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

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.

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.

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

In-person Striped Bass Angler Preference Questionnaire Results by Question

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.

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%).

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%).

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%).

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.

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.

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

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

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

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

In an effort 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.

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, Table 1). Anglers were neutral on whether they wanted to see a maximum size, with respondents split nearly 50-50 on their responses (Question 5, Table 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, Table 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 (Table 1). To reach a larger number of anglers, an electronic version of the APQ was developed.

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.

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 A1. Electronic Striped Bass APQ details including 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

Electronic Striped Bass Angler Preference Questionnaire Results by Question

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.

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%).

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%).

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

Overall, 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. 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).

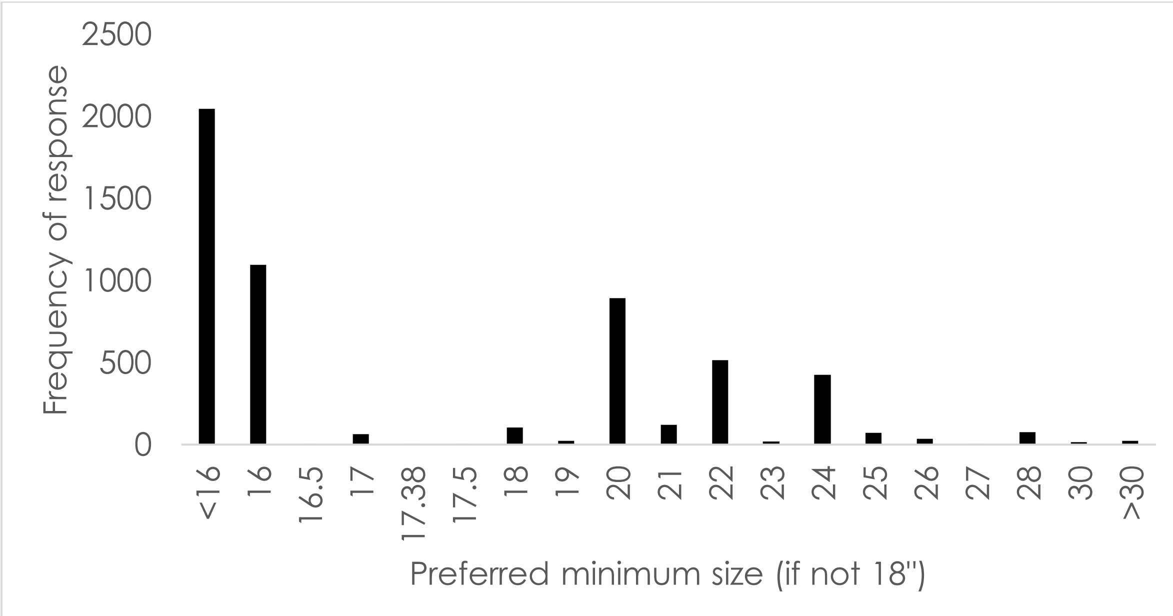

Figure A1. There were 5,527 written responses for preferred minimum sizes other than the current 18-inch minimum size (although some respondents entered 18 inches as their preference).

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 2. There were 13,887 responses to Question 5.

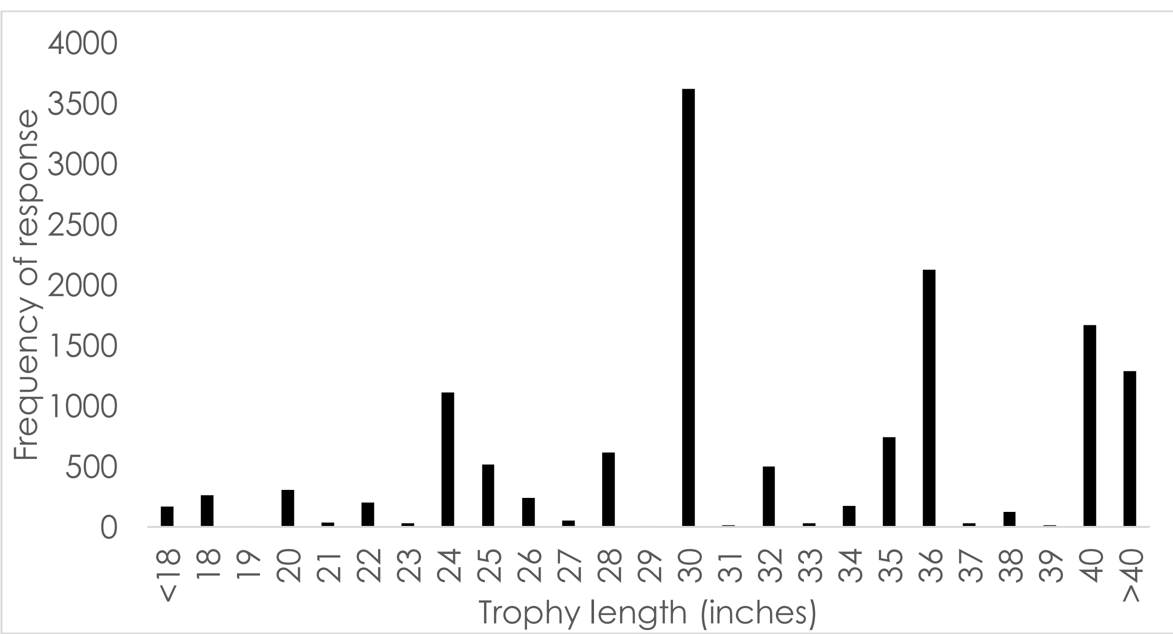

Figure A2. Fill-in-the-blank responses to what size Striped Bass anglers considered a trophy.

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.

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%).

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

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

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

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

In an effort 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.

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 in order 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.

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 in order 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.

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, Questions 2-4; Table 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 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).

There was also general support for a catch-and-release trophy Striped Bass fishery (Table 1, Question 6; Table 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 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 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 2023.

APPENDIX 2. STRIPED BASS POPULALATION MODEL PARAMETER INPUT JUSTIFICATIONS

Fishery Inputs

A2a. 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. A2). 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).

Table A2. 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%

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. A2). 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 A2). 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. A2).

Table A3. 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%

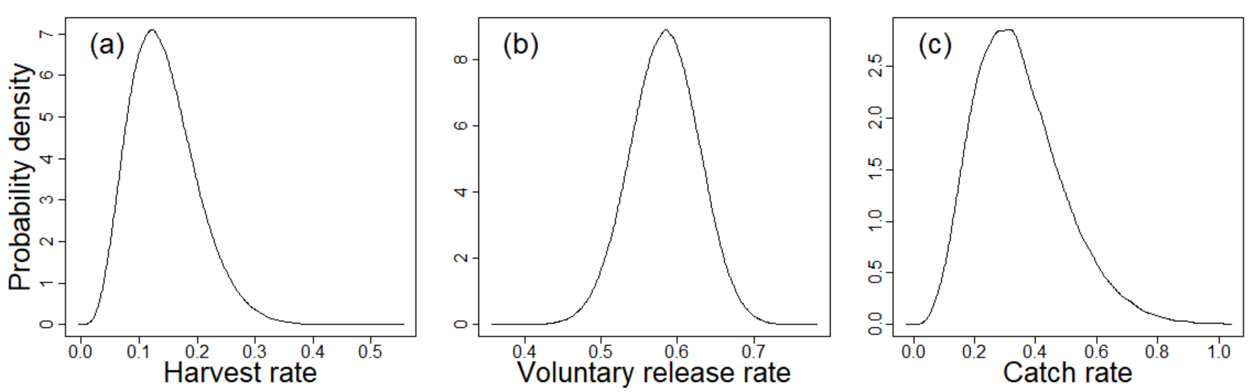

Figure A3. Probability distributions of parameter values for (a) harvest, (b) voluntary release rate, and (c) catch rates used to inform $U, \delta, \dot{U}$ (respectively) in the model.

A2b. 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 A3). 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 $\beta = 9.25$. 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 A3), 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 (Benaka et al., 2014).

Table A4. 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%

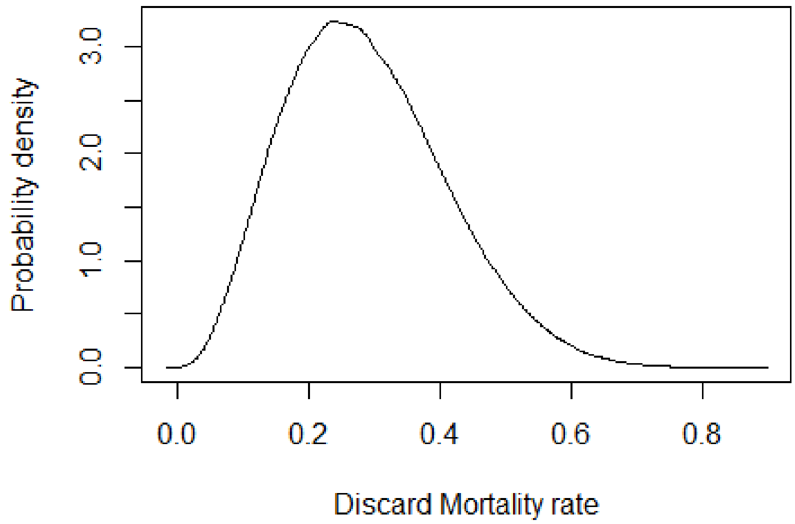

Figure A4. Probability distribution of parameter values for discard mortality rate used to inform D in the model.

A2c. 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. A4a). 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. A4b). 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. A4c).

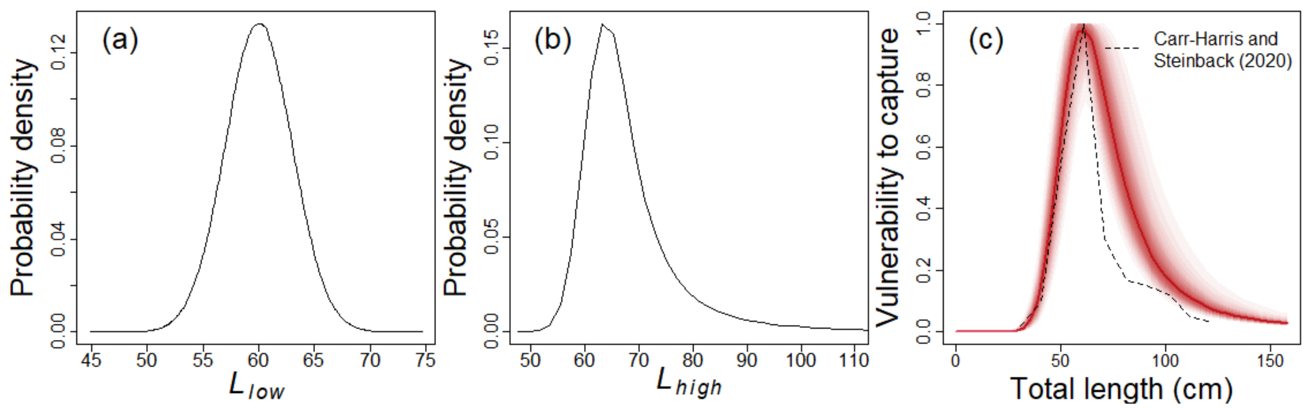

Figure A5. Probability distributions of parameter values for (a) lower length at 50% vulnerability to capture and (b) upper length at 50% vulnerability to capture used to inform the vulnerability of fish of length L to capture (c). The bold red line in panel (c) represents the length-based capture probability 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.

Life History Inputs

A2d. 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 X1) 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 $\bar{L}_{\infty}$ (Table X1, Table A4), which approximates the 95% probability range of a normal distribution with a means of $\bar{L}_{\infty}$ 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 $\bar{L}_{\infty}$ and a standard deviation 10% of $\bar{L}_{\infty}$ (Gwinn et al. 2015; Walters and Martell 2004).

Table A5. Mean and 95% probability of minimum and maximum asymptotic lengths for growth-type-group assignments.

Parameter	Average length (cm)	95% probability	
		2.5%	*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

A2e. 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.

A2f. 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).

A2g. 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.

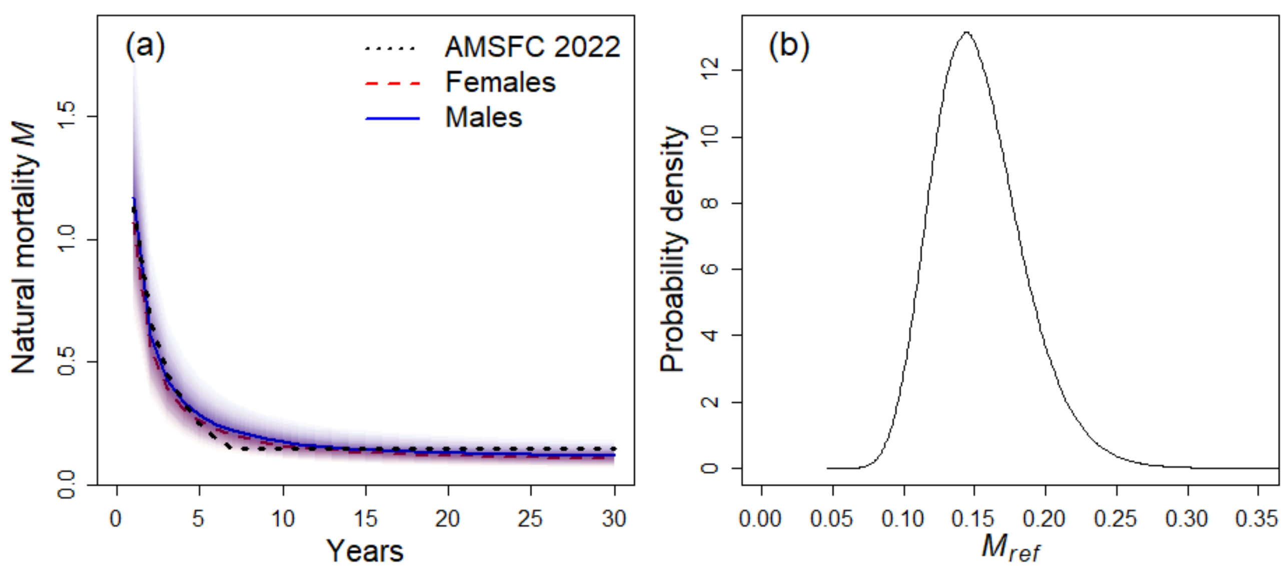

Figure A6. Sex-specific natural mortality-at-age estimates for Pacific Striped Bass (bold blue line and dashed red line) compared to natural mortality reported for Atlantic Striped Bass (dotted line; 2022 ASMFC) (a). Panel (b) describes the probability distribution of parameter values for M_{ref} used to inform natural mortality M.

Reproduction and Recruitment Inputs

A2h. CR, R_0, and 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. A6). 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.

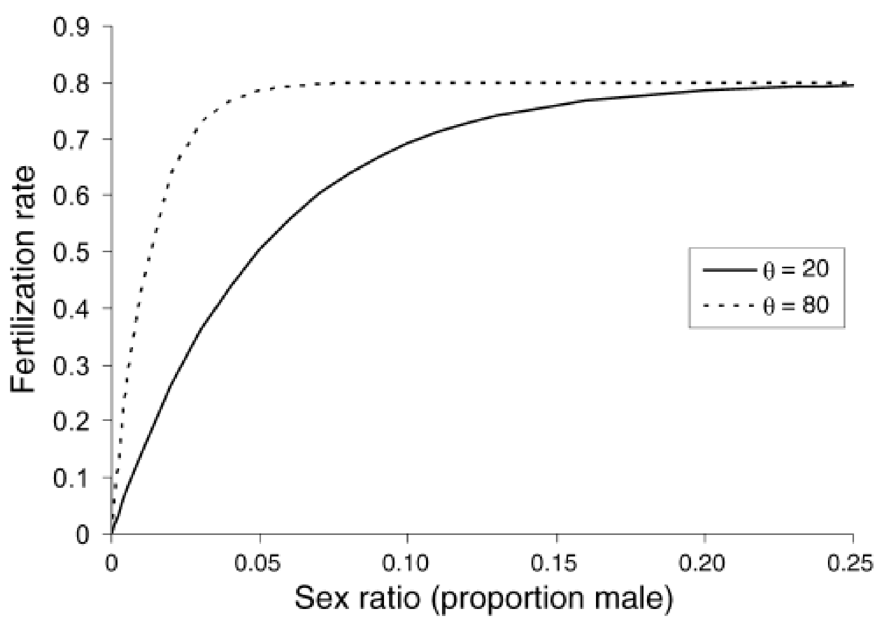

Fig. A7. Model relationship between fertilization rate and sex ratio (proportion of males) based on two different levels of fertility function, θ (Fig.3 from Heppell et al. 2006)

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

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.

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.

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. *Draft in Review.*

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 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 A6. *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.

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 1). In other words, larger Striped Bass consumed a greater size range of prey than smaller Striped Bass.

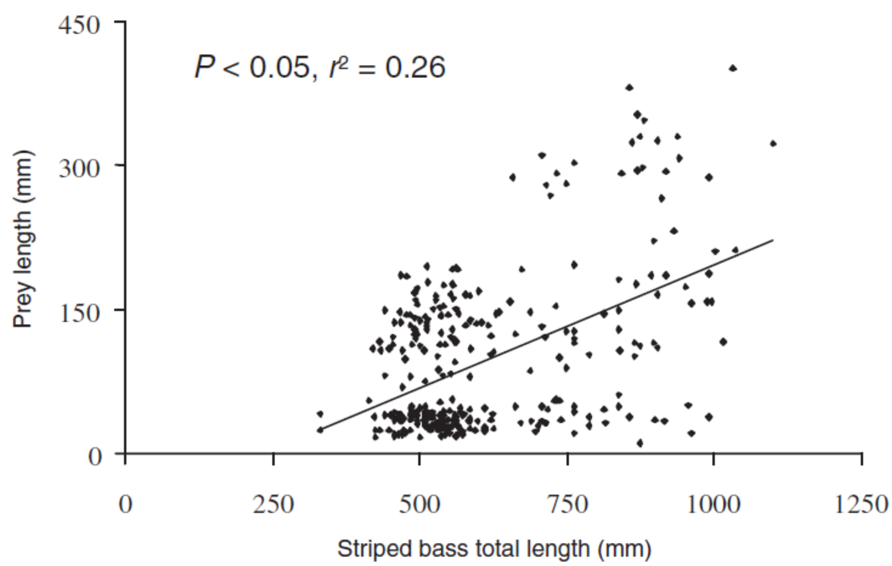

Figure A8. *In* Walter and Austin 2003 (Figure 4). Plot of prey total length against total length for Striped Bass.

- 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 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.

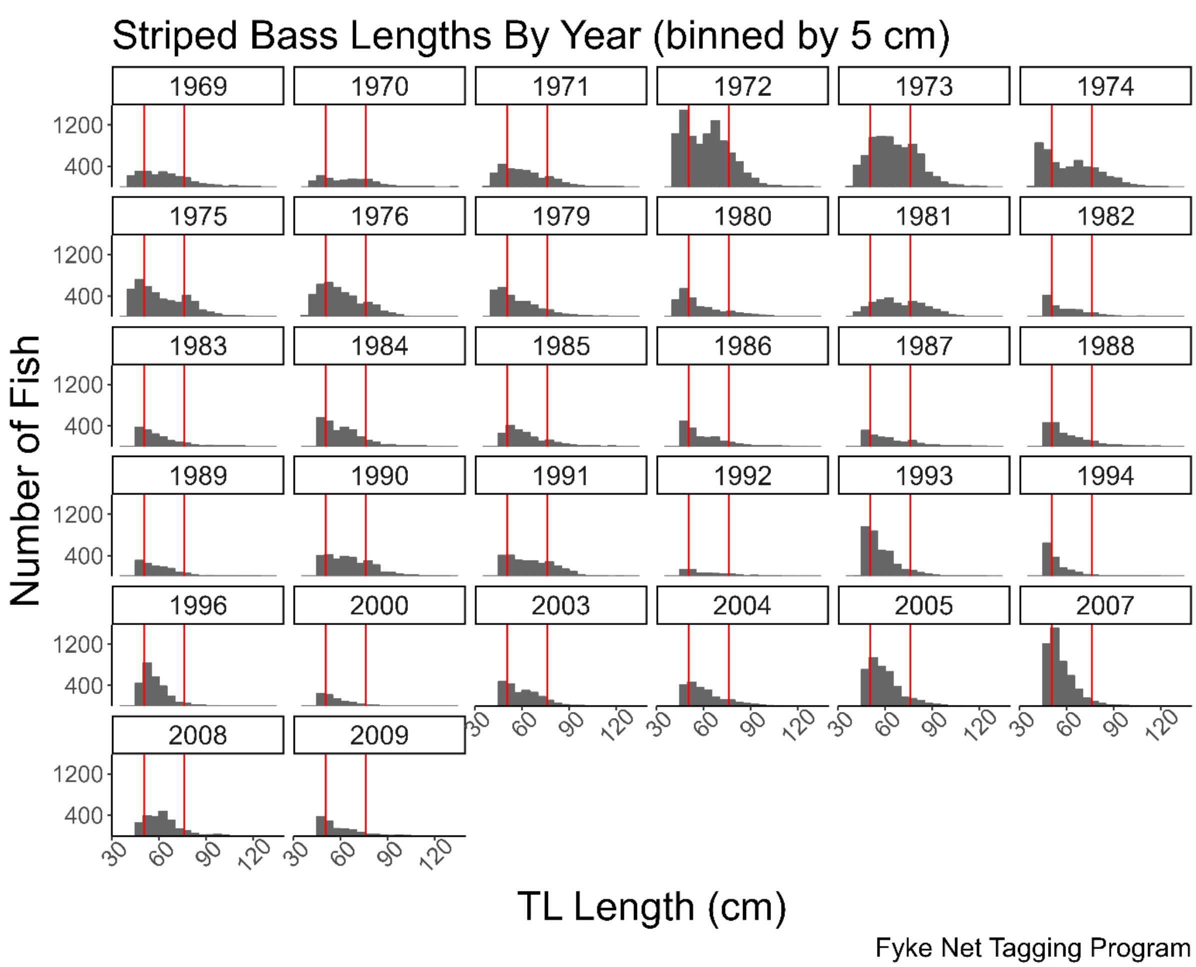

Figure A9. Length-frequency histograms for Striped Bass sampled from fyke nets. Parallel vertical red lines indicate the proposed 20-30 inch slot limit. Data Source: Striped Bass Tagging Program.

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).

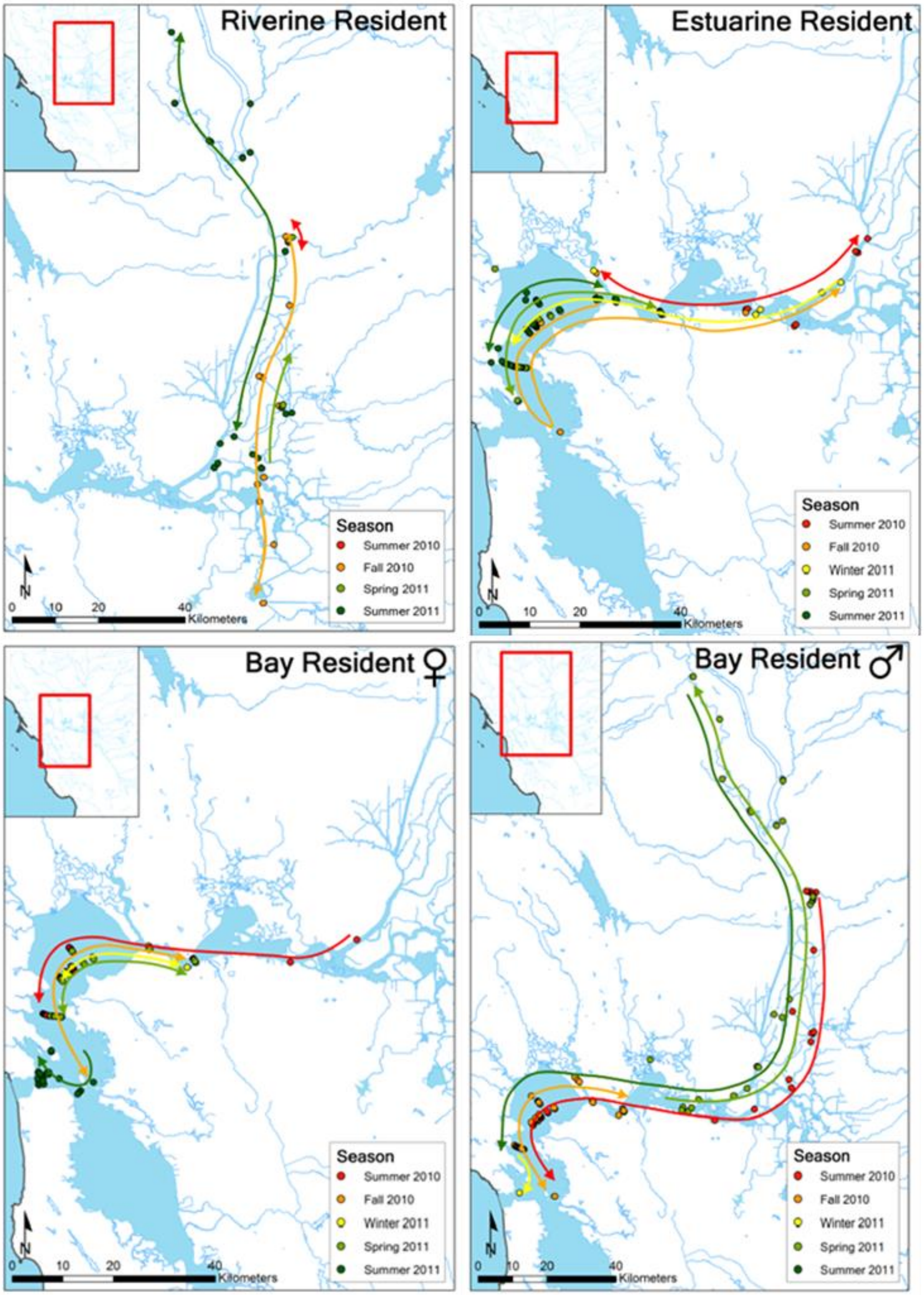

Figure A10. *In* Le Doux-Bloom 2012. Figures depict seasonal movement patterns of male and female Striped Bass in the summer of 2010 and 2011.

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.

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 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 assertion 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.