 on their responses (Question 5, Section 1.2.1). However, when asked if they would support a catch and release fishery for trophy sized Striped Bass, anglers were generally in favor (60% yes, Question 6, Section 1.2.1).

Comments received from anglers were recorded in a notes section of the datasheet. Comments ranged from anglers wanting smaller or larger bag limits, smaller minimum sizes, the desire for the implementation of a slot limit, and the desire to see regulations removed from Striped Bass because they are an introduced species. Additionally, many anglers reported already practicing catch-and-release fishing on large Striped Bass that they perceived as female. Lastly, despite being in favor of a catch-and-release trophy fishery, some respondents expressed concern about additional restrictions imposed with a maximum size limit. Instead, they desired other anglers to self-regulate the size of Striped Bass harvested instead of CDFW imposing a maximum size limit. This may explain the discrepancies in the responses between questions 5 and 6 (Section 1.2.1). To reach a larger number of anglers, an electronic version of the APQ was developed.

1.4 Electronic Striped Bass Angler Preference Questionnaire

An electronic questionnaire was developed using the existing in-person APQ questions as a template. The questions were reviewed by managers in Fisheries Branch, human dimensions experts in Wildlife Branch (to assess for bias), and with staff from the Office of Communication and Outreach (OCEO). Because the questionnaire was going to be reaching a larger angling constituent, the original questions were slightly changed and expanded in scope. The available platform for CDFW electronic questionnaires was Survey Monkey and could only be distributed in English because of the distribution timing. Translation services contracts were in-flux due to proximity to the new fiscal year (June-July 2022).

Electronic Striped Bass APQ questions with response choices.

The electronic Striped Bass APQ was distributed through direct email, social media post, CDFW website, a press release, and through the Angler Update email newsletter.

1. Do you fish for Striped Bass?
    - Yes
    - No
2. Do you support the current minimum size?
    - Yes
    - No
3. Do you support the current bag limit?
    - Yes
    - No
4. a. Would you like to see the minimum size limit for harvest of Striped Bass:
    - <18 inches
    - >18 inches

    - No change
    - No minimum size

   b. Preferred minimum size (if not 18 inches)?

    - Fill in the blank

5. What length Striped Bass do you consider a trophy (in inches)?
   - Fill in the blank
6. Would you support a catch and release fishery for trophy sized Striped Bass? This would require setting a maximum size/slot limit on Striped Bass that can be harvested.
   - Yes
   - No
7. Are you a member of any professional fishing associations?
   - Yes
   - No
8. Are you associated with any state natural resource agency?
   - Yes
   - No
9. What method do you use to catch Striped Bass? (select all that apply)
   - Artificial lure
   - Bait
   - Fly
   - Spear
   - Other (please specify)
10. Why do you fish for Striped Bass? (select all that apply)
    - Catch and eat
    - Catch and release
    - Fishing Guide
    - Other (please specify)

The questionnaire was distributed to approximately 960,000 licensed anglers through emails stored on the CDFW Automated License Data System (ALDS) database. Licensed anglers received an electronic APQ email if they had both 1) provided an email when they purchased their fishing license, and 2) if they had purchased a fishing license in the last three years (to cut down on the volume of emails). Additionally, the updated APQ was distributed through social media, a news release, posted to the CDFW Striped Bass webpage, and through the CDFW Angler Update email newsletter. For a timeline of important APQ details, see Table 1.1.

Initially the electronic APQ was only distributed in English because the distribution timing aligned with the change of the State of California fiscal year (July 1) and new translation services contracts were in-flux. Since then, the contract has been renewed and the questionnaire was redistributed (through email and social media posts) in non-English languages which include Spanish, Tagalog, Vietnamese, Russian, Simplified Chinese, and Traditional Chinese.

Table 1.1. Electronic Striped Bass Angler Preference Questionnaire details. Includes how the questionnaire was distributed and when, as well as when the questionnaire was translated, and the closing date.

Electronic Striped Bass APQ Detail	Date
Links to the APQ are posted to the CDFW Striped Bass webpages	7/25/2022
Electronic APQ is emailed and successfully delivered to 914,784 anglers	7/26/2022
Social media, press release, and Angler Update newsletter are posted and sent via email	7/28/2022
The StripedBass@wildlife.ca.gov mailbox was created to answer questions; webpages updated with email contact information	8/11/2022
Striped Bass town hall meeting held at Fisheries Branch headquarters	8/24/2022
Language interpretive/translation services contract renewed, and questionnaire gets translated into 6 non-English languages (Spanish, Tagalog, Vietnamese, Russian, Simplified Chinese, and Traditional Chinese)	8/2022-9/2022
Links to the APQ are reposted to the CDFW Striped Bass webpages –	9/21/2022
non-English questionnaires are added	
Social media posts are reposted with links to non-English questionnaires	9/22/2022
Updated electronic APQ is emailed and successfully delivered to 945,550 anglers (added 2 additional years of emails from ALDS)	9/27/2022
Questionnaire closed and links were deactivated/ removed from websites	11/1/2022

1.5 Electronic Striped Bass Angler Preference Questionnaire Results by Question

1.5.1 Question 1. Do you fish for Striped Bass?

Yes (%)	No (%)	Number of Responses
71	29	26,410

Anglers contacted (i.e. respondents) overwhelmingly answered that they fished for Striped Bass. If an angler answered "no" to Question 1, the questionnaire ended. If an angler answered "yes", they moved on to Question 2. Approximately 10,000 respondents ended the questionnaire at Question 1.

1.5.2 Question 2. Do you support the current minimum size limit?

Yes (%)	No (%)	Number of Responses
71	29	16,875

The majority of respondents answered that they support the current minimum size limit of 18 inches (71%).

1.5.3 Question 3. Do you support the current bag limit?

Yes (%)	No (%)	Number of Responses
68	32	16,808

The majority of respondents answered that they support the current bag limit of 2 fish per day (68%).

1.5.4 Question 4. Would you like to see the minimum size limit for harvest of Striped Bass?

No change (%)	No minimum size (%)	Lower than 18 inches (%)	Higher than 18 inches (%)	Number of Responses
54	8	20	18	16,621

Approximately half of anglers contacted preferred the current minimum size limit of 18 inches (54%). Most of the remaining respondents were split on whether they supported lowering the minimum size limit below 18 inches (20%) vs. increasing it above 18 inches (18%). A small fraction of respondents (8%) supported no minimum size limit. Anglers had the option to write in a preferred minimum size if not 18 inches. This portion of Question 4 received 5,527 fill-in-the-blank responses summarized in Figure 1.1. Of the anglers that wrote in preferred minimum size limits, 58% of anglers would prefer a smaller than 18-inch minimum size limit (Fig. 1.1).

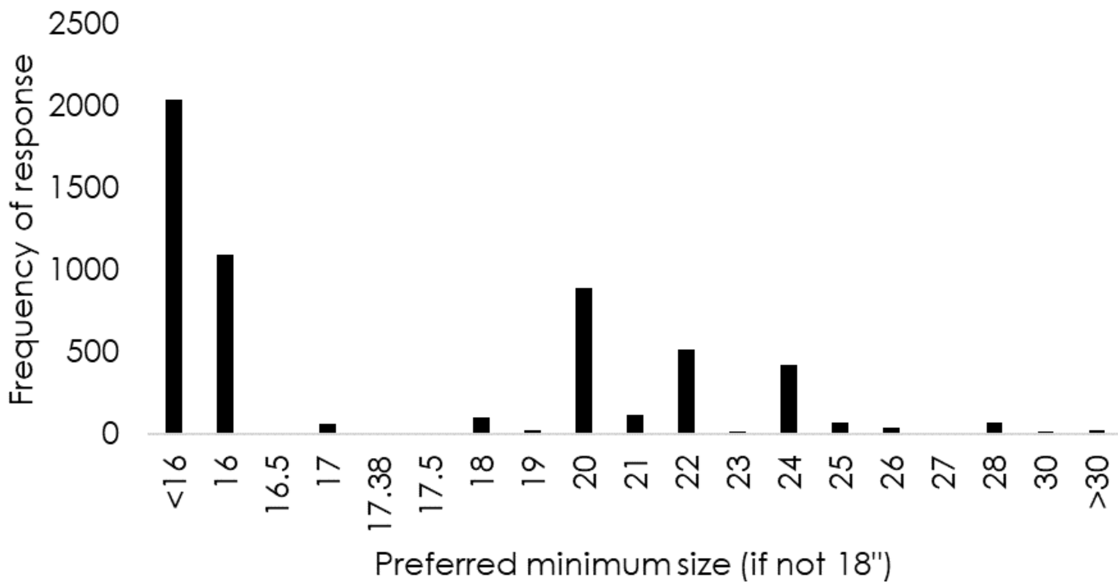

Figure 1.1. There were 5,527 written responses for preferred minimum sizes other than the current 18-inch minimum size (although some respondents entered 18 inches as their preference).

1.5.5 Question 5. What length Striped Bass do you consider a trophy?

This question was a fill-in-the-blank question. The responses are summarized in Figure 1.2. There were 13,887 responses to Question 5.

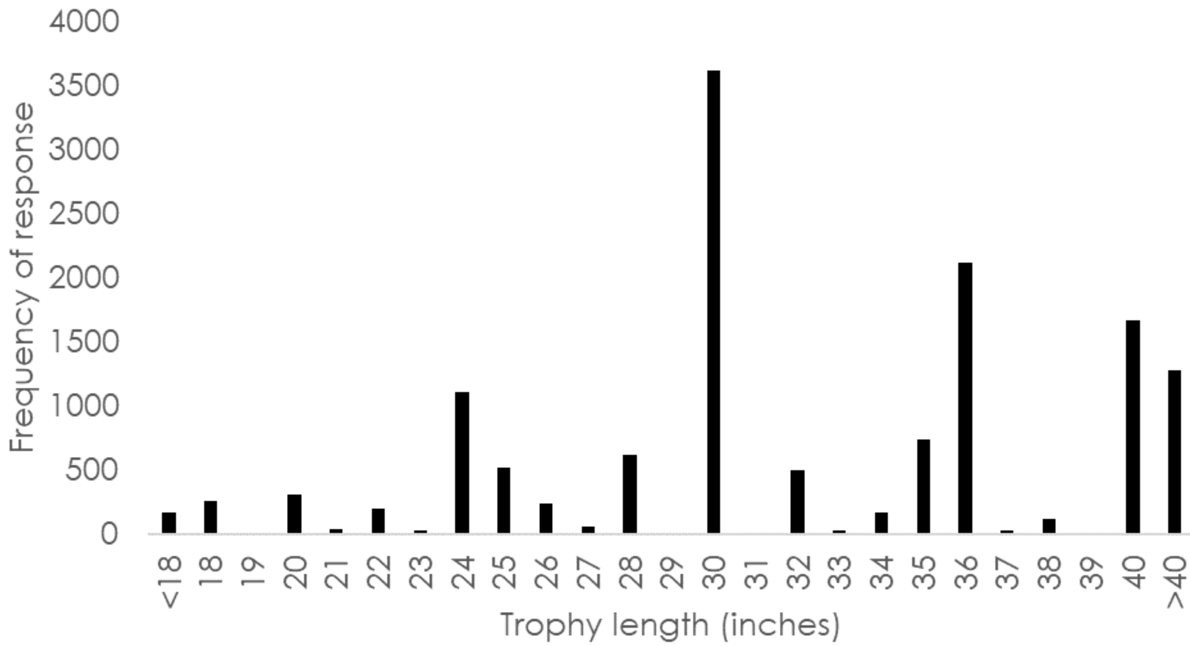

Figure 1.2. Fill-in-the-blank responses to what size Striped Bass anglers considered a trophy.

Responses show that anglers consider a wide range of sizes to be trophies, with 30 inches (26%), 36 inches (15%), and 40 inches or greater (21%) as the most frequent responses.

1.5.6 Question 6. Would you support a catch and release fishery for trophy sized Striped Bass? This would require setting a maximum size/slot limit on Striped Bass that can be harvested.

Yes (%)	No (%)	Number of Responses
64	36	16,797

Anglers overwhelmingly supported the implementation of a maximum size limit on harvestable Striped Bass (64%).

1.5.7 Question 7. Are you a member of any professional fishing association?

Yes (%)	No (%)	Number of Responses
9	91	16,873

1.5.8 Question 8. Are you associated with any state natural resource agency?

Yes (%)	No (%)	Number of Responses
4	96	16,836

To evaluate whether the questionnaire was reaching a broad fishing community, and not just those anglers represented by professional fishing associations or natural resource agencies, anglers were asked Questions 7 and 8. In both cases, less than 10% of respondents represented the aforementioned groups, demonstrating that the questionnaire was successful in reaching a broad fishing community.

1.5.9 Question 9. What method do you use to catch Striped Bass?

Artificial lure (%)	Bait (%)	Fly (%)	Spear (%)	Other (%)	Total Responses
47	42	10	<1	<1	28,524

This question was asked to understand the general methodologies that anglers use to catch Striped Bass and to identify potential methodologies that may be affected by regulation changes (i.e., slot limits). Anglers could choose more than one option (select all that apply), which is why the total number of responses is higher than in previous questions. Artificial lures (47%) and bait (42%) are the most common methods used to catch Striped Bass.

1.5.10 Question 10. Why do you fish for Striped Bass?

Catch and Eat (%)	Catch and Release (%)	Fishing Guide (%)	Other (%)	Total Responses
51	42	1	6	23,812

This question was asked to understand how and why anglers utilize the Striped Bass fishery. Anglers could choose more than one option (select all that apply), which is why the total number of responses is higher than in previous questions. Responses to Question 10 indicate that anglers primarily utilize the Striped Bass fishery for a food resource (51%, catch and eat), followed by for sport (42%, catch and release). Less common responses to this question included: occupation, time in nature, family bonding, and species protection/predator control. Combined, these responses accounted for less than 8% of total responses.

1.6 Striped Bass Angler Preference Questionnaire Summary

Despite being an introduced species and an opportunistic predator, Striped Bass represent one of the largest fisheries in California. Angler Preference Questionnaires were used to quantitatively describe anglers' sentiment towards the fishery. The questionnaire was distributed to over 900,000 licensed California anglers, and more through social media posts, resulting in an unprecedented 26,000 responses and more than 16,000 completed questionnaires.

In general, Striped Bass anglers that took either the in-person APQ and/or the electronic APQ (there is most likely overlap), were supportive of the current Striped Bass fishing regulations (Table 1.1, Questions 2-4; Table 1.2, Questions 2-4). However, given the opportunity for change, anglers' preferences for the Striped Bass fishery varied widely.

Though 54% of anglers would prefer to see no changes made to the minimum size of harvestable Striped Bass, 20% of anglers would like to see the minimum size lowered (Table 1.2, Question 4). Written responses for "preferred minimum size if not 18 inches" showed that a minimum size of 16 inches or less was preferred for 57% of respondents (Figure 1.1).

There was also general support for a catch-and-release trophy Striped Bass fishery (Table 1.1, Question 6; Table 1.2, Question 6), even though that would mean setting a maximum size limit on harvestable Striped Bass (implementing a slot limit). This response indicates that anglers would support restricting the maximum size of harvestable Striped Bass to achieve protection for larger Striped Bass. In fact, written comments from respondents indicate that many anglers already practice catch-and-release fishing on "large" Striped Bass. The implementation of a maximum size limit would ensure that all anglers followed this practice. When asked what size defined a trophy Striped Bass, responses ranged widely (Figure 1.2), with 30, 36, and >40 inches reported most frequently.

Though opinions varied on how anglers would change the Striped Bass fishery, what was clear was that anglers value the fishery for both food and sport (Table 1.2, Question 10), and any changes to Striped Bass fishing regulations will impact thousands of anglers.

Information obtained from Striped Bass Angler Preference Questionnaires will be incorporated into the regulation change petition evaluation completed by CDFW. The evaluation will include a biological assessment of the fishery, potential impacts that the regulation change may have on the fishery and California anglers, as well as anglers' perspectives on the Striped Bass fishery. Together these components will shape CDFW's assessment of the regulation change petition which is expected in summer 2024.

APPENDIX 2. STRIPED BASS POPULALATION MODEL PARAMETER INPUT JUSTIFICATIONS

2.1 Fishery Inputs

2.1.1 Harvest (U) and capture rate ($\dot{U}$) of fish vulnerable to angling

There are no recent published estimates of harvest rates (U) of Striped Bass on the west coast of the U.S.A. Thus, we chose a range of U to represent lower plausible bounds of exploitation and upper plausible bounds that are likely to lead to overfishing. We represented the uncertainty in U with a beta distribution parameterized with an $\alpha = 5$ and $\beta = 30$. This resulted in a mean U of 0.14 and 95% probability between 0.05 and 0.27 (Fig. 2.1). This distribution included the range of historic published estimates of U on the west coast of 0.12-0.19 for 1965 to 1978 (Sommani 1972, Miller 1974), unpublished estimates from CDFW's adult Striped Bass mark-recapture study of 0.04-0.29 (2011-2022), as well as estimates from the Atlantic coast stock assessment from 2011 to 2021 of 0.13-0.32 (2022 ASMFC). It results in a 0.35 and 0.24 probability of U greater than the Atlantic coast management target and threshold of 0.16 and 0.18, respectively (2022 ASMFC).

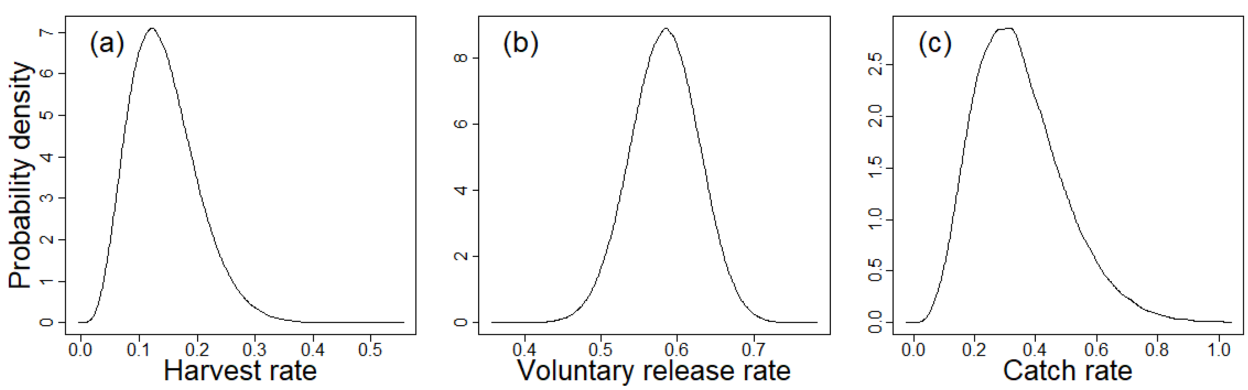

Figure 2.1. Probability distributions of parameter values for (a) harvest, (b) voluntary release rate, and (c) catch rates used to inform $U, \delta, \dot{U}$ (respectively) in the model.

We informed the capture rate $\dot{U}$ indirectly with estimates of voluntary release rates of Striped Bass (δ) as $\dot{U} = U/(1-\delta)$ because δ is easier to inform than $\dot{U}$. We represented δ with a beta distribution with an $\alpha = 70$ and $\beta = 50$, resulting in a mean voluntary release rate of 0.58 with 95% probability between 0.49 and 0.67 (Fig. 2.1). This range represents current patterns of voluntary catch and release practices by recreational anglers in the Sacramento-San Joaquin Delta and tributaries reported by CVAS ($\dot{U}$ = 0.74-0.90), is consistent with the total release rates between 0.43 and 0.75 for Striped Bass reported through the California Recreation Fisheries Survey (CRFS, sourced from Recreational Fisheries Information Center [RecFIN]), and through commercial passenger fishing vessels (CPFV) guide logbook records for the Pacific Oceans and San Francisco Estuary ($\dot{U} =$ 0.14-0.58) (Table 2.1). Furthermore, δ results in model outputs of total release (i.e., the sum of voluntary and legally mandated release) that approximate patterns among δ, U, and $\dot{U}$ reported for Atlantic Striped Bass stocks (2022 ASMFC). The distribution of angler capture rates that resulted from the specified U and δ parameters had mean of 0.35 with 95% probability between 0.12 and 0.69 (Fig. 2.1).

Table 2.1. Estimated harvest rates and literature sources for Striped Bass recreational fisheries.

Source	Harvest rates
Miller (1974)	12-19%
Sommani (1972)	9.6-17.6%
2022 ASMFC	13-32%
CDFW Adult Tagging Program (2011-2022; unpublished)	4-29%

2.1.2 Discard mortality rate

Published mortality rates of captured and released Striped Bass by anglers range between <1% to 67% and can depend on fishing practices (Table 2.2). Because actual angling practices occur in less controlled environments than discard mortality studies, it is likely that this range underrepresents the true levels of discard mortality (e.g., Tenningen et al., 2021). Thus, we specified discard mortality rates with a beta distribution parameterized with an $\alpha = 3.75$ and $\beta = 9.25$ (Fig 2.2). This specification resulted in a mean discard mortality rate of 0.29 and 95% probability range between 0.09 and 0.55, encompassing discard rates in the literature (Table 2.3), those applied in 2022 ASMFC (i.e., 37%), and representing common discard mortality rates applied in stock assessments of a variety of large-bodied marine fisheries (z et al., 2014).

Table 2.2. Estimated voluntary release rates and data/literature sources for Striped Bass recreational fisheries.

Data	Source	Release rates
CRFS 2005-2022	RecFIN (https://www.recfin.org)	43-75%
CPFV logbook records 1995-2020	CDFW Marine Logs System	14-58%
CVAS 1991-2016	Wixom et al. 1995; CDFW 2021	74-90%

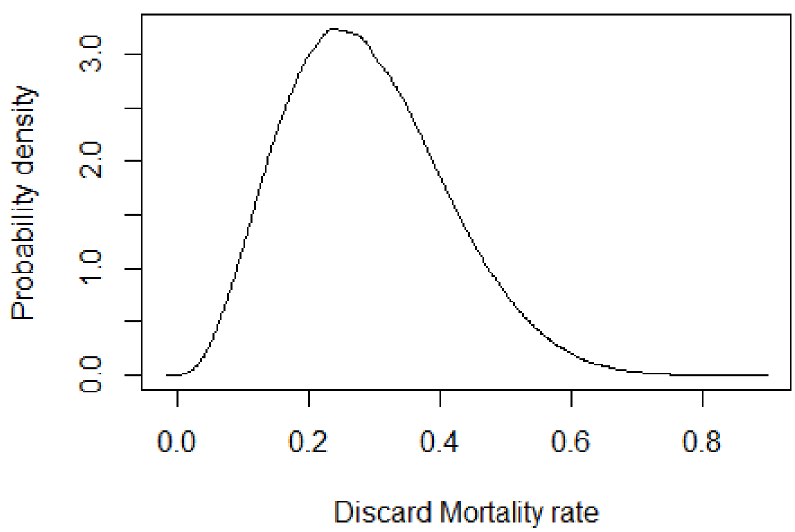

Figure 2.2. Probability distribution of parameter values for discard mortality rate used to inform D in the model.

Table 2.3. Estimated discard mortality rates and literature sources for Striped Bass recreational fisheries.

Source	Release mortality rates
Harrell (1988)	15.6-30.7%
Hysmith et al. (1993)	38%
Diodati and Richards (1996)	3-26%
Nelson (1998)	6-27%
Bettoli and Osborne (1998)	14-67%
Lukacovic and Uphoff (2002)	0.8-9%
Millard et al. (2003)	8-18%
May (1990)	26-30%
Childress 1989a,b	22-27%
Millard et al. (2005)	9-23%

2.1.3 Length-based vulnerability to capture.

Variation in length-based vulnerability to capture can result from complex interactions among fishery and fish characteristics (O'Boyle et al. 2016, Patterson et al. 2012, Garner et al. 2014, Micah et al. 2021). Selectivity patterns of Striped Bass are likely governed by variation in fishing practices targeting harvest versus trophy catch as well as the relative spatial and temporal distribution of angling effort relative to ontogenetic shift in the spatial distribution of fish and temporal migration patterns. Carr-Harris and Steinback (2020) estimated a single strongly dome-shaped selectivity curve for Chesapeake Bay and Atlantic coast Striped Bass fisheries that closely aligns with the strong dome shaped selectivity's of other large-bodied recreational fish species, including red snapper, grey trigger fish and Murray cod (2010 SEFSC, Patterson et al. 2012, Garner et al. 2014, Garner et al. 2017, Gwinn et al. 2019, Micah et al. 2021). Thus, we specified a strongly dome shaped selectivity pattern similar to Carr-Harris and Steinback (2020) with greater uncertainty in the vulnerability of larger fish to capture. We represented the selectivity pattern with a double logistic model with lower lengths at 50% vulnerability to capture (L_{low}) drawn from a normal distribution with $\mu = 60$ and $\sigma = 3$. This resulted in a 95% probability between 54 cm and 66 cm (Fig. 2.3a). The upper length at 50% vulnerability to capture (L_{high}) was modeled as $L_{high} = L_{low} + \Delta$, where Δ was drawn from a log-Normal distributions with $\mu = \log(5)$ and $\sigma = 1$. This resulted in L_{high} with a mean of 68 cm and 95% probability between 57 cm and 96 cm (Fig. 2.3b). We specified the standard deviation of the double logistic model as the product of a coefficient of variation of 0.15 and the length of the fish (i.e., $\sigma_{\text{logit}} = cv * L$). To ensure that the maximum capture probability did not fall below a value of 1, we scaled the vulnerability curve by dividing the outputs by the maximum probability in each growth-type-group. This resulted in a mean L_{low} of 48 and L_{high} of 79 (Fig. 2.3c).

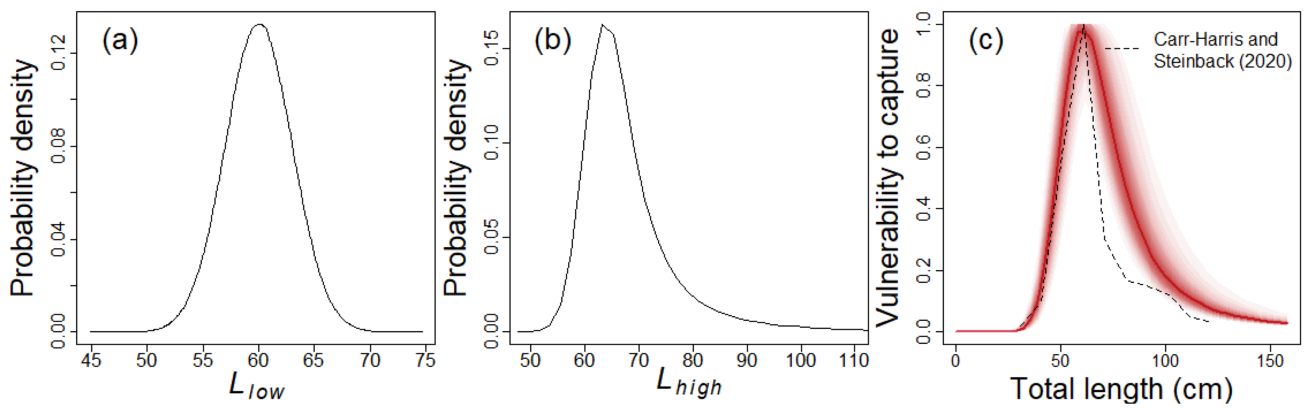

Figure 2.3. Probability distributions of parameter values for (a) lower length at 50% vulnerability to capture and (b) upper length at 50% vulnerability to capture used to inform the vulnerability of fish of length L to capture (c). The bold red line in panel (c) represents the length-based capture probability used in the model compared to capture probabilities modeled for Atlantic Striped Bass (dashed line; Carr-Harris and Steinback 2020). Light red lines represent the standard deviation of the capture probability for Pacific Striped Bass, indicating greater uncertainty in the vulnerability of larger fish to capture.

2.2 Life History Inputs

2.2.1 Length at age

A total of 21 growth-type-groups were simulated, following procedures in Gwinn et al. (2015). In brief, asymptotic length for each growth-type-group g for each sex s ($L_{\infty,g,s}$) was assigned at evenly spaced intervals between $L_{\infty,min}$ and $L_{\infty,max}$ (Table 2.4) for a total equal to the number of growth-type-groups. Values for $L_{\infty,min}$ and $L_{\infty,max}$ were set as $\pm$ 20% of the mean asymptotic length $\overline{L}_{\infty}$ (Table 2.4), which approximates the 95% probability range of a normal distribution with a means of $\overline{L}_{\infty}$ and a standard deviation of 10% of the mean. The proportion of fish recruiting to each growth-type-group g for each sex s ($p_{g,s}$) was specified as the normal probability density of $L_{\infty,g,s}$, with a mean of $\overline{L}_{\infty}$ and a standard deviation 10% of $\overline{L}_{\infty}$ (Gwinn et al. 2015; Walters and Martell 2004).

Table 2.4. Mean and 95% probability of minimum and maximum asymptotic lengths for growth-type-group assignments.

Parameter	Average length (cm)	*95% probability at 2.5%*	95% probability at 97.5%
$L_{\infty,min}^{female}$	106.3	93.4	121.3
$L_{\infty,max}^{female}$	159.5	140.1	181.9
$L_{\infty,min}^{male}$	96.8	85.2	109.8
$L_{\infty,max}^{male}$	145.2	127.9	165

2.2.2 Length-weight relationship.

Length-weight parameters were estimated with a standard length-weight regression fit to data collected during creel surveys (Wixom et al. 1995; CDFW 2021) conducted from 1991-2016 in the San Francisco estuary and Sacramento-San Joaquin Delta. Length-weight parameters were estimated as $\alpha = 4.8 * 10^{-5}$ and $\beta = 2.7$ for males and $\alpha = 2.7 * 10^{-5}$ and $\beta = 2.8$ for females.

2.2.3 Von Bertalanffy growth parameters and Length-at-maturation

Growth and maturation rates of Striped Bass are known to be sex specific, with females growing to larger sizes and maturing at larger sizes and ages then males (Robinson 1960, Mansueti 1961, Turner and Kelley 1966). To account for these differences, we estimated von Bertalanffy growth parameters (Bertalanffy 1938) using an existing long-term fishery-independent length and age data set collected between 1969 and 2009 (total sample size of 250,125). Data were collected with fyke nets and experimental gill nets in the Sacramento-San Joaquin River Delta and tributaries, providing representation of a broad range of sizes and ages (Danos et al. 2020). The growth model was specified with common t_0 and k parameters and a sex-specific L_∞ parameters, and fit with a Normal likelihood via maximum likelihood methods. This analysis resulted in maximum likelihood estimates of $t_0 = -1.4$, $k = 0.1$ (95% probability between 0.08 and 0.13), $L_\infty^{male} = 121$ cm (95% probability between 106.6 cm and 137.5 cm) , and $L_\infty^{female} = 132.9$ cm (95% probability between 116.8 cm and 151.6 cm) . The mean length at maturation (L_{mat}) was set to 35.1 cm for males (95% probability between 30.5 cm and 40.5 cm) and 58 cm for females (95% probability between 50.5 cm and 67 cm), which approximates maturation at 2 years for males and 4-5 years for females (Coutant 1986, Scofield 1930, Calhoun et al. 1948).

2.2.4 Natural mortality

Natural mortality M is difficult to measure directly (Vetter 1988), and there are no known estimates of age-specific M for Striped Bass on the west coast. Thus, we modeled natural mortality as size-dependent following Lorenzen (2000):

$$M_{a,g,s} = M_{ref}\left(\frac{L_{ref}}{L_{a,g,s}}\right),$$

where L_{ref} is a reference length where the natural mortality rate is known to be a given value (i.e. M_{ref}). We inform L_{ref} using the natural mortality schedule given for Atlantic Striped Bass in recent stock assessments by adjusting L_{ref} to mirror the Lorenzen mortality curve at $M_{ref} = 0.15$ (2022 ASMFC). This resulted in $L_{ref} = 90$ cm for males and females, with a mean M of 0.15 and a 95% probability between 0.10 and 0.22 (Fig. 2.4).

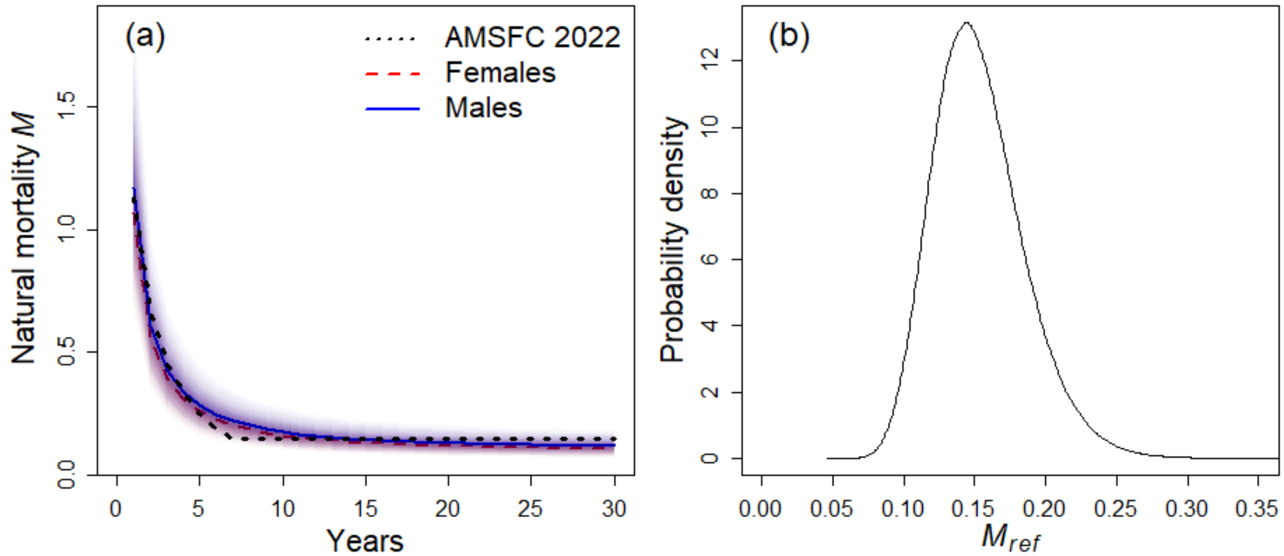

Figure 2.4. Sex-specific natural mortality-at-age estimates for Pacific Striped Bass (bold blue line and dashed red line) compared to natural mortality reported for Atlantic Striped Bass (dotted line; 2022 ASMFC) (a). Panel (b) describes the probability distribution of parameter values for M_{ref} used to inform natural mortality M.

2.3 Reproduction and Recruitment Inputs

2.3.1 Compensation Ratio (CR), scaling parameter (R_0), and fertility function (θ)

The parameter CR is the Goodyear compensation ratio (Goodyear 1977, 1980) that describes the maximum relative increase in juvenile survival as the total fecundity is reduced from the unfished biomass (φ_0) to near zero. There are no available estimates of CR for pacific Striped Bass; however, Meyers et al. (1999) reports a value of $CR = 18.2$ for the species and the recent stock assessment of Atlantic stocks estimated and applies a value of $CR = 6$ (2022 ASMFC). We applied a mean value of $CR = 11.6$ in our Monty Carlo process based on the Fishlife analysis updated with the estimates of Myers et al. (1999) and 2022 ASMFC. This resulted in a 95% probability of CR between 4.4 and 25.8. Because R_0 is a scaling parameter that does not influence the comparison of alternative regulations, we set it to $R_0 = 1$ to present results on a 'per-recruit' scale.

The term θ (Eq. 2) was used investigate the interaction of fertility and sex ratio at various levels, ranging from $\theta = 20$ (representing a "low fertility" function) to $\theta = 80$ (representing a "high fertility" function) (Heppell et al. 2006; Fig. 2.5). Values for θ were drawn from a random uniform distribution, which resulted in a mean of 50.4 and 95% probability between 22 and 78.

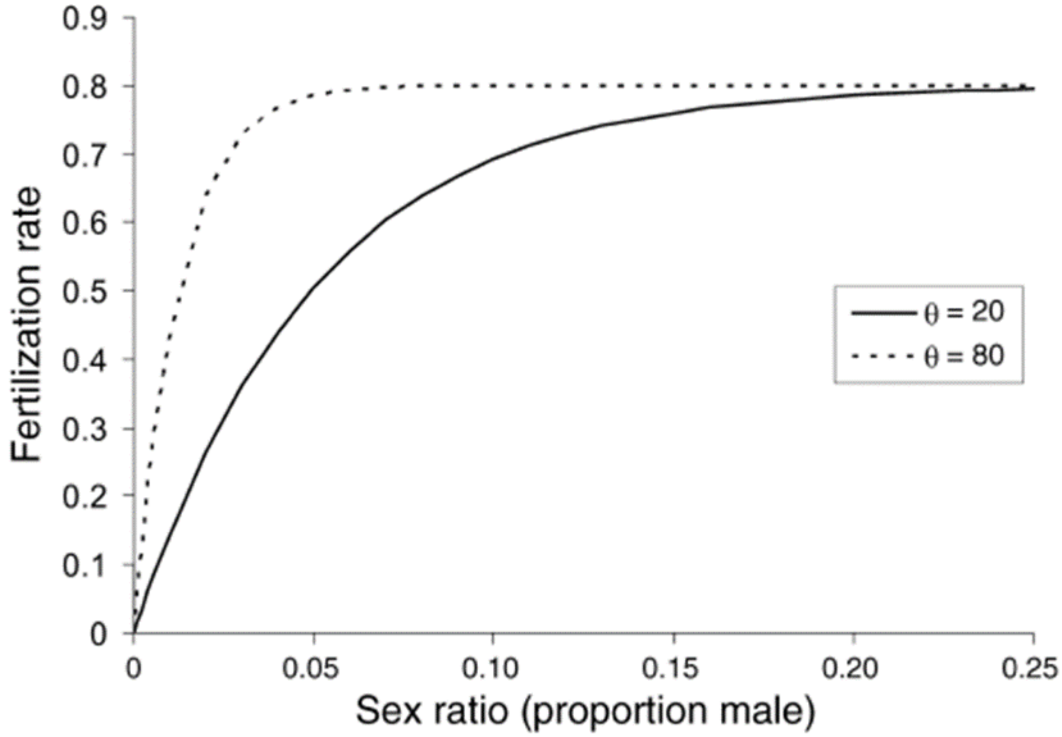

Figure 2.5 Model relationship between fertilization rate and sex ratio (proportion of males) based on two different levels of fertility function, θ (Fig.3 from Heppell et al. 2006).

APPENDIX 3: CALIFORNIA DEPARTMENT OF FISH AND WILDLIFE'S STRIPED BASS DIET, FORAGING BEHAVIOR, AND PREDATION LITERATURE REVIEW

3.1 Literature Review Purpose

In the Fall of 2020, the Nor-Cal Guides and Sportsman's Association (NCGASA) submitted a regulation change petition to the Fish and Game Commission. The proposed regulation change would restrict the harvest of Striped Bass to a "slot limit" between 20 and 30 inches for inland anadromous waters. In the summer of 2022, the NCGASA submitted a second petition which would apply the 20-to-30-inch harvest slot limit to Striped Bass caught in marine (ocean and bay) waters as well. The NCGASA petition stated that the regulation change would protect the earliest spawners as well as the largest most fecund individuals, which would then over time, increase the population size of Striped Bass. The NCGASA also stated that they had polled their membership and that there was overwhelming support for a 20-to-30-inch slot limit. In response to the petition filing, the California Department of Fish and Wildlife (CDFW) began compiling and reviewing the available science to evaluate the efficacy of the science presented in the proposal. The goal of this literature review is to understand trends in the Striped Bass population, trends in inland and marine fisheries, and impacts that the proposed slot limit may have on listed species (if any) through predation.

During the evaluation process, several questions arose which necessitated a literature review which specifically focused on Striped Bass diet, foraging behavior, and predation. The review was needed to better understand how diet and feeding behavior of Striped Bass could vary temporally, spatially, by life-stage, and sex. The review also included pertinent literature that discussed factors that may influence feeding behaviors including environmental conditions, Striped Bass migration and distribution, and predator-prey abundance, among others.

The information included in the literature review included: study funding source (if listed and/or easily discernable), study period, geographic range, predator and prey assemblages evaluated/detected by the study, key findings from the study, and an overall take away from the paper. Information listed in the "key findings" and "overall" sections of the review include text taken directly from the document that was reviewed as well as text that reflects the opinions of the reviewer. Final impressions and findings from this literature review will inform and be presented in the CDFW evaluation of the NCGASA slot limit proposal document. This review is a living document and will be updated as new research is conducted and literature published.

3.2 General Striped Bass diet and foraging behavior

Loboschefsky et al. 2012

Loboschefsky, E., G. Benigno, T. Sommer, K. Rose, T. Ginn, A. Massoudieh, and F. Loge. 2012. Individual-level and Population-level Historical Prey Demand of San Francisco Estuary Striped Bass Using a Bioenergetics Model. San Francisco Estuary and Watershed Science 10(1).

Funding Source. DWR and IEP.

Study Period. Dates ranging between 1969-2004 were selected because it was a composite study to create a model and not a study to collect data.

Geographic Range. San Francisco Estuary.

Predator assemblage evaluated. Sub-adult (age 1 and 2) and adult (age 3+) Striped Bass.

Prey species detected. Diet analysis was compiled from many sources and over different time scales. Prey item categories included: fish, decapod/isopods, mysids, and “other”.

Key Findings.

- Quantified the individual and population-level consumption by Striped Bass.
- Mean length at age, and subsequent calculated mean weight began to decrease in the early 1990s for fish older than age 4.
- Adult Striped Bass diet consisted primarily of prey fish during all time-periods analyzed and was not observed to change significantly over time.

- Sub-adult Striped Bass became more piscivorous during the study period beginning in 1990, with a commensurate decline in the proportion of mysids in their diet. Prey fish increased from 2.5% to 12.2% in the diet of age one and from 78.5% to 82.1% in the diet of age two between 1980 and 1990, and mysids in the diets decreased from 95.9% to 58.5% and from 18.4% to 8.4%.

- Sub-adult population total consumption was variable from year to year and was statistically correlated to the sub-adult abundance estimates for age one.

- Adult population total consumption was statistically correlated to Striped Bass abundance estimates.

- From 1990 through 2001, piscivorous predation rates increased coincident with higher population numbers of adult Striped Bass and sub-adults.

Overall. This study found that individual consumption by adult females was higher than adult males at comparable age–classes. This may be because of the larger sizes and growth rates of females than of males, and the higher energetic cost of spawning in females than in males. One of the key findings of this paper is that population total consumption by sub-adult Striped Bass was similar to the population total consumption by adult Striped Bass. While the individual total consumption by adults was greater than that of the sub-adults, the larger sub-adult population abundance resulted in very similar total consumption (e.g., mean = 18.1× 106 kg prey for sub-adults versus 17.9 × 106 kg prey for adults). Prey located outside of the estuary represents an unknown percentage of the estimated total prey consumed by adults. By contrast, since sub-adults primarily reside in the estuary, and since the simulations showed that this demographic frequently consumes more than adults, sub-adults have a particularly large consumption demand within the estuary. Sub-adult Striped Bass can be highly abundant in shallow-water habitat (Nobriga and Feyrer 2007). A high percentage of prey consumed by sub-adult Striped Bass may originate inshore rather than in pelagic habitat.

Nobriga and Feyrer 2008

Nobriga, M., and F. Feyrer. 2008. Diet composition in San Francisco Estuary Striped Bass: does trophic adaptability have its limits? Environmental Biology of Fishes. DOI 10.1007/s10641-008-9376-0.Funding Source.

Funding Source. DWR and the CALFED Science Program.

Study Period. Used data collected from Stevens 1966 (1963-1964) and Nobriga and Freyrer 2007 (2001-2003), excluding winter samples from Stevens to make data sets temporally comparable.

Geographic Range. Sacramento San Joaquin Delta (16 sites).

Predator assemblage evaluated. Striped Bass diets.

Prey species detected. Variable, but focused on Inland Silverside, Threadfin Shad, and decapod shrimp.

Key Findings.

- This study examined trophic adaptability, as changes in diet over time shifted with prey availability.
- Results indicate that Striped Bass could effectively incorporate new prey into their diet at an intermediate time scale between one to two years. This was observed by Stevens 1966 after Threadfin Shad established populations in the San Francisco Estuary and were identified as a new prey source in the early 1960s.
- Threadfin Shad was a close second in importance to cannibalized Striped Bass as a prey fish and remained at similar frequencies in Striped Bass stomachs 40 years later.
- Logistic regression models for the three prey taxa tested showed their presence–absence in Striped Bass stomachs was significantly affected by both prey density and predator length. Larger Striped Bass (>400 mm FL) were less likely to consume smaller prey fishes such as Inland Silverside, and more likely to consume Threadfin Shad and decapod shrimp.
- Striped Bass and Mysid shrimp often form a predator–prey association in estuaries, and there is evidence to suggest that San Francisco

Estuary (SFE) Striped Bass productivity has declined in part because Mysid shrimp productivity has declined.

Overall. SFE Striped Bass exhibited, and continue to exhibit, considerable trophic adaptability. Striped Bass have adapted by incorporating certain prey into their diet as prey were introduced and rose to prominence in the estuary's faunal assemblage. They speculate that as continued species introductions push the SFE food web further away from a pre-existing state, it is increasingly unlikely that Striped Bass will find a suite of invading 'alternate prey' that can fully replace their established historical prey which may lead to declines in Striped Bass productivity.

Stevens 1966

Stevens, D.E. 1966. Food habits of Striped Bass, *Roccus saxatilis*, in the Sacramento–San Joaquin Delta. California Department of Fish Game Fish Bulletin 136:68–96.

Funding Source. Delta Fish and Wildlife Protection Study through DWR and the California Water Bond Act.

Study Period. September 1963 through August 1964.

Geographic Range. Sacramento-San Joaquin Delta.

Predator assemblage evaluated. Striped Bass food habits (n= 8,628 stomachs).

Prey species detected. Various aquatic macroinvertebrate and fish species (see key findings below). Percentages reported below represent average % by volume across seasons (see Tables 5, 6, 7, and 8 in document)

Key Findings.

- Data were analyzed by frequency of occurrence in the stomachs and percent of diet by volume.
- Young bass between 5-12 cm (September 1963) and 12-23 cm (August 1964) consumed crustaceans (56%), insects (trace), mollusks (1%), Threadfin Shad (36%), and small Striped Bass (12%).

- Juvenile bass between 13-25 cm (September 1963) and 24-35 cm (August 1964) consumed crustaceans (14%), Threadfin Shad (31%), Striped Bass (18%), American Shad (3%), Delta Smelt (listed as pond smelt in document, 5%), King Salmon (spring and summer)(2%), insects (trace), and mollusks (trace).

- Sub-adult bass between 26-37 cm (September 1963) and 36-47 cm (August 1964) consumed Threadfin Shad (43%), Striped Bass (35%), unidentified fishes (10%), American Shad (1%), King Salmon (spring and summer) (3%), and crustaceans (4%).

- Adult bass longer than 38 cm (September 1963) and longer than 48 cm (August 1964) were considered at least three years old. Their diet included Striped Bass (45%), unidentified fishes (6%), Threadfin Shad (26%), American Shad (4%), Delta Smelt (trace), King Salmon (spring)(1%), and crustaceans (trace).

- King Salmon were observed in the diets of sub-adult (fall and spring) and adult Striped Bass (spring) in the lower San Joaquin River, but not in the middle or upper San Joaquin River.

- Diets of Striped Bass caught in the south delta were dominated by crustacean species for young through sub-adult Striped Bass. Adult diets were dominated by fishes, primarily other Striped Bass and Threadfin Shad.

Overall. Five items frequently occurred in the diets of Striped Bass of any age, including Mysid shrimp, amphipods, small Striped Bass, Threadfin Shad, and discarded or stolen sardine and anchovy bait. Young Striped Bass were one of the important foods of adult and sub-adult bass. In the fall, they were discovered in two-fifths of sampled sub-adults and adults' stomachs. In the winter and spring, as the young bass became less abundant and larger, they were eaten less frequently. In the summer, when the new year-class of young bass became available, there was a sharp increase in the percentage of the sub-adults and adults that had eaten small bass. These new young-of-the-year bass were also of importance as a food of juvenile bass.

Thomas 1967

Thomas, J.L. 1967. The Diet of Juvenile and Adult Striped Bass Roccus Saxatilis, in the Sacramento-San Joaquin River System. Cal Fish and Game 53(1):49-62.

Funding Source. Federal Aid to Fish Restoration Funds (Dingell-Johnson Project California).

Study Period. Incidental collection took place between 1957-1960. In 1961, the Young of Year (YOY) were collected monthly. In 1962, both juveniles and adults were collected monthly.

Geographic Range. (i) San Francisco Bay (SFB), (ii) San Pablo Bay, (iii) Sacramento River and bays from Crockett to Pittsburg, (iv) Delta, (v) Lower Sacramento River, and (vi) Upper Sacramento River.

Predator assemblage evaluated. Striped Bass only.

Prey species detected. Both vertebrates and invertebrates were collected (see Table 2 in Thomas 1967). Prey detected included Chinook Salmon.

Key Findings. Results are presented by season, location, and size class, and are reported as frequency of occurrence and percentage volume. Below is a summary of detected prey species size classes with volume reported.

- Adults (> 16 inches).
    - Spring diet largely consisted of Shiner Perch (50%) and anchovies (34%). Individuals were found in the SFB.
    - Summer diet largely consisted of Northern Anchovies and Shiner Perch. Individuals were found in the SFB.
    - Fall diet largely consisted of Northern Anchovies and Shiner Perch (>50% by volume combined), Pacific Tomcod and herring (22% by volume combined). Young Striped Bass also appeared in the diet. Individuals were found in the Delta.
- Juveniles (size group not stated, assuming < 16 inches).
    - Spring diet largely consisted of King Salmon (65%). Individuals were found in the Upper Sacramento River.

- Summer diet largely consisted of King Salmon and carp (73% combined). Individuals were found in the Upper Sacramento River.

- Summer diet largely consisted of Mysid shrimp (80%). Individuals were found in the Delta.

Overall. The study did not differentiate diet by fish size for all locations and times of the year. Therefore, results where diet composition across size classes differentiated were summarized. Generally, adults in San Francisco Bay contained larger volumes of Shiner Perch and anchovies in stomachs, while juveniles in the Upper Sacramento River and Delta contained more King Salmon, carp, and Mysid shrimp.

Young et al. 2022

Young, M.J., Feyrer, F., Smith, C.D., and D.A. Valentine. 2022. Habitat-specific foraging by Striped Bass (*Morone saxatilis*) in the San Francisco Estuary, California: implications for tidal restoration. San Francisco Estuary & Watershed Science 20 (3).

Funding Source. U.S. Bureau of Reclamation (Interagency Agreement).

Study Period. Spring (March 26-April 5) 2018 and Summer (July 9-18) 2018.

Geographic Range. Ryer Island in the north-central delta was targeted for this study. Three habitat types were sampled: marsh, shoal, and channel. These habitats were sampled both day and night using gill nets and trawls to minimize time of day and gear type bias.

Predator assemblage evaluated. Striped Bass were evaluated at a size range of 63 to 671 mm standard length, and an age range spanning 1-5 years.

Prey species detected. Stomach contents revealed 9,989 prey items representing 46 prey taxa.

Key Findings.

- Tested for differences in fish size and stomach fullness across season and habitat types using ANOVA.

- Collected 269 Striped Bass of which 34 had empty stomachs (n = 235 individuals).
- Diets were dominated by invertebrates.
- Diets only differed by Stiped Bass size in the spring.
- There were significant diet differences across habitats in both spring and summer. Striped Bass collected in marsh habitat had significantly different stomach contents than Striped Bass collected in channel or shoal habitat. The channel and shoal habitat stomach contents were not significantly different from each other.

Overall. The prey variability observed in this study, coupled with shifts in dominant prey types over time in the estuary, indicate that Striped Bass are an adaptable and opportunistic predator able to adjust to changing environmental conditions and prey availability. In this study, total invertebrate consumption was generally consistent across seasons, and variability was instead associated with specific invertebrate categories. Fish were only the most important diet item for large Striped Bass in the marsh in spring, and not any other habitat/season combination, consistent with Zeug et al. (2017). The dominant fish diet items were littoral or benthic fish species of least concern, with few pelagic or special status-fishes observed in diets.

Zeug et al. 2017

Zeug, S.C., Feyrer. F.V., Brodsky, A., and J. Melgo. 2017. Piscivore diet response to a collapse in pelagic prey populations. Environmental Biology of Fishes 100: 947-958.

Funding Source. U.S. Bureau of Reclamation.

Study Period. November and December 2010 and 2011.

Geographic Range. Study was located at the San Francisco Estuary and centered on Suisun Bay and San Pablo Bay using multimesh gill nets.

Predator assemblage evaluated. Striped Bass, Sacramento Pikeminnow, Largemouth Bass.

Prey species detected. Generalized into 16 prey categories (see Table 1 in Zeug et al. 2017).

Key Findings.

- Across the study duration, 348 total stomachs were examined. Out of this total, 25% of stomachs had no identifiable contents.
- Striped Bass comprised the majority of piscivores collected (89%) followed by Sacramento Pikeminnow (10%). Two Largemouth Bass were collected (0.6% of total) but were excluded from comparisons among species due to the low sample size.
- Benthic prey accounted for 80% of all prey by weight and pelagic prey accounted for 7%. The remaining 13% consisted of other sources such as terrestrial or could not be identified (excessive digestion).
- Prey items in the stomachs of Striped Bass were gravimetrically dominated by *Crangon* spp. (26%), "other Osteichthyes" (17%), and Isopoda (16%; see Figure 4 in Zeug et al. 2017). No other prey item made up more than 10% of the diet by gravimetric proportion.
- In both years the category "other Osteichthyes" occurred in the greatest density near the confluence of the Sacramento and San Joaquin rivers.
- No special status species were detected in any piscivore stomach examined. However, small sample sizes, and time of year could have contributed to this.

Overall. The results indicate there has been a significant reduction in the contribution of pelagic prey resources to Striped Bass diets when compared to earlier studies (e.g., Johnson and Calhoun 1952; Thomas 1967) concomitant with the pelagic organism decline. Striped Bass responded to the pelagic organism decline by consuming greater proportions of benthic fish and invertebrates whereas Sacramento Pikeminnow diets were more specialized and consisted primarily of benthic fish in both years. If there has been a decline in SFE Striped Bass abundance, it could be linked to reduction in preferred prey resources.

3.3 Predation focused Striped Bass diet and foraging behavior studies

Michel et al. 2018

Michel, C.J., Smith, J.M., Demetras, N.J., Huff, D.D., and S.A. Hayes. 2018. Non-native fish predator density and molecular-based diet estimates suggest differing effects of predator species on juvenile salmon in the San Joaquin River, California. San Francisco Estuary and Watershed Science 16(4).

Funding Source. DWR.

Study Period. Sampling took place from early May 2014 through April 2015 using electrofishing boats. Sampling was scheduled to occur during historical peak out-migration of sub-yearling fall-run Chinook Salmon.

Geographic Range. Three sites near Old River in the Lower San Joaquin River.

Predator assemblage evaluated. Largemouth Bass (LMB), Channel Catfish (CHC), White Catfish (WHC), and Striped Bass (STB).

Prey species detected. The diet analysis focused on 12 selected prey species and is not considered a full comprehensive diet analysis. Largemouth bass, Striped Bass, Mississippi Silverside, Chinook, Sacramento Splittail, Threadfin Shad (TFS), Rainbow Trout/steelhead, Green Sturgeon, Delta Smelt, Longfin Smelt, Sacramento Pikeminnow, and White Sturgeon were all identified as prey through DNA assays.

Key Findings.

- Largemouth Bass (42%) and Striped Bass (40%) were by far the most captured predators in the study reaches, followed by White Catfish, Channel Catfish, and other Centrarchid species.

- The catch composition between these two habitats also varied; Largemouth Bass dominated the littoral habitat, and Striped Bass dominated the channel habitat. This could be a sampling (electrofishing) bias. Striped Bass were patchily distributed between sampling reaches.

- A total of 582 predator diets were collected, comprising 253 LMB diets, 186 STB diets, 107 WHC diets, and 36 CHC diets.

- CHC had the widest variety of prey species in their diets. The least frequent prey items found in CHC diets was STG, LFS, SPM, and STW.

- LMB was found in the highest proportion of diets for all species, followed by STB, MSS, CHK, and SPT, in approximately that order for all predators. DSM, RBT, and TFS were found in low frequencies in all four predator species.

- Contribution of salmonids to predator diets (2014 and 2015 combined): 27.7% of CHC diets tested positive for Chinook Salmon, followed by 4.8% of STB diets, 4.7% of WHC diets, and 2.8% of LMB diets. For Steelhead, 5.5% of CHC diets and 2.2% of STB diets had Steelhead; no WHC or LMB diets tested positive for Steelhead. Combined, salmonids were present in 33.3% of CHC diets, followed by 7.0% of STB diets, 4.7% of WHC diets, and 2.8% of LMB diets.

- Non-native predator (Largemouth Bass, Channel and White Catfish, and Striped Bass) diets were mostly comprised of other non-native predator species. Salmonid prey were found in only 7% of STB diets.

Overall. Michel et al. 2018 found that Striped Bass in these size-classes are mostly found in roving aggregations, and whether they are found in a study reach during the time of a survey is highly variable. This is consistent with the understanding that Striped Bass are highly mobile, migratory, and aggregating fish as sub-adults or small adults. This study also found that although all tested predator species ate salmonids, the predators tested positive more frequently for non-native piscivorous species. They also tested positive for many non-native prey species at higher frequencies. Other studies throughout the Delta have found similarly low frequencies of salmonids in predator diets, with typically less than 5% of Striped Bass diets containing salmonids, even during peak out-migration and in regions with higher densities of salmonids (Stevens 1966; Thomas 1967; Nobriga 2007). Only in the rare exception of when a migratory corridor becomes spatially constricted do salmonids become a major component of Striped Bass diets in the Delta (such as with fish ladders; Sabal et al. 2016).

Nobriga and Feyrer 2007

Nobriga, M., and F. Feyrer. 2007. Shallow-water piscivore-prey dynamics in California's Sacramento–San Joaquin Delta. San Francisco Estuary & Watershed Science 5(2).

Funding Source. IEP.

Study Period. March-October 2001 and March-October 2003 using beach seines and gill nets for nearshore sampling.

Geographic Range. The study was located within the Sacramento-San Joaquin Delta. Central sampling locations were found on Liberty, Decker, and Sherman islands. Southern sites included Medford and Mildred islands.

Predator assemblage evaluated. Striped Bass, Largemouth Bass, and Sacramento Pikeminnow.

Prey species detected. See Table 1 *in* Nobriga and Freyrer (2007).

Key Findings.

- Striped Bass had the broadest spatio-temporal distribution. Largemouth Bass had the narrowest spatio-temporal distribution.
- All three piscivores had diverse diet compositions comprised of numerous invertebrate and fish taxa.
- Field observations of changes in piscivore stomach contents through time have indicated that piscivorous fishes exhibit prey switching behavior. Striped Bass are opportunistic feeders that shift in prey items as the fish get larger/older (Stevens 1966).
- There were noticeable seasonal shifts in prey fish consumed by all three piscivores. Collectively, most native fish use occurred during spring (March-May) and the highest prey species richness occurred during summer (June-August).
- Largemouth Bass preyed on a greater number of native fish than the other two piscivores and consumed native fish farther into the season (July) than the other two piscivores (May).

- Striped Bass piscivory was significantly affected by season (chi-square = 24.6; *P*= 0.00002), but not fork length (chi square = 7.37; *P* =0.06).
- Striped Bass typically only exceeded the 50% piscivory threshold during summer and fall regardless of size.

Overall. This study indicates that all three predators frequently occur in Delta shallow-water habitats. However, they acknowledge that having only five sampling sites limited the ability to generalize about piscivore distributions across the entire Delta. This study found that piscivore prey choices are functions of encounter and capture probabilities. Both encounter and capture probabilities are probably affected by prey relative abundance. Encounter probabilities also are influenced by environmental factors such as turbidity and vegetation density.

Peterson et al. 2020

Peterson, M., J. Guignard, T. Pilger, and A. Fuller. 2020. Stanislaus Native Fish Plan: Field Summary Report for 2019 Activities. Technical Report to Oakdale Irrigation District and South San Joaquin Irrigation District. *<u>Draft in Review.</u>*

Peterson et al. 2023

Peterson, M., T. Pilger, J. Guignard, A. Fuller, and D. Demko. Diets of Native and Non-native Piscivores in the Stanislaus River, California, Under Contrasting Hydrologic Conditions. San Francisco Estuary & Watershed Science 2: 1-22.

Funding Source. Oakdale and South San Joaquin Irrigation Districts.

Study Period. Spanned four months from March 1, 2019, through June 30, 2019.

Geographic Range. Lower Stanislaus River from Oakdale Recreation Area 66.9 river kilometer (rkm) to the confluence with the San Joaquin River.

Predator assemblage evaluated. While 17 predator species were targeted, black bass, stiped bass, hardhead, Sacramento Pikeminnow, sunfish, and catfish were most evaluated.

Prey species detected. A variety of invertebrates fishes, and crustaceans.

Key Findings.

- Predator composition included black bass (51%), Striped Bass (13%), sunfish (13%), Hardhead (12%), and Sacramento Pikeminnow (8%).

- Habitat types assessed in the study included rip-rap, submerged vegetation, overhanging vegetation, woody debris, open water, and unknown. Flows during the study period were between 3,000 and 4,000 cfs, and the dominant habitat types at these flows were submerged and overhanging vegetation.

- Black bass were ubiquitous throughout the study area and observed in all habitat types, but submerged vegetation was the most common. Striped Bass were concentrated in the middle and lower reaches and most often observed in overhanging and submerged vegetation, but also found in open water and woody debris.

- Invertebrates (insects, crustaceans, and annelids) dominated predator diets. Ninety percent of all identified prey items were invertebrates. Fish made up only seven percent of the total identified diet and were primarily consumed by black bass and Striped Bass.

- The two most observed consumed fish were Chinook Salmon and lamprey. Chinook salmon made up 8.5% of Striped Bass diet by number, and lamprey made up 6.7%.

    - Twenty four percent of Striped Bass caught were observed to have consumed at least one Chinook Salmon. Black bass were observed to consume Chinook Salmon at a lower rate of 9.2%.

    - Black bass that consumed salmon were 175-300 mm fork length (FL).

    - Striped Bass that consumed salmon were between 240-660 mm FL.

    - Striped Bass consumed Chinook Salmon and lamprey at a rate that increased gradually in March and April, peaked in May, and decreased slightly in June.

- Fork length (FL) of Striped Bass that consumed salmon significantly decreased over the study period, while FL of black bass that consumed salmon increased slightly. However, mean FL of black bass did not change over sampling period, suggesting smaller black bass that ate salmon early in the season may not have been able to consume salmon later in the season with increases in prey sized. Striped Bass appeared to consume salmon independent of prey size.

- Total estimated monthly consumption was highest for Striped Bass across the study period (March- June). Striped bass holds the highest estimated population-level impact on Chinook Salmon based on rotary screw trap estimates of salmon migration into the study reach.

- The total number of juvenile Chinook Salmon entering the study area occurred at the same time of diet collections. Mismatch in temporal scales would most likely overestimate the predation impact on Chinook Salmon.

Overall. Overall fish consumption was low (7% of total predator diets), and most often observed in black bass and Striped Bass. Fish species consumed by Striped Bass primarily consisted of Chinook Salmon (8.5%) and lamprey (6.7%), but also included non-natives such as bluegill (0.6%), carp (3%), green sunfish (0.6%), loach (0.6%), and Striped Bass (0.6%). Chinook Salmon occurrence was observed in Striped Bass 240-660 mm FL (9-25 inches). Consumption of Chinook Salmon appeared to be dependent on prey size for black bass, but independent for Striped Bass. Striped Bass were estimated to have the largest impact on salmon populations in the study area compared to other predators. Consumption estimates rely on assumptions that may or may not have been violated.

Stompe et al. 2020

Stompe, D.K., Roberts, J.D., Estrada, C.A., Keller, D.M., Balfour, N.M., and A.I. Banet. 2020. Sacramento River predator diet analysis: a comparative study. San Francisco Estuary & Watershed Science 18(1).

Funding Source. Northern California Water Association and CDFW.

Study Period. Hook and line sampling occurred between March 2017-November 2017. Sampling occurred over three habitat types. riprap, natural, and manmade.

Geographic Range. Sacramento River (middle) near Chico, and Ord Bend in the Glenn-Colusa Irrigation District.

Predator assemblage evaluated. Striped Bass between 22.5 cm and 47 cm and Sacramento Pikeminnow were evaluated. The study analyzed predator size, distribution, and diet. Predator Catch Per Unit Effort (CPUE) was used as a measure of abundance.

Prey species detected. Prey species were determined through visual ID and PCR primers. Major prey categories included macroinvertebrates, crayfish, and fishes (see table for index of relative importance IRI%).

Key Findings.

- Out of the 155 target species that were captured, 68 were Sacramento Pikeminnow and 87 were Striped Bass. Of these individuals, Sacramento Pikeminnow (n=30) and Striped Bass (n=47) contained stomach contents that were identifiable.
- Sampled Striped Bass and Sacramento Pikeminnow were evenly distributed across all habitat types.
- Temporal distribution showed that Striped Bass CPUE was higher in summer than in fall.
- Of the individuals that contained stomach contents, piscivory was observed in 71% of Sacramento Pikeminnow and 84% of Striped Bass.
- The two most important prey items for both predator species, as enumerated by %IRI, were macroinvertebrates (excluding crayfish) and Chinook Salmon (Sacramento Pikeminnow: 77% and 15%, respectively; Striped Bass: 78% and 17%, respectively; Table 3.1 below).
- %IRI and PERMANOVA modeling indicate no difference in diets between Sacramento Pikeminnow and Striped Bass.
- Prey frequency of occurrence showed no relationship with species or habitat type but was significantly influenced by water temperature.

Table 3.1. *In* Stompe et al. 2020 (Table 3). Table represents %IRI values for Sacramento Pikeminnow and Striped Bass captured via hook and line sampling near Chico, Ca.

Prey Species	Sacramento Pikeminnow	Striped Bass
American Shad	0.08	0.64
Chinook	14.57	17.03
Crayfish	2.56	0.17
Green Sturgeon	0.00	0.08
Hardhead	0.48	2.75
Macroinvertebrate spp.	76.90	78.09
Pacific Lamprey	0.90	0.11
Sculpin spp.	4.51	1.03
Tule Perch	0.00	0.10

Overall. %IRI and PERMANOVA modeling indicated no difference in diets between Sacramento Pikeminnow and Striped Bass. While there are obvious life-history differences between these two species, on a per capita basis, neither appears to have a higher impact on observed prey, including Chinook Salmon, than the other. Both Sacramento Pikeminnow and Striped Bass are opportunistically feeding on seasonally available prey populations. Results support the notion that Sacramento Pikeminnow and Striped Bass exhibit prey-switching behavior, both spatially and temporally. This likely occurs in the presence of high densities of certain prey, such as during in-river releases of hatchery Chinook Salmon. The observed proportion of Chinook Salmon in predator diets within the Sacramento River was lower than was seen by Thomas (1967). Overall predator diets in the Sacramento River were substantially different than those observed within the Delta (Stevens 1966; Nobriga and Feyrer 2007). This could indicate that predation pressure or likelihood of being predated upon is different during the river migratory phase versus in the more open-water habitat of the delta. PERMANOVA modeling showed that water temperature was the only variable measured that significantly affected predator diets. Because of the association between water temperature and seasonality, this may indicate a temporal association of predator diets, which would support the conclusion that both Sacramento Pikeminnow and Striped Bass are opportunistically feeding on seasonally available prey populations.

3.4 Size specific Striped Bass diet and foraging behavior

Heubach et al. 1963

Heubach, W., Toth, R.J., and A.M., McCready. 1963. Food of young-of-the-year Striped Bass (*Roccus saxatilis*) in the Sacramento-San Joaquin River System. California Fish and Game 49 (4): 224-239.

Funding Source. Dingell-Johnson Project California F-9-R, and Federal Aid to Fish Restoration.

Study Period. Opportunistically collected in conjunction with other field activities from June-November 1956-1961.

Geographic Range. Lower Sacramento-San Joaquin River system (tow net and seining stations).

Predator assemblage evaluated. Juvenile Striped Bass (YOY).

Prey species detected. Planktonic species.

Key Findings.

- This study took place prior to the California Water Plan establishing baseline diets for YOY Striped Bass in the delta.
- The percentage frequency of copepod occurrence was greater in small bass than large ones. Larger plankton, *Neomysis* and *Corophium,* occurred more frequently in larger YOY Striped Bass.
- Salinity affected prey distribution/availability and therefore diets. The occurrence of plankton species in YOY stomachs generally coincided with the distribution of plankton in the environment.

- In this study, several major groups comprising over 20 species of small animals were eaten by young-of-the-year Striped Bass. Many of these organisms were also reported in previous food habits studies (cited within Heubach et al. 1963).

- Fish were unimportant in the diet of YOY Striped Bass.

Overall. Fish were unimportant in the diet of young-of-the-year Striped Bass. The occurrence of organisms in the stomachs generally agreed with the distribution of plankton organisms in the environment. Thus, food habits in any area were largely controlled by the factors controlling plankton distribution. Salinity and water flow were the most important of these factors.

Walter and Austin 2003

Walter, J.F., and H.M. Austin. 2003. Diet composition of large Striped Bass (*Morone saxatilis*) in Chesapeake Bay. Fishery Bulletin 101: 414-423.

Study Period. March 1997 through May 1998.

Geographic Range. Chesapeake Bay, tributaries, and Chesapeake Bay mouth.

Predator assemblage evaluated. Striped Bass.

Prey species detected. Through diet analysis, 34 different species of fish and 18 species of invertebrates were detected (see Table 2 *in* Walter and Austin 2003).

Key Findings.

- Two size classes of Striped Bass were analyzed. Striped Bass between 458-710 mm were classified as resident and migratory fish. Striped Bass between 711-1255 mm were classified as a coastal migrant fish.

- Out of the 1225 fish analyzed, 56% contained items in stomach (these results are similar to Brandl et al. 2021)

- Clupeid fishes dominated the diet, particularly Atlantic Menhaden. Menhaden accounted for 44% of the weight and occurred in 18% of all stomachs.

- Menhaden ranged in length from 103 to 360 mm total length, and scored higher on the index of relative important compared to any other species as calculated in the equation below.
    - $IRI = (\%N + \%W) \times \%FO$
    - Where %N = the percentage of a prey species by number, %W = the percentage of a prey species by weight, and %FO = the percent frequency of occurrence of a prey species.
- Size appeared to indicate potential differences in Striped Bass diets. Smaller Striped Bass consumed Bay Anchovy, juvenile Spotted Hake, whereas larger Striped Bass consumed anadromous herrings.
- There was a significant relationship between Striped Bass total length and prey length (P<0.05, r2=0.26), indicating that larger and older Striped Bass ate larger prey. The regression fit was poor, indicating that large fish also consumed small prey (Figure 3.1). In other words, larger Striped Bass consumed a greater size range of prey than smaller Striped Bass.

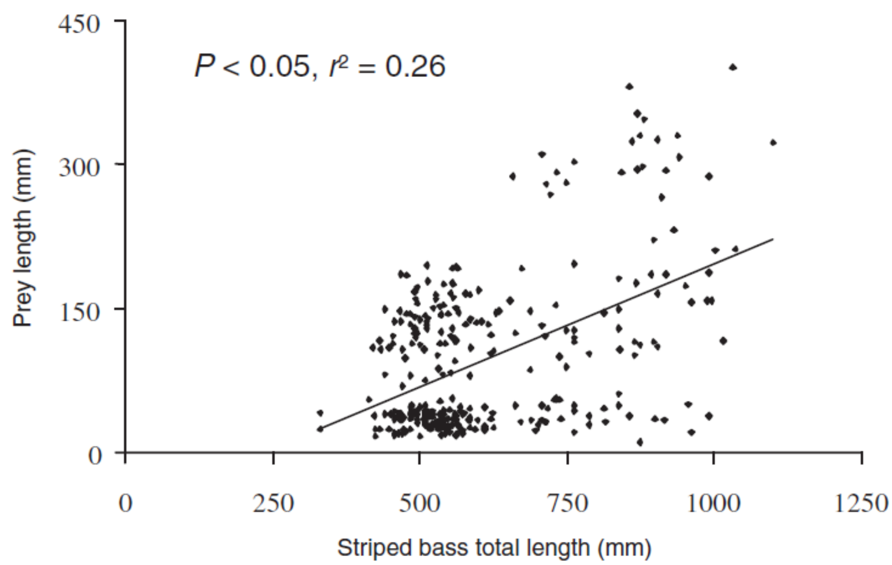

Figure 3.1. *In* Walter and Austin 2003 (Figure 4). Plot of prey total length against total length for Striped Bass.

- Smaller Striped Bass consumed prey that approached 40% of their total length. However, most prey consumed by all sizes of Striped Bass were smaller, young-of-the-year fishes. This is corroborated by Overton 2002 who predicted an optimal prey size to be 21% of the Striped Bass length.

- Spring feeding on anadromous fishes like Gizzard Shad, anadromous herring, and White Perch indicated a seasonal trend which corresponded to spawning migrations of Striped Bass.

Overall. Smaller Striped Bass (18-28 inches) consumed up to 40% body length, but mostly ate smaller, YOY fishes (corroborated by Overton 2002), whereas larger Striped Bass (> 28 inches) consumed both small and large prey. This study further supports the idea that Striped Bass interact with out-migrating anadromous fishes during their spawning migrations, and so the temporal overlap of these interactions are important when thinking about out-migrating salmonids in CA. Fyke data show that most Striped Bass entering the Sac River in the spring are in this < 28 inch range (see Figure 3.2 below), and therefore may exhibit feeding patterns of the 'smaller' Striped Bass in this study. Goertler et al. 2021 suggests that climate change, particularly warming ocean temperatures and decreased precipitation could increase migration timing of Striped Bass, thus potentially resulting in more temporal overlap with out-migrating juvenile salmonids.

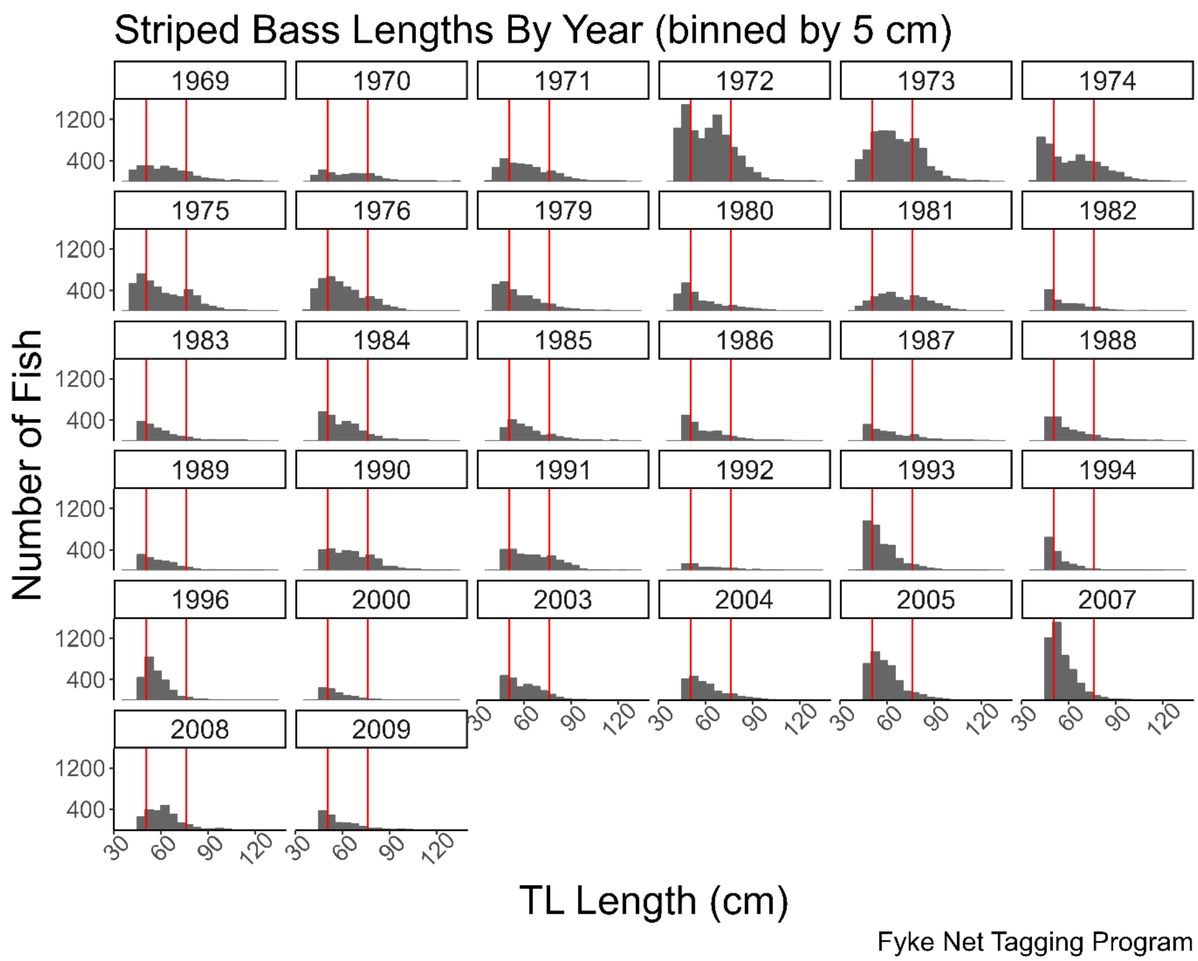

Figure 3.2. Length-frequency histograms for Striped Bass sampled from fyke nets. Parallel vertical red lines indicate the proposed 20-30 inch slot limit. Data Source: Striped Bass Tagging Program.

3.5 Striped Bass migration timing in relation to environmental conditions

Calhoun 1952

Calhoun, A.J., 1952. Annual migration of California Striped Bass. California Fish and Game 38(3): 391–403.

Funding Source. Unknown, CDFG funded most likely.

Study Period. Tagging took place January and November 1947, Spring 1950 and 1951. Tag recoveries took place November through April soon after tagging.

Geographic Range. Sacramento-San Joaquin Delta.

Predator assemblage evaluated. Adult Striped Bass (>20 ") caught in gill nets (n = 4,136) and marked with Disc tags.

Prey species detected. NA.

Key Findings.

- Seasonal movement of adult Striped Bass.
    - During winter-early spring, Striped Bass were recaptured close to tagging locations. (Antioch and Franks Tract) within the Delta, no signs of large migrations.
    - During spring (April), Striped Bass spread out throughout the delta and up into rivers to spawn.
    - During late spring-early summer, Striped Bass are post spawn. Striped Bass are still spread widely across the delta but in greater concentrations in the delta central indicating that they are moving back into the delta.
    - During summer, Striped Bass recaptures indicate that they are moving toward salt water. Recaptures are further downstream in San Pablo Bay.

- During fall, Striped Bass recaptures are once again higher up in the delta near tagging locations but widespread (not in tributaries though), mostly sloughs in the delta.
- During winter, Striped Bass showed the same pattern as previous year. Clumping near tagging locations, more concentrated than in the fall.

Overall. The results of tagging studies conducted in 1947, 1950, and 1951 indicate that in the summer months, adult bass are distributed mainly in San Francisco Bay and the ocean. In the fall and winter most of them move upstream to San Pablo Bay, Suisun Bay, and the Delta. In the spring the spawning population moves farther upstream where they spawn, mostly during May and June, in fresh water of 15°C or higher. After spawning, most large fish return to the lower bays and the ocean.

Goertler et al. 2021

Goertler, P., Mahardja, B., and T. Sommer. 2021. Striped Bass (*Morone saxatilis*) migration timing driven by estuary outflow and sea surface temperature in the San Francisco Bay-Delta, California. Scientific Reports 11: 1510. DOI 10.1038/s41598-020-80517-5.

Funding Source. Interagency Ecological Program and CDWR.

Study Period. 1969-present.

Geographic Range. San Francisco Estuary, Sacramento-San Joaquin Delta, and tributaries.

Predator assemblage evaluated. NA.

Prey species detected. NA.

Key Findings.

- Median migration timing varied from the third week of May to the fourth week of June.
- Striped Bass migrated later in years when Delta outflow was greater and sea surface temperature was cooler.
- Results suggest increased sea surface temperature congruent with decreased precipitation could shift Striped Bass migration earlier in spring.
- Findings are consistent with Striped Bass movement in their native range in the Chesapeake Bay, where warmer spring water temperature is linked with earlier spawning migration.
- Early migration has implications for predation risk on seaward migrating juvenile Chinook Salmon. There may be more temporal overlap if Striped Bass migrate earlier, as most juvenile salmon exited rivers by late June.
- Estuary outflow was positively related to median date, indicating that Striped Bass migration was delayed when estuary outflow was high.

- Results may indicate increased residence time in the estuary in response to food web and habitat benefits.

Overall. Warming temps and decreased precipitation could increase migration timing of Striped Bass, which has the potential to create more temporal overlap with out-migrating Chinook Salmon.

Le Doux-Bloom 2012

Le Doux-Bloom, C. M. 2012. Distribution, habitat use, and movement patterns of sub-adult Striped Bass *Morone saxatilis* in the San Francisco Estuary Watershed, California. University of California, Davis ProQuest Dissertations Publishing.

Funding Source. DWR and IEP.

Study Period. Summer 2010- summer 2011.

Geographic Range. Regions include Central Bay, South Bay, San Pablo Bay, Carquinez Strait, San Joaquin River, Central Delta, East Delta, South Delta, Sacramento River, Cache Complex, American River, and Feather River.

Predator assemblage evaluated. Striped Bass (n = 99) with a length range of 9-17 inches.

Prey species detected. NA.

Key Findings.

- *Chapter 2: Distribution and Habitat Use of Sub-adult Striped Bass (Morone saxatilis) in the San Francisco Estuary Watershed*
    - During fall, Striped Bass occupied Central Bay, Cache Complex, Central Delta, Sacramento River, and Carquinez Strait. Over winter, fish shifted toward the ocean, generally staying around Carquinez Strait, Central Bay, and the lower Sacramento River. Some study fish may have emigrated to the ocean, evidenced by low detections in the bays and delta. Striped Bass dispersed in the spring, expanding from nearshore Pacific Ocean and 65 river kilometers (rkm) to Coyote Creek in the South Bay, near San Jose to the upper Sacramento River near Colusa and 264 rkm upstream on the

Feather River. This could be related to increased temperatures in the San Francisco Estuary Watershed, and timing of upstream migration may be temperature-dependent, as this occurred when temps went from cold to cool.

  - In 2010, an average flow year, most fish were observed between Carquinez Straight and Sacramento River (rkm 192). During a high flow year (2011) more fish aggregated toward the ocean.

  - Temperature appeared to influence habitat use in winter and spring. Fish shifted to higher salinity habitat when temperature decreased, and only revisited upstream locations when temperature increased above 10°C.

  - Results indicate Striped Bass inhabited shoal habitat across all seasons, with channel and shoal habitat used equally over winter.

- *Chapter 3: Movement Patterns of Sub-adult Striped Bass in the San Francisco Estuary Watershed:*

  - There were N = 43 individual fish detected.

  - The study found three movement patterns for Striped Bass: River residents, estuarine residents (freshwater to mesohaline habitats) and bay residents (predominantly polyhaline to euhaline habitats).

  - Summer movement patterns were segregated by salinity, while movements increased in all resident groups during late fall and spring. Riverine fish moved from higher in the watershed to lower freshwater habitats which may reflect a preference for warmer water to over-winter in. While receivers recorded movement into the south delta, their actual whereabouts over the winter could not be detected due to comparatively fewer receivers there. As temperatures increased in late spring, riverine fish returned to upstream habitats.

- The water temperature of both river and ocean may trigger sub-adult movement by bay and riverine groups.
- There was some evidence of spawning migration, where individuals moved upstream in the spring, and returned a few weeks later to higher salinity habitat.

Overall. There were three distinct movement patterns detected from tagged Striped Bass that appeared to be related to salinity. There is also a strong correlation between temperature preference and salinity. Fish shifted to higher salinity habitat when temperatures decreased, and revisited upstream locations when temperatures increased above 10°C. Striped Bass in this study tended to utilize both channel and shoal habitat ubiquitously throughout the seasons (Figure 3.3).

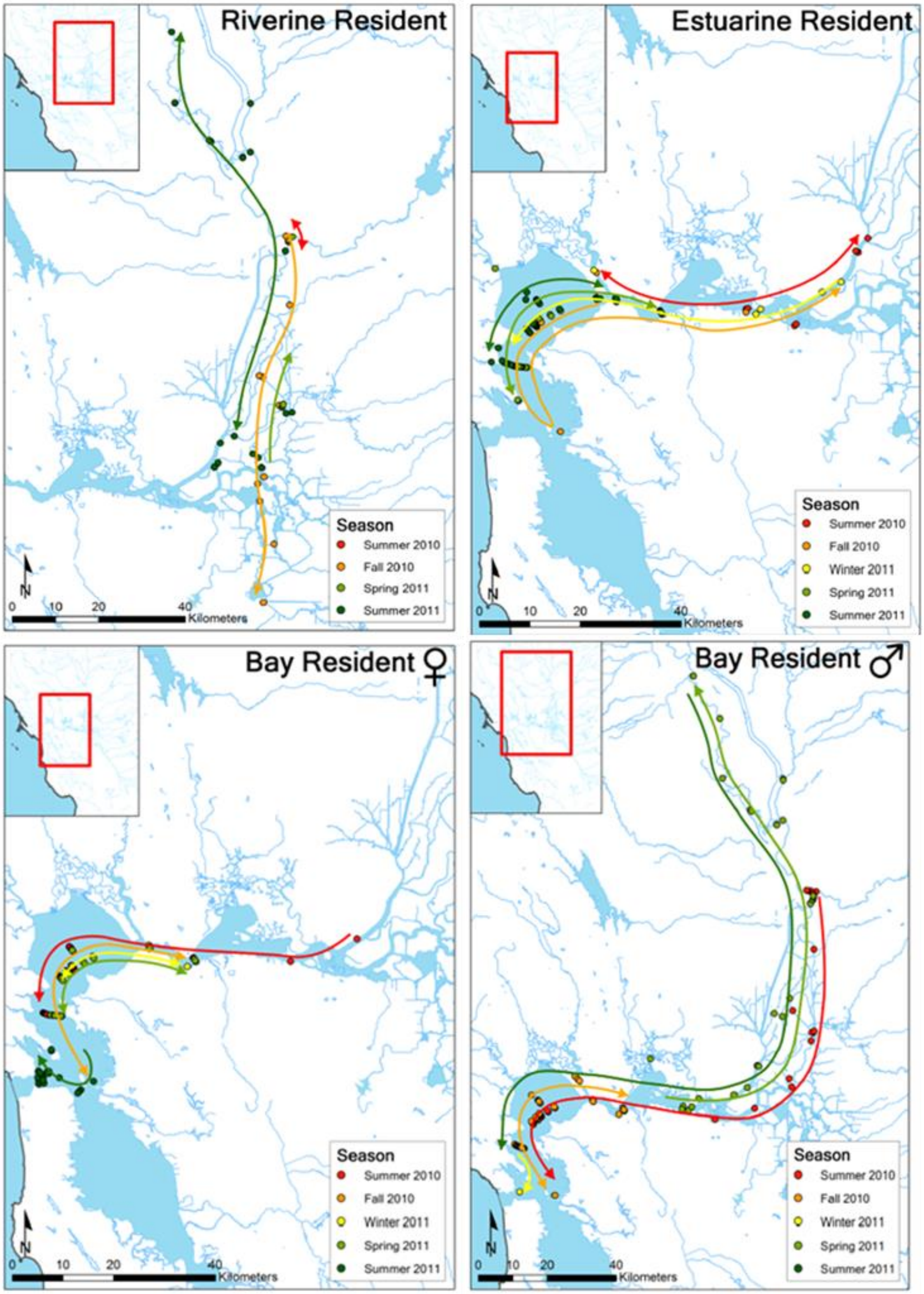

Figure 3.3. *In* Le Doux-Bloom 2012. Figures depict seasonal movement patterns of male and female Striped Bass in the summer of 2010 and 2011.

3.6 Habitat alteration and predation

Michel et al. 2020

Michel, C.J., M.J. Henderson, C.M. Loomis, J.M. Smith, N.J. Demetras, I.S. Iglesias, B.M. Lehman, and D.D. Huff. 2020. Fish predation on a landscape scale. Ecosphere 11(6): e03168. DOI 10.1002/ecs2.3168.

Funding Source. CDFW Research Regarding Predation on Threatened and/or Endangered Species in the Delta, Sacramento and San Joaquin Watersheds Proposal Solicitation Package

Study Period. April 3- May 13, 2017.

Geographic Range. A Generalized Random Tessellation Stratified algorithm was used to select twenty sites in the South Delta and San Joaquin Basin.

Predator assemblage evaluated. This study did not target anything specific, and no predator species was identified.

Prey species detected. Predation Event Recorders (PERS) were employed using tethered, drifting hatchery Chinook Salmon.

Key Findings.

- Percent of preyed-upon PERs varied through time and between sites, ranging from 0% to 37%. In total, they deployed 1,670 PERs during the spring of 2017, of which 15.7% (~262) were preyed upon.
- Predation risk for salmonids and other similar prey species in the South Delta were strongly influenced by water temperature, time of day, predator density, and bottom roughness.
- The upper limit of temperatures measured during sampling in the spring of 2017 (20°C) is approximately the lower end of the thermal preference of Striped Bass. Predation rates may have changed under other different thermal conditions that favored Striped Bass presence in the study area.

- This study found a strong influence of predator densities on predation risk, indicating that predation risk is not solely mediated through habitat and environmental conditions.

Overall. This study identified areas of predation hotspots and environmental covariates associated with increased predation. However, they used tethered prey so results likely represent higher predation rates, don't represent how prey can evade predators, or how prey naturally interact with their environments. Juvenile salmonid distribution, health, and overall vulnerability to predation were not considered.

Sabal et al. 2016

Sabal, M., Hayes, S., Merz, J., and J. Setka. 2016. Habitat alterations and nonnative predator, Striped Bass, increase native Chinook Salmon mortality in the Central Valley, California. North American Journal of Fisheries Management 36: 309-320.

Funding Source. NOAA/ NMFS.

Study Period. April 23-May 24, 2013. Each site (n=30) was sampled 3 times.

Geographic Range. Mokelumne River at Woodbridge Irrigation District Dam (WIID).

Predator assemblage evaluated. Striped Bass.

Prey species detected. Chinook Salmon smolts (hatchery).

Key Findings.

- Combined Striped Bass relative abundance surveys with diet analysis to compare rates of salmon predation across different habitat types.
- A total of 10 sites were sampled using electrofishing. Each site was assigned to one of 3 habitat types (WIDD, other altered, and natural).
- A before-after control impact design using predator removal was paired with Chinook Salmon releases (n= 2,000 total Chinook Salmon, over 2 release groups).

- The Striped Bass removal–salmon survival experiment showed a 10.2% increase in survival of juvenile Chinook Salmon after 11 Striped Bass were removed.

- Diet energetic analysis demonstrated that 7.9–13.1% of the emigrating juvenile Chinook Salmon were consumed.

- A local predation hot spot (WIDD) was associated with increased per capita consumption (PCC) of juvenile Chinook Salmon by Striped Bass and attracted larger numbers of Striped Bass, thus decreasing the survival of emigrating juvenile salmon by 8–29%

- According to this study, a single Striped Bass could consume between 0.71–1.20% of the released juvenile Chinook Salmon population (n=2000).

Overall. Striped Bass aggregated at WIDD, exhibiting an eightfold increase in CPUE compared with that at other altered locations and a 60-fold increase in CPUE compared with that at natural locations. Diets of Striped Bass collected at WIDD consisted primarily of juvenile Chinook Salmon, and the per capita impact of Striped Bass on juvenile salmon was higher at WIDD than at other altered locations. However, 2,000 Chinook Salmon smolts were released for this study so diets should primarily consist of the most abundant prey item, especially when passing through a pinch point such as the WIDD. This study indicated that Striped Bass could have a major population level impact on released hatchery Chinook Salmon smolts but extrapolation to wild smolts is challenging.

3.7 Predation impacts on listed species

Boughton and Ohms 2020

Boughton, D.A., and H.A. Ohms. 2020. Carmel River Steelhead Fishery Report - 2018. 56 p. Santa Cruz (CA): Prepared by National Marine Fisheries Service for the California-American Water Company in fulfillment of the Memorandum of Agreement SWC-156.

Funding Source. California-American Water Company.

Study Period. Juvenile and adult Striped Bass diet sampling occurred from June to January in 2010 and 2011 and was conducted by CDFW. Carmel River Steelhead Association (CRSA) used eDNA methods in June and July of 2017 to identify contents of Striped Bass diet.

Geographic range. Carmel River.

Predator assemblage evaluated. 525 Striped Bass (SB) diets analyzed over the two year period (2010-2011). Twenty two SB diets (sizes ranging from 16-31 inches) were analyzed using eDNA in 2017.

Prey species detected. Crustaceans and fishes.

Key Findings.

- In both years, the majority of SB stomachs were empty (61% and 74%, 2010 and 2011, respectively). Unknown as to whether this reflects quick digestion of prey items or the inability of SB to find and consume prey items.

- Of the contents that could be identified, prey items included Crustaceans (mysids, amphipods, and isopods) and fish (steelhead/ Rainbow Trout, sculpin, Three-spine Stickleback, lamprey, and goby). Crustaceans and fishes were found in roughly equal numbers.

- eDNA analysis from 22 SB diets indicated that 59% (n=13) contained steelhead DNA, and 27% (n= 6) contained other fish contents in their stomachs or upper intestines.

Overall. The results of this study indicate that SB consumed all known fish species in the Carmel River; however, fish species consumption was found in roughly equal proportions as crustaceans. The potential effects of SB on steelhead in Carmel River is still unknown, there isn't data available to determine whether SB predation is contributing to the decline of steelhead in this location. Future approaches to address this question included: stable isotope analysis of SB muscle tissue, bioenergetics modeling, environmental data collection, and life-cycle modeling.

Brandl et al. 2021

Brandl, S., Schreier, B., Conrad, L.J., May, B., and M. Baerwald. 2021. Enumerating predation on Chinook Salmon, Delta Smelt, and other San Francisco estuary fishes using genomics. North American Journal of Fisheries Management 41: 1053-1065.

Funding Source. CDFW's Ecological Restoration Program.

Study Period. The months of December, April, and June from Dec 2012-June 2014 were chosen to encompass critical periods of native fish migration. However, analysis was confined to April 2014 to avoid confounding factors associated with seasonal effects, extreme catch variability among our sampling months, and other factors. Catch of Striped Bass was variable, and 63% of all Striped Bass catch occurred in April 2014. The native prey abundance was statically correlated with samples from April 2014.

Geographic range. Northern Delta:

- Steamboat slough (Chinook Salmon outmigration corridor).
- Miner/Sutter slough (Chinook Salmon outmigration corridor).
- Sacramento River (Chinook Salmon outmigration corridor).
- Liberty Island (rearing area for Delta Smelt and other native species).
- Sac Deep Water Shipping Channel (rearing area for Delta Smelt and other native species).

Predator assemblage evaluated. Striped Bass was the primary target. The following predators were also sampled opportunistically; Largemouth Bass, Smallmouth Bass, White Catfish, Channel Catfish, and Sacramento Pikeminnow.

Prey species detected. 13 prey taxa.

- **Non-native.** Striped Bass (17%) and Mississippi Silverside (9%)- most frequently detected in all predators.
- **Native.** Sacramento Pikeminnow (16%) and Chinook Salmon (13%) Delta Smelt (4%) and Longfin Smelt (6%). White Sturgeon,

Green Sturgeon, and steelhead were all ~ 0% (only 0-3 total detections for each species). Results focus on Striped Bass predation of Chinook Salmon, as very few Delta Smelt were detected in gut analysis.

Key Findings.

- Results of this study reflected the proportions of prey items detected in fish that had contents in their stomachs. Proportions of empty stomachs varied (Channel catfish 65%, Largemouth Bass 81%, Sacramento Pikeminnow 47%, Smallmouth Bass 74%, Striped Bass 74%, White Catfish 50%).

- A wide range of prey taxa were detected in Striped Bass, indicating that they are not highly selective in prey choice.

- For Striped Bass with prey in gut, 60% of detections were native species (Sacramento Pikeminnow (n = 32), Chinook Salmon (n = 29), and Splittail (n =18)). This corresponds to native species in 15% of Striped Bass sampled.

- Detection of Striped Bass predation on Chinook Salmon was higher in habitats with relatively higher temperature and lower conductivity (Brandl et al. 2021, Table 5).

- Predatory fish made up a relatively high proportion of diets of other predatory fish. Striped Bass consumed other predatory fish at similar rates as more traditional prey items like Chinook or Threadfin Shad

- Longfin Smelt were detected in gut contents of 20% of Sacramento Pikeminnows (*n* = 13). Approximately 1% of Striped Bass contained Delta Smelt. Because of the low detections of Delta Smelt, this species wasn't included in further analyses.

- Chinook Salmon were detected in 27% of Smallmouth Bass guts, and 18% of Striped Bass guts. Chinook Salmon were not found in Largemouth bass, White Catfish, Channel Catfish, or Sacramento Pikeminnow guts.

Overall. This study found high prevalence of empty guts in Striped Bass (74%), but those that contained prey had a significant level of native species detected (60%). Predatory species were also frequently detected in Striped Bass, noting that Chinook Salmon presence occurred in similar quantities as other predatory species. Striped Bass predation on Chinook was correlated with higher temps and lower conductivity.

Grossman et al. 2013

Grossman, G., Essington, T., Johnson, B., Miller, J., Monsen, N., and T. Pearsons. 2013. Effects of fish predation on salmonids in the Sacramento River–San Joaquin Delta and associated ecosystems. Panel final report. 71 p. Sacramento (CA): California Department Fish Wildlife, Delta Stewardship Council, and National Marine Fisheries Service.

Funding Source. CDFW, Delta Stewardship Council, and NMFS workshop proceedings.

Study Period. Panel review of predation literature and presentations from the 2013 Fish Predation Workshop.

Geographic Range. Sacramento-San Joaquin Delta.

Predator assemblage evaluated. Varied by study evaluated.

Prey species detected. Salmonids.

Key Findings.

- In the case of juvenile salmonid prey in the Delta, predators may display positive selectivity for these species because they are energy-rich, are easily handled (i.e., soft-rayed, and fusiform) and potentially naive to invasive predators.
- Fish predation on salmonids in the Delta is specific to the smolt life stage. This and the context dependency of these predator-prey relationships, given the variable Delta environment, undoubtedly will make the population-level effects of fish predation on salmonid survivorship/adult returns challenging to detect.
- Population data show conflicting results, and some studies show adult Striped Bass (age-3+) declining in abundance whereas other studies show a long-term decline in age-0 fish, but a relatively stable adult population (see section 2A in document, pg. 21).

- The causal factors driving divergent trends in age-0 and adult Striped Bass abundance are unclear. In part, they may be due to a shift towards shallower habitats by age-0 fish, thereby reducing catches in the midwater trawl survey which has used permanent sampling stations.

Overall. There is little information on the spatial distribution and size/age structures of fish predator populations, or how these characteristics vary over time. This greatly limited the Panel's ability to make quantitative inferences regarding the effects of fish predation on salmonids at the population level. Populations of some fish predators (e.g., Striped Bass) have declined over time, but this decline has not coincided with concomitant increases in salmonid populations and there is uncertainty regarding variation in the abundance of sub-adult Striped Bass (Loboschefsky et al. 2012). Juvenile salmon are clearly consumed by fish predators and several studies indicate that the population of predators is large enough to effectively consume all juvenile salmon production. However, given extensive flow modification, altered habitat conditions, native and non-native fish and avian predators, temperature and dissolved oxygen limitations, and overall reduction in historical salmon population size, it is not clear what proportion of juvenile mortality can be directly attributed to fish predation.

Grossman 2016

Grossman, G.D. 2016. Predation on fishes in the Sacramento-San Joaquin Delta: current knowledge and future directions. San Francisco Estuary & Watershed Science 14(2).

Funding Source. Delta Stewardship Council.

Study Period. This is a Review Study using gray literature, presentations from the 2013 Fish Predation Workshop, and 2015 IEP Workshop.

Geographic Range. Sacramento-San Joaquin Delta.

Predator assemblage evaluated. Literature was searched and researchers actively working on dietary or predator–prey studies on Delta fishes were contacted. Out of the resulting data, a matrix of predator species and their piscine prey was compiled.

Prey species detected. Prey varied by study reviewed.

Key Findings.

- Many factors induced variation into predator–prey relationships including: (1) the presence and type of shelter (e.g., submerged aquatic vegetation (SAV) or woody debris), (2) the ratio of prey size to predator size, (3) seasonal changes in abundance of the prey array, (4) defensive morphological (e.g., spines) or behavioral adaptations, and (5) seasonal changes in habitat quality for prey, such as those produced by influxes of contaminants during winter–spring high flows or high water temperatures during summer and fall.

- The act of predation may be broken into several component rates, including search and encounter, pursuit and attack, capture and handling, and consumption. These components are affected by a variety of changes that have occurred in the Delta. In unmodified environments, these components are affected by factors such as prey abundance and availability, spatial and temporal overlap of predator and prey, habitat complexity, turbidity, behavior, physiology, and morphological adaptations that facilitate (predator) or inhibit (prey) the predation process.

- The effects of both contaminants and invasive species may be magnified by environmental changes that have occurred in the Delta over the last 100 years. Those changes include: (1) species invasions that alter physical habitat structure, (2) alterations of hydrologic regimes, temperature regimes and turbidity levels, (3) wetland loss, and (4) anthropogenic changes in physical structure (levees, canals, and abstraction facilities). Additionally, those factors are coupled with changes in climate, as well as (6) eco-system effects of invasives (e.g. shifts in food webs, changes in structural complexity of littoral habitats by invasive plants, etc.).

- The data indicated that most predators were only occasional consumers of individual prey species. See Table 2 in Grossman 2016 for ranked predator-prey interactions by species.

- Moderate consumption was observed in Sacramento Pikeminnow consuming Longfin Smelt, Striped Bass consuming Sacramento Splittail, and Largemouth Bass consuming Prickly Sculpin.

- Common consumption was observed in Striped Bass consuming Chinook Salmon, Largemouth Bass consuming Sacramento Pikeminnow, and Channel Catfish consuming Largemouth Bass.

Overall. Some invasive predators have been established in the Delta for over 100 years (e.g., Striped Bass) and it is possible that prey species have had sufficient time to develop behavioral adaptations to these predators. This analysis yielded few generalizations regarding predator–prey interactions for Delta fishes other than the observation that most predators were unspecialized and consumed a wide variety of both native and invasive fishes. Most predators fed primarily on invasive species. Given the generalist nature of vertebrate predators, this likely represents consumption of prey in proportion to their abundance.

Lindley and Mohr 2003

Lindley, S.T., and M.S. Mohr. 2003. Modeling the effect of Striped Bass (*Morone saxatilis*) on the population viability of Sacramento River winter-run Chinook Salmon (*Oncorhynchus tshawytscha*). Fishery Bulletin 101(2): 321-331.

Funding Source. National Center for Ecological Analysis and Synthesis which is funded by an NSF grant, UC Santa Barbara, and the State of California.

Study Period. NA.

Geographic Range. NA.

Predator assemblage evaluated. Striped Bass through adult mark-recapture data between 1968-1995 (Kohlhorst 1999).

Prey species detected. Winter-run Chinook Salmon adult spawning estimates from Red Bluff Diversion Dam (RBDD)1967-1996 (Myers et al. 1998).

Key Findings.

- The current Striped Bass population of roughly 1×10^6 adults consume about 9% of winter-run Chinook Salmon outmigrants. By comparison, based on prey consumption rates and predator and prey abundances, Jager et al. (1997), using a spatially explicit individual based model, estimated that between 13% and 57% of fall-run chinook fry were consumed by piscivorous fish in the Tuolumne River, California.

- The model predicts that if the Striped Bass population declines to 512,000 adults as expected in the absence of stocking, winter-run Chinook Salmon will have about a 28% chance of quasi-extinction (defined as three consecutive spawning runs of fewer than 200 adults) within 50 years. If stocking stabilizes the Striped Bass population at 700,000 adults, the predicted quasi-extinction probability is 30%. A more ambitious stocking program that maintains a population of 3 million adult Striped Bass would increase the predicted quasi-extinction probability to 55%.

Overall. Striped Bass predation at the current population level may be a nontrivial source of mortality for winter-run Chinook Salmon. Striped Bass may have declined along with winter-run Chinook Salmon, so predicted predation impacts may have changed. A significant increase in Striped Bass abundance could substantially increase the risk of winter-run Chinook Salmon extinction and reduce the likelihood of recovery. What constitutes a "significant increase" is not defined.

Nobriga et al. 2021

Nobriga, M.L., Michel, C.J., Johnson, R.C., and J.D. Wikert. 2021. Coldwater fish in a warm water world: Implications for predation of salmon smolts during estuary transit. Ecology and Evolution, 11:10381–10395. DOI 10.1002/ece3.7840

Funding Source. USFWS and NMFS.

Study Period. 2012-2019.

Geographic Range. Sacramento River Basin**.**

Predator assemblage evaluated. Striped Bass and Largemouth bass (LMB).

Prey species detected. Predation Event Recorders (PERS) were employed using tethered, drifting hatchery Fall-run Chinook Salmon.

Key Findings.

- Neither distance from shore nor water temperature was observed to influence the willingness of Striped Bass to attack PERs, which supports the assertation that Striped Bass are temperate pelagic predators. Largemouth Bass attacked PERS most frequently in warmer water, near shorelines. Thus, as temperatures warm, Chinook Salmon face higher near shore predation risk.

- PERS data suggests the combined effect of Striped Bass and LMB appears additive, Striped Bass predation rates remained the same as LMB predation increased with warmer temperatures.

- Modeled Striped Bass prey consumption was 17 g/day and was consistent across water temperatures, while Largemouth Bass prey consumption increased with increasing temperatures. The per capita quantitative impact of LMB on Chinook Salmon was about half that of Striped Bass.

Overall. Chinook Salmon survival is generally water temperature dependent. Striped Bass predation does not seem to depend on temperature, while LMB feeding does. Simulation models predict LMB predation impacts to be comparatively lower than Striped Bass. Hypotheses for future research are listed below:

- If Striped Bass adults resume foraging quickly after spawning, this would coincide with smolt outmigration. At warmer temps, this would predict lower smolt survival as a function of water temperature. To test this, a study investigating post-spawn resumed foraging times for Striped Bass is recommended.

- LMB have an undocumented but substantial impact on Chinook Salmon. Increase in submerged aquatic vegetation (SAV) increases water clarity and allowed LMB to proliferate and enabled large increases in LMB in the past three decades. Population estimates of LMB would be useful in better understanding impacts on Chinook Salmon.

- Disease could be playing a more substantial role in survival than previously thought. Salmon typically survive in 20°C temps in hatchery conditions, so temperature alone shouldn’t impact survival. Higher disease at these temperatures in the wild could impact swimming speeds, which would leave salmon more vulnerable to predation.

Photo Credit: CDFW

INLAND SPORT FISHING REGULATIONS

Updates for 2026

Presentation to the Commission Wildlife Resources Committee

September 12, 2024 | Maggie McCann

Fisheries Branch, California Department of Fish and Wildlife

Proposed Regulation Changes 1-2

1. Black Bass Size Restriction (Lassen and Modoc counties): Remove minimum size requirement from all waters, except for Mountain Meadows Reservoir.
2. Susan River (Lassen County) Regulation Simplification Clean Up: Revert fish regulations to historic traditional trout opener and update specific kids fishing section of regulations.

Proposed Regulation Changes 3-4

3. Bait Fish Use in the Sacramento River (Shasta and Tehama counties): Move the upper limit of the Sacramento River upstream from Highway 32 Bridge to Deschutes Bridge.

4. Sierra District Anadromous Regulations Clean Up:
   - Increase fishing opportunity by allowing the use of bait during specific times within anadromous streams.
   - Add new special regulation sections for Clear Creek, Cow Creek, Cotton Creek, and Paynes Creek.
   - Change Antelope Creek boundary.

Proposed Regulation Changes 5-6

5. Trout General Statewide Regulations Clean Up: Add 7.00 to the list of sections associated with 5.85(a)(2) for clarity for enforcement.
6. Arroyo Seco River (Monterey County) Rainbow Trout Restriction: Change the trout bag limit from 5 trout to 5 Brown Trout and 0 Rainbow Trout. Add a gear restriction of "only artificial lures with barbless hooks may be used."

Proposed Timeline

- January 15, 2025 WRC Meeting – Recommendation
- April 16-17, 2025 Commission Meeting – Request to go to notice
- June 18-19, 2025 Commission Meeting – Discussion hearing
- August 13-14, 2025 Commission Meeting – Adoption hearing
- January 1, 2026 – If approved, new regulations go into effect

Questions/Contact

Photo Credit: CDFW

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From: Mike Costello <mike@howlforwildlife.org>
Sent: Tuesday, August 20, 2024 6:01 PM
To: FGC <FGC@fgc.ca.gov>
Subject: WRC Meeting - Agenda Ideas for Sept.

Hello, this is for Commissioners Zavaleta and Anderson - please forward accordingly.

Please see attached, I have provided several ideas and questions which would be great to see discussed in September. There are abundant opportunities for increased hunter participation and increased landowner participation statewide. These opportunities equate to increased tag, license and program revenue which fuels research, management and conservation for the benefit of all Californians and all wildlife.

If a single day of WRC does not present time for robust discussion to advance ideas our hunting and conservation communities are clamoring for, can we please schedule a 2nd day workshop?

Thank you in advance!

Mike Costello
HOWL for Wildlife
[redacted]

Hello Commissioners, I am requesting the below items be discussed in the September Wildlife Resource Committee Meeting:

1) **Elk and the opportunity to expand tag allocations in the below situations:**
   - **Archery hunting:** hunters nationwide are eager to hunt elk, and archery is a primary method-of-take for most elk tags in western states. With a low (5-10%) success rate, 10 hunters can take to the field for every elk harvested, providing a great lever for R3 as well as funding critically needed research and management programs. New tag allocations in CA should lean into archery, while preserving the existing core of "100% success" hunts for those who want to wait on the Big Game Draw.

   - **Tehachapi Zone:** SHARE tags planned here have not been issued and landowner enrollment lags far behind the need to hunt and harvest Rocky Mountain Elk from this unit. The Tehachapi EMU contains a great amount of BLM and National Forest, and elk are moving east/north towards that public land. The elk tags which were expected to allocate via SHARE should be flipped to Big Game Draw, as a mix of archery and rifle. Hunters will choose this hunt if they are comfortable with the opportunity presented, and elk tags will be allocated.

   - **Marble Mountains EMU:** are the 30(?) "scientific collection" permits issued to harvest elk from National Forest (public land) in this unit going to recur every year? Is a Scientific Collection permit the right mechanism for enabling elk harvest from public land? With a CDFW study demonstrating a population of ~1400 in the unit, what next steps are needed to expand elk tag allocations in the Big Game Draw?

   - **Questions:**
     a) What is the mechanism (math) that goes into deciding tag allocations, harvest goals and quotas as % of herd? There is a lack of clarity/transparency for this currently.
     b) When will the Dept respond to herd abundance and sustainable populations to increase public (Big Game Draw) tag allocations, and not be solely focused on responding to "conflict"?
     c) What is the Dept. plan to manage elk and elk hunting proactively, with staff and leadership support covering gaps in the "Elk Manager" seat?
     d) As elk are known to be dispersing into areas outside the existing EMUs, what metrics is the Dept using to identify new huntable populations, and to establish new hunting opportunities?

2) **SHARE program**: increase transparency of program details, availability, financial opportunity to landowners, huntable species, season and method of take opportunity, landowner obligations and choices/decisions, contract requirements if enrolled.
   - "Up to $30/acre" is not transparent… Ex: what is the mechanism that determines the range from $0/acre to $30/acre? Ex: If a landowner has 1000 acres, does that mean that a single tag/hunt for a highly valued opportunity could be worth $30k in payment to a landowner? If not, what is the limiting factor? Question: why is this information hidden away and not shared with a high degree of transparency? Question: are landowners told to keep the details of their SHARE contract private, so that it is not publicly available?

3) **Black Bear Conservation:** we know that the new Conservation Plan is going to be presented in Q4-2024, and barring dramatic changes or reversals of data in the DRAFT there are reasonable changes to Black Bear hunting which could be initiated for the 2025 license year.

- **Season structure simplification:** Archery starts July 1 and extends until the overlapping deer zone general season starts. General season starts when the overlapping deer zone opens for general season and extends until 12/31.
- **2nd Tag Option, 2 bear limit:** BMUs overlapping with D7, D6, D3-5, C1-4, B1-6, A-North, X9AB, X12, X8, X7AB, X6AB, X4 and X1.

4) **PLM Program Questions:**

- Can PLM program tag allocations extend a season past 12/31 of the license year? Example: Catalina Island PLM tag allocation would yield much greater success, improved opportunity and more functional hunt if extended to 2/28 every year.
- Can a PLM tag allocation for bear have a season start that is earlier than current bear season? (after the first year of the program participation). This could be a route to piloting a small # of spring bear harvests, with a rigorous feedback loop to inform future opportunity.

5) **"Late Season Buck Hunts" in response to CWD?** This topic has surfaced in multiple CDFW forums in the last few months. While the hunting community loves the idea of more late season hunting (ie: Premium hunts via the Big Game Draw), these cannot be taken lightly as they can do irreparable damage to herds if not carefully managed.

- If used as a response to CWD, can these hunts be done as "early season general methods" hunts with a < 5000' elevation restriction so that non-migratory bucks are targeted in the habitat where CWD is most likely being spread?
- If used to extend hunting opportunity throughout the B, C and D zones, will the tags issued in a "late season Buck hunt" also remove a quantity of tags from the general season allocation, using harvest success ratios as a gearing mechanism to inform the general season reduction? (Ie: "100 late season D4 Zone Buck tags" with a 60% success rate expected, would require 600 general season D3-5 tags removed as they have a 10% success rate).

6) **Question for the Dept biologists:** to what extent is black bear abundance creating a difficult time for mountain lions (and deer) in California?

- Right now, numerous rural leaders and communities are frustrated by their inability to proactively manage mountain lions. The Dept has not initiated an IPM survey with the same rigor as they're doing for Black Bear. Because mountain lions are behaving differently, dangerously and recklessly many people assume that mountain lions are "over-populated".
- Perhaps mountain lions are not overpopulated. Instead, perhaps mountain lions are turning to human habitat for prey because black bears are crushing the fawn populations and stealing 60-75% of mountain lion deer-kills (both referenced in the Bear Conservation Plan). Perhaps a more balanced approach to black bear harvest and population management will reduce pressure on mountain lions, deer herds and our rural communities?