Vol. 41 Issue 2, 2022

Interagency Ecological Program for the San Francisco Estuary

IEP Newsletter

In this Issue:

Interagency Ecological Program

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IEP Newsletter

Interagency Ecological Program for the San Francisco Estuary

Vol. 41 Issue 2, 2022

The Newsletter is a triannual product of the Interagency Ecological Program (IEP) that publishes perspectives on our Program and community, reviews, data reports, research articles, and research notes. The Newsletter is a forum for resource managers, scientists, and the public to learn about recent important programmatic and scientific topics from across the San Francisco Estuary. Articles in the IEP newsletter are intended for rapid communication and are not peer reviewed. Primary research results reported in the Newsletter should, therefore, be considered preliminary and interpreted with caution.

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Article Submission Deadlines for this Calendar Year:

Issue	Article Submission Deadline
1 (Winter)	February 15
2 (Spring)	June 15
3 (Summer/Fall)	October 15

Above: A Striped Bass being held by Dylan Stompe (CDFW Sport Fish Lead Scientist) during the sturgeon trammel net survey. Credit: David Hull (CDFW)

Cover: An adult White Sturgeon being released during the sturgeon trammel net survey in Suisun Bay. Credit: Dylan Stompe (IEP & CDFW)

Of Interest to Managers

This issue of the newsletter features the following science articles:

Feasibility of formalin-fixed Delta Smelt for genetic identification

At UC Davis, Dr. Kurobe and colleagues developed PCR protocols that facilitate genetic species identification of Delta Smelt preserved in 10% phosphate-buffered formalin for as long as 11 years. This new technique may allow managers to assess accurate identification of Delta Smelt from archived specimens.

Fish Salvage at the State Water Project's and Central Valley Project's Fish Facilities during the 2021 Water Year

Geir Aasen and **Walter Griffiths** summarized results from the 2021 water year for fish salvage associated with water exports by the federal Central Valley Project (CVP) and California's State Water Project (SWP). In general, total fish salvage has been influenced by exports in recent years (i.e., lower salvage occurs with decreased exports). This trend was generally seen at both facilities in water year (WY) 2021 but was not found at the SWP during WY's 2017 and 2019 when total fish salvage was low despite high exports. A trend of decreasing exports has occurred simultaneously as decreasing fish population abundance trends resulting in low salvage and detection difficulties. Salvage of species including Chinook Salmon, steelhead, Striped Bass, Delta Smelt, Sacramento Splittail, Threadfin Shad, and Green Sturgeon in WY 2021 decreased, whereas Longfin Smelt salvage, continued to increase as compared to recent WYs.

2021 Delta Juvenile Fish Monitoring Program - Nearshore Fishes Annual Report

This report of nearshore, non-salmonid fish assemblages in the Bay and Delta is written by Adam Nanninga, Eric Huber, and Adelaide Robinson of the USFWS. The authors describe in this report the status and trends of four native species (Hardhead, Threespine Stickleback, Pacific Staghorn Sculpin, Northern Anchovy) and four non-native species (Redear Sunfish, Western Mosquitofish, White Catfish, Common Carp) from 1995 to 2021. Observed trends are linked to fish life histories, habitat preferences, regional habitat conditions, and climatic events.

2019-2020 Yolo Bypass Fisheries Monitoring Status and Trends Report

The 2020 water-year Yolo Bypass fish community, dominated by Mississippi Silverside, is described in a data report by JT Robinson (DWR) and colleagues. They describe fish community patterns in the community across the water year in the context of environmental conditions, including hydrology and water quality, with an emphasis on the effect of data gaps from limited sampling during the COVID-19 pandemic.

2020 and 2021 Delta Juvenile Fish Monitoring Program - Salmon Annual Report

The purpose of this report is to summarize juvenile salmonid boat trawl and beach seine sample data obtained during the dry 2020 (Aug 2019 to Jul 2020) and critically dry 2021 (Aug 2020 to Jul 2021) DJFMP monitoring years. Authors Adam Nanninga and Eric Huber (USFWS) present status and trend information about: 1) immigration into the Delta from the Sacramento and San Joaquin Rivers; 2) occupancy within the Delta; and

3) emigration from the Delta into the San Francisco Bay. Relevant results include, (1) Fewer winter-run juvenile salmon were sampled in the North and Central Delta in monitoring year 2021 compared to monitoring year 2020, (2) No winter-run or steelhead were sampled in either monitoring year in the South Delta, and (3) No natural-origin steelhead were sampled by seine in both MYs, and very few steelhead were captured in 2021 at Delta entrance from the Sacramento River.

2021 Status and Trends Report for Pelagic Index Fishes in the San Francisco Estuary

The authors present the 2022 Status and Trends Report for Pelagic Fishes in the San Francisco Estuary. The report includes data from six of the Interagency Ecological Program's (IEP) long-term fish monitoring surveys: 1) Spring Kodiak Trawl Survey, 2) 20-mm Survey, 3) Summer Townet Survey, 4) Fall Midwater Trawl, 5) the San Francisco Bay Study and 6) US Fish and Wildlife Service (USFWS) Beach Seine Survey. Each year the California Department of Fish and Wildlife, along with the USFWS, publish a series of memos reporting abundance indices and distribution of select fishes in the Estuary. This report contains the relative abundance indices and catch per unit effort for select pelagic fishes in the upper San Francisco Estuary, many of which were previously reported as separate memos and is summarized here. Fishes reported here include American Shad (Alosa sapidissima), Threadfin Shad (Dorosoma petenense), Delta Smelt (Hypomesus transpacificus), Longfin Smelt (Spirinchus thaleichthys), Splittail (Pogonichthys macrolepidotus), and Striped Bass (Morone saxatilis). Many of the focal species, particularly natives, have undergone significant population declines since the start of these long-term surveys. However, some increases in Longfin Smelt indices (Fall Midwater Trawl and San Francisco Bay Study) did increase relative to 2020. This was in contrast to the decreases of other species, partly in response to the second year of significant drought affecting the San Francisco Estuary.

Research

Feasibility of formalin-fixed Delta Smelt for genetic identification test

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Introduction

Preserving fish in the field can be a challenging task when researchers want to maximize endpoints from individual fish, such as morphometric analyses, biomarker analyses, otolith measurements, genetic tests, and histology. There are several critical criteria for preservation in the field; firstly, preserving fish in the field must be simple and fast to process fish samples immediately and avoid compromising the quality of samples. Enzymatic activities and tissue integrities start to decrease immediately after fish collection, which can affect biomarker analyses and histological examinations. Secondly, researchers need to consider compatibility of preservative solutions and analyses. For example, otoliths can be stored in ethanol but not in formalin since formalin dissolves bones, including otoliths (Glick and Shields 1993). In contrast, for histology, tissues can be stored in formalin but not in ethanol since fixation and preservation in ethanol can result in shrinkage and tissue brittleness (Warmington et al. 2000). Therefore, preserving whole fish in one type of fixative solution in the field limits number of endpoints that researcher can obtain. To address these issues, our laboratory developed a 'flash-freezing' method using liquid nitrogen for subadult and adult stages of Delta Smelt (Teh et al. 2016); in the field, crews wrap individual fish with unique identification tag in aluminum foil packets labeled with unique IDs and place them in liquid nitrogen. Later in a laboratory, researchers dissect fish and preserve tissues in the proper preservative solutions for each analysis. This cryopreservation method enables researchers to obtain data for (1) morphometric analyses (body weight and fork length, body and organs condition indices), (2) histology (gills, gonads, and livers), (3) biomarker analyses, (4) otoliths, (5) disease analyses, and (6) genetic tests from individual fish (Teh et al. 2016). However, this cryopreservation method is not ideal for small specimens such as larval stage of Delta Smelt since researchers need to sort out

Table 1. Delta Smelt samples used for species identification by genetic test. These fish samples were fixed and preserved in 10% phosphate-buffered formalin.

Sample ID	Preserved in formalin for	Tissue wet weight (mg) used for extraction	gDNA concentration (ng/µL)	Description
1	11 years	1.3	10.4	Sampled on 2/14/2007, DELTA SMELT #3, Sex Maturation 2006-07, provided by Dr. Lindberg, FCCL
2	11 years	2.6	14.3	Sampled on 2/14/2007, DELTA SMELT #10, Sex Maturation 2006-07, provided by Dr. Lindberg, FCCL
3	11 years	1.9	23.7	Sampled on 2/14/2007, DELTA SMELT #1, Sex Maturation 2006-07, provided by Dr. Lindberg, FCCL
4	1 year	1.4	8.1	Sampled on 1/30/2017, 263 dph
5	1 year	2.2	11.9	Sampled on 1/30/2017, 231 dph

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                                      >>>>>>>>>>>>>>>>>>>> 64_Hypomesus_F1
HQ667171.1      AAAAACCATCGTTGTTAATTCAACTACAAGAACCCTAATGGCCAACCTTCGGAAAACCCA
HQ667170.1      AAAAACCATCGTTGTCAATTCAACTACAAGAACCCTAATGGCCAACCTTCGGAAAACCCA
                *************** ********************************************


HQ667171.1      TCCCCTCCTGAAAATTACCAACGACGCTCTTGTTGATCTGCCTGCACCCTCCAATATTTC
HQ667170.1      CCCCCTCCTAAAAATTACCAATGACGCCCTAGTTGATTTACCTGCACCCTCCAATATTTC
                 ******** *********** ***** ** ****** * ********************

HQ667171.1      TATCTGATGAAACTTTGGCTCCCTCCTTGGACTATGTCTTATTATTCAAATCCTCACAGG
HQ667170.1      AATCTGATGAAACTTTGGATCCCTTCTTGGGCTGTGTCTTATTATCCAAATCCTTACGGG
                 ***************** ***** ***** ** *********** ******** ** **

HQ667171.1      CCTATTCCTAGCCATGCACTACACTGCCGAGACTGCTACAGCATTTTCTTCTGTAGTACA
HQ667170.1      CCTCTTTTTGGCTATGCACTATACTGCTGAGACTGCTACCGCTTTTTCCTCTGTTGTTCA
                *** **  * ** ******** ***** *********** ** ***** ***** ** **

                                    66_Hypomesus_R1   <<<<<<<<<<<<<<<<<<<<<
HQ667171.1      CTTATGCCGGGACGTTAATTACGGGTGACTAATCCGGAACATGCACGCTAACGGAGCATC
HQ667170.1      CCTCTGCCGAGACGTTAATTACGGCTGACTAATCCGTAACATGCACGCTAACGGAGCATC
                * * ***** ************** *********** ***********************

HQ667171.1      TTTCTTCTTTATTTGTATTTATCTTCATATTGGCCGAGGTCTTTACTACGGCTCCTTCCT
HQ667170.1      TTTCTTCTTTATTTGCATTTACCTTCATATTGGCCGAGGTCTTTATTACGGCTCATTCCT
                *************** ***** *********************** ******** *****
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Figure 1. Primers for Hypomesus mitochondrial cytochrome b gene (Delta Smelt: GenBank accession number HQ667171.1 and Wakasagi: HQ667170.1; Baerwald et al. 2011)

and identify Delta Smelt from other fish and environmental debris first.

Currently, California Department of Fish and Wildlife (CDFW) and U.S. Fish and Wildlife Services (USFWS) field sampling crews use formalin to preserve larval fish. While formalin preserved fish samples are ideal for histology and morphometric analyses, it is unclear whether researchers can use such fish samples for genetic tests since formalin causes fragmentation on genomic DNA and formation of protein-DNA cross-links (Campos and Gilbert 2012). Although there are papers reporting genomic DNA extraction from 10% phosphate-buffered formalin fixed and preserved tissues (Yuan et al. 2014), there is no data available on Delta Smelt. Also, it is unclear whether genomic DNA can be extracted from samples that have been preserved in formalin >10 years. Studying larval Delta Smelt fitness is critically important since larval fishes are susceptible to various stressors such as food limitation (Li and Mathias 1987). In addition, survival during early life stages can directly affect their abundances at later stages. In this study, we examined whether species identifications on fish preserved in 10% phosphate-buffered formalin for up to 11 years could be made.

Materials and Methods

Genomic DNA extraction, PCR, and sequencing for formalin-fixed and preserved Delta Smelt tissue samples.

Delta Smelt samples, preserved in 10% phosphate-buffered formalin for 11 years or 1 year, were used for genomic DNA extraction using QIAamp DNA FFPE Tissue kit (QIAGEN; Cat No./ID: 56404) (Table 1; see Table 2 for the contents of 10% phosphate-buffered formalin). The caudal fin was clipped for use in this experiment. Since residual formalin

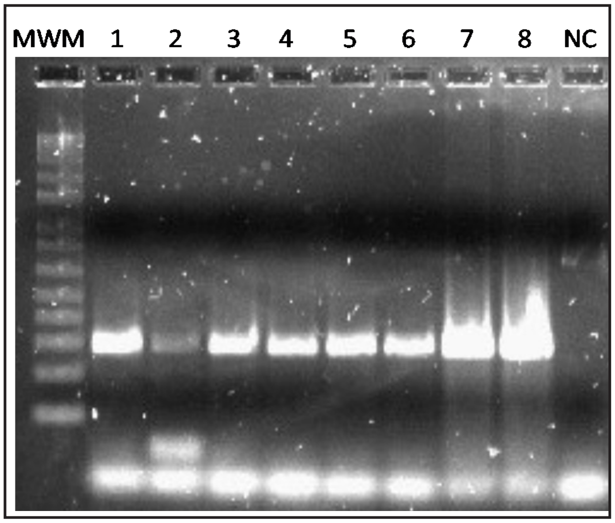

Figure 2. PCR results for Delta Smelt cytochrome b gene. (From left) Molecular weight marker (MWM); 1-3: formalin-preserved samples (11 years); 4-6: formalin-preserved samples (1 year); 7-8: positive control (ethanol preserved tissue); NC: negative control (no genomic DNA).

can inhibit Proteinase K, the fin clip samples were dehydrated prior to the genomic DNA extraction as follows: 1) washing in 70% ethanol for 30 minutes twice, 2) washing in 80% ethanol for 30 minutes twice, 3) washing in 90% ethanol for 30 minutes twice, 4) washing in 100% ethanol for 30 minutes twice. After dehydration, the samples were air dried for 10 min at room temperature and then ATL buffer with Proteinase K was added. We followed the manufacturer's instruction for the rest of the process. The genomic DNA was eluted in 100 µL of ATE buffer, and then the genomic DNA concentrations were measured by Nanodrop (Table 1).

PCR was performed using a pair of custom primers developed in our laboratory based on the reference Delta Smelt and Wakasagi mitochondrial cytochrome b gene sequences deposited by Baerwald et al. (2011): 64_Hypomesus_F1: 5'- ACT ACA AGA ACC CTA ATG G - 3' and 66_Hypomesus_F2: 5'- GAT GCT CCG TTA GCG TGC ATG - 3' (Figure 1). The PCR cocktail and PCR cycling conditions are shown in Tables 3 and 4. We doubled the amount of Taq DNA polymerase compared to the manufacturer's instruction to maximize the amplification efficiency (Table 3). This is because genomic DNA extracted from formalin-preserved tissues is severely degraded and fragmented. For the same reason, the PCR was performed for 45 cycles (Table 4). In the reaction, we included two positive controls (samples fixed and preserved in 70% ethanol for 6 months) and one negative control (reaction cocktail without genomic DNA). All the PCR amplified DNA fragments were submitted to the UC Davis DNA Sequencing Facility for direct sequencing reactions using the custom primers.

Results and Discussion

DNA bands at the expected size were amplified from the 10% phosphate-buffered formalin fixed samples as well as positive controls (Figure 2). The weaker signal observed in Sample No. 2 could be due to the poor gDNA quality associated with formalin preservation or other causes such as sample processing (Figure 2). No band was observed

Table 2. Recipe for 10% phosphate-buffered formalin.

Ingredients	Volume/Weight
Distilled water	3600 mL
37% formalin	400 mL
Na2HPO4	26 g
NaH2PO4 • H2O	16 g

Table 3. PCR cocktail for amplifying the cytochrome b gene from 10% phosphate-buffered formalin fixed samples.

Reagents	Volume (µL per reaction)
10´ Buffer	5
dNTP (10 mM)	1
MgCl2 (50 mM)	1.5
H2O	33.1
Taq (Platium Taq Polymerase)	0.4
Primer (Fw, 10 µM)	2
Primer (Rv, 10 µM)	2
Template DNA	5

Table 4. PCR cycling conditions for amplifying the cytochrome b gene from 10% phosphate-buffered formalin fixed and preserved samples.

Temperature	Incubation time	Step	
95 ºC	5 min.	Initial denaturing	
95 ºC	30 sec.	Denaturing	
55 ºC	30 sec.	Annealing	45 cycles
72 ºC	1 min.	Extension	

in the negative control. The BLASTN search results demonstrated that all the PCR amplified DNA fragments encoded the Delta Smelt cytochrome b gene (data not shown).

We were able to amplify a portion of the cytochrome b gene from archived samples that were preserved for 11 years in 10% phosphate-buffered formalin. As expected, the band intensities from formalin-fixed samples were not as strong as the ones from ethanol preserved samples (Figure 2). Although the instruction of the genomic DNA extraction kit indicates that DNA fragmentation becomes more severe as tissues are preserved in formalin for longer periods, we did not observe differences between the tissue samples preserved 11 years and 1 year in the PCR results (Figure 2).

The results from this study indicate that Delta Smelt preserved and archived in 10% phosphate-buffered formalin can be used for genetic tests, which potentially provides us opportunities to expand research to understand the health and population structure of Delta Smelt. For example, larval stage of Delta Smelt preserved in 10% phosphate-buffered formalin could be used for morphometric analysis to assess fitness of fish, followed by histological analysis to evaluate energy storage in liver, and a genetic test to confirm species identification (Takács et al. 2016; Teh et al. 2016). In addition, we can use archived wild Delta Smelt samples collected from a pre-Pelagic Organism Decline period, provided there are specimens available. Fish specimens could be used for genetic analyses and may provide key information regarding the historical population structure of Delta Smelt and Delta Smelt hybrids (Benjamin et al. 2018). Although additional steps are required for processing formalin preserved tissues and quality of gDNA extracted from formalin preserved fish was not as good as ethanol preserved fish, it is still feasible to amplify short DNA fragments by PCR for genetic analyses. The dehydration process with a series of ethanol solutions used in this study was adopted from our laboratory protocol for hematoxylin and eosin staining. This process can be shortened after running additional optimization experiments.

Acknowledgements

We are grateful to the CDFW and USFWS field crews for collecting the fish, and to the UC Davis AHP staff for fish dissection. We also thank Ching Teh, Khiet Huynh, Franklin Tran, Wilson Ramírez Duarte, Jessica Hsiung and Elizabeth Berry for their technical support. Partial funding for this study was provided by US Bureau of Reclamation R17AC00129. The views expressed are those of the authors and do not represent the official opinion of the U.S. Bureau of Reclamation.

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2021 Delta Juvenile Fish Monitoring Program Nearshore Fishes Annual Report

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Introduction

The Delta Juvenile Fish Monitoring Program (DJFMP) of the United States Fish and Wildlife Service (USFWS) has monitored fishes within the Sacramento-San Joaquin Delta (Delta) and San Francisco Bay (Bay) since 1976. Over time, the monitoring program has evolved in response to emerging water management needs and threatened and endangered species listings under the federal Endangered Species Act (ESA). Initially, the objectives were to (1) monitor juvenile Chinook Salmon (Oncorhynchus tshawytscha) abundance in the system, (2) evaluate the importance of the Bay as nursery habitat for juvenile salmon, and (3) determine the effect of altered river flows from the proposed Peripheral Canal on juvenile salmon rearing and migration (Brandes and Mclain 2000). Following the rejection of California Proposition 9 (Peripheral Canal Act) in 1982, the DJFMP's focus shifted to evaluating the effects of through-Delta water conveyance on the relative abundance, distribution, and survival of juvenile Chinook salmon in the Delta and Bay. The program expanded geographically and temporally in the 1990s in response to ESA listings of Sacramento River Winter-run Chinook Salmon and California Central Valley Steelhead (O. mykiss). With the growing recognition of importance of other members of the fish community in shaping ecosystem health and resilience, the objectives of DJFMP were expanded to include documenting the abundance and distribution of non-salmonid species in the Delta and San Francisco Bay (Bay).

This report describes inter-annual abundance trends and distributional patterns of select nearshore resident fishes within the Delta and lower mainstem Central Valley rivers from 1995 to 2021 and Bay from 1997 to 2021 (information for our salmonid catch trends can be found in the DJFMP Salmonid Annual Report also presented in this newsletter). All years are presented as monitoring years which runs from August of the previous year stated to July of the stated year. We choose these time periods because the DJFMP began sampling the Delta and rivers year-round in 1995 (i.e., August 1994 to July 1995) and resumed Bay sampling in 1997. Prior to 1995, sampling in the Delta and rivers did not occur in late spring and summer when non-salmonid juveniles typically recruit into sampling gear. The DFJMP sampled the Bay in 1981 and 1982 and the California Department of Fish and Game (now California Department of Fish and Wildlife, CDFW) sampled from 1983-1986.

Currently, the DJFMP is one of the few long-term monitoring programs that broadly surveys littoral habitats throughout the Delta and Bay, which (1) permits a holistic understanding of fish community changes (Nobriga et al. 2005) and (2) documents the invasions and expansion of non-native fishes in nearshore habitats (Moyle and Bennett 2008, Mahardja et al. 2020). Due to the high species richness in the system (>50 species), we limit our analyses on a rotating basis to six fish species occurring in the Delta (Hardhead, Mylopharodon conocephalus; Threespine Stickleback, Gasterosteus aculeatus; Redear Sunfish, Lepomis microlophus; Western Mosquitofish, Gambusia affinis; White Catfish, Ameiurus catus; Common Carp, Cyprinus carpio) and two species primarily occurring primarily in the Bay (Northern Anchovy, Engraulis mordax; Pacific Staghorn Sculpin, Leptocottus armatus). Pacific Staghorn Sculpin has limited presence outside the Bay. The complete DJFMP dataset, including 1) a complete description of sampling procedures, 2) non-salmonid catch data, and 3) environmental data not included in this report, is available at DJFMP's Environmental Data Initiative Data Portal (IEP et al. 2022).

Methods

Beach seine surveys (hereafter "seines") were implemented by DJFMP to sample fishes at 58 sites throughout the Bay, Delta, and lower Sacramento and San Joaquin rivers (Figure 1). In this report we use relative site names in place of our traditional seine region numbers to aid in the spatial orientation of readers, thus: Seine Region 1 = Lower Sacramento River (8 sites); Seine Region 2 = North Delta (9 sites); Seine Region 3 = Central Delta (9 sites); Seine Region 4 = South Delta (10 sites); Seine Region 5 = Lower San Joaquin River (9 sites); Region 6 = Bay Seine (9 sites; Figure 1). From 2002-2005 and 2009-2019 a total of 21 seine sites in the North Delta region were sampled at Liberty Island (Figure 1; see Steinhart et al. 2021 for more information).

A complete description of the historical and current methods is available on the DJFMP's Environmental Data Initiative Data Portal (IEP et al. 2022). Briefly, the DJFMP seined at fixed sites within regions during daylight hours (between 06:00 and 18:00) using a 15.2 x 1.3 m seine net with 3 mm delta square mesh and a 1.2 m bag in the center of the net. A float line and lead line were attached to 1.8-m tall wooden poles on each side. Beach seines were pulled toward the shoreline by two crew members in unobstructed habitats including boat ramps, mud banks, and sandy beaches.

All sites were surveyed once per week throughout the year except for the Bay Seine region which was sampled once every two weeks throughout the year and a few North Delta and Lower Sacramento River seine sites which were sampled three times per week from 1-Oct through the last week of January to intensely monitor for juvenile Winter-run Chinook Salmon abundance and migration timing. Depending on caudal fin morphology, captured fishes ≥ 25 mm total length (TL) or fork length (FL) were measured for size (with the exception of Threespine Stickleback and

Western Mosquitofish which are identified at ≥ 20 mm). If more than 30 individuals of a species were captured, a subsample of 30 individuals were randomly selected and measured for length. Captured fish in excess of 30 per species were enumerated but not measured (referred to as a "plus count"). Size frequency histograms were plotted for each species and the percentage of juveniles captured and measured were calculated using published length-at-maturity threshold values. In cases where minimum length-at-maturity was not reported in FL for fishes with a forked caudal fin, we used the TL (e.g., Redear Sunfish, Common Carp) or standard-length (SL; e.g., Hardhead, Northern Anchovy) value reported in the scientific literature as the threshold FL value for the analyses presented here.

While not presented here, water quality variables (water temperature, conductivity, dissolved oxygen, and turbidity) were measured for each trawl or seine haul. Also, Secchi depths were measured for each trawl and substrate compositions and flow velocities were measured for each seine haul. The environmental data are publicly available at DJFMP's Environmental Data Initiative Data Portal (IEP et al. 2022).

Before estimating catch-per-unit-effort (CPUE, fish·m-3), we filtered the DJFMP dataset (IEP et al. 2022) by excluding samples collected during poor sampling conditions, such as net twists or snags (i.e., gear condition code >2 in the dataset) and technical errors identified by sampling volume outliers. To compare the CPUE of species across space and time, we calculated mean annual CPUE values for each of the six seine regions. To avoid overweighting sampling sites due to differences in sampling frequency, months and sites were equally weighted in the calculation of annual regional CPUE values:

$$\text{Sample Volume } (m^3) = \text{Seine Width}(m) \times \text{Seine Length}(m) \times \text{Seine Depth } (m) \times 0.5$$

$$\text{Sample CPUE}_{i_j} = \frac{\text{Count}_{i_j}}{\text{Sample Volume } (m^3)}$$

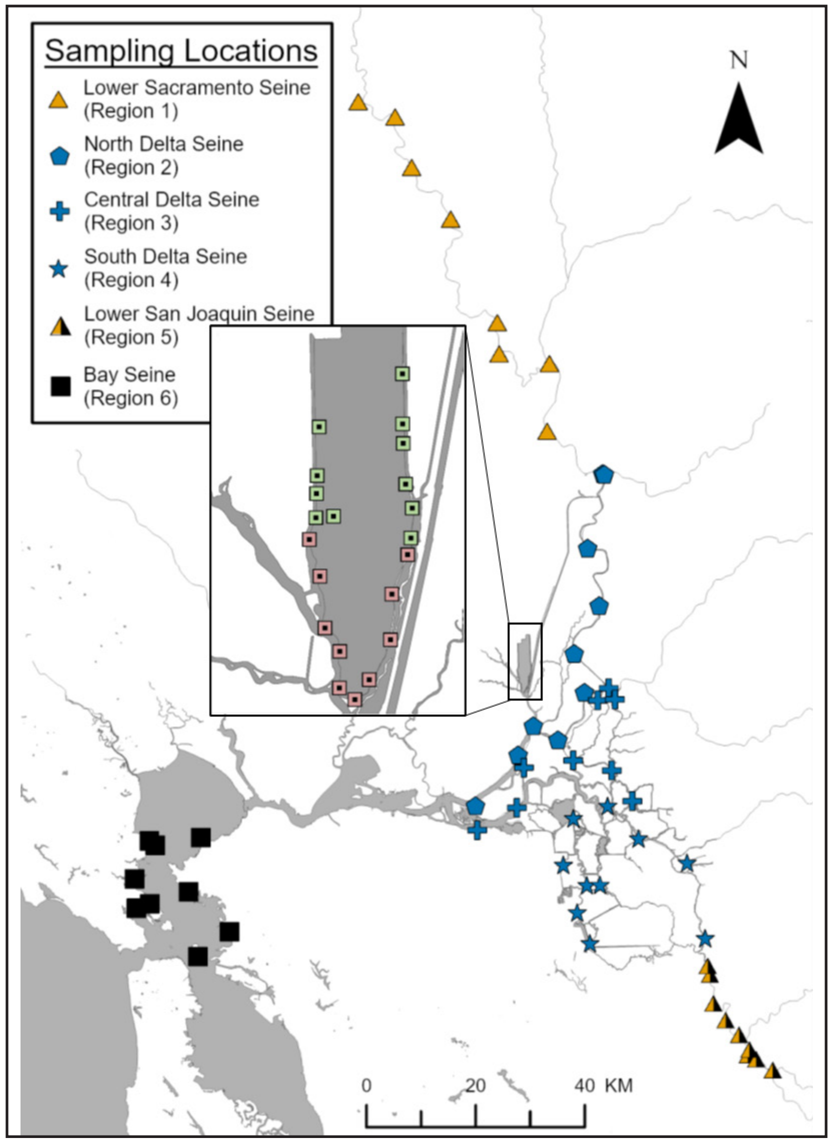

Figure 1: Map of the United States Fish and Wildlife Service (USFWS) Delta Juvenile Fish Monitoring Program (DJFMP) beach seine sampling sites and regions in the Sacramento-San Joaquin Delta and San Francisco Bay. Data from Liberty Island seine sites (red dots in inset) are in the North Delta region and included in this report for monitoring years 2002-2005 and 2009-2019.

where i indexes species and j indexes seine sites. We then averaged sample CPUE values within each site by month to calculate a mean monthly CPUE for each site:

$$\text{Monthly CPUE}_{ij} = \frac{\sum_{\text{site:month}} \text{Sample CPUE}_{ij}}{N}$$

We then averaged the mean monthly site CPUE values within each seine region by month to calculate a mean monthly CPUE for each region:

$$\text{Monthly CPUE}_{ik} = \frac{\sum_{\text{region:month}} \text{Monthly CPUE}_{ij}}{N}$$

where k indexes seine regions. We then averaged the mean monthly CPUEs for each region to calculate an annual CPUE for the Delta:

$$\text{Annual CPUE}_{ik} = \frac{\sum_{\text{region:year}} \text{Monthly CPUE}_{ik}}{N} \times 10{,}000$$

An expansion factor of 104 was used for data presentation purposes.

Monitoring Disruptions - In 2021, the DJFMP seine sampling effort was curtailed due to the COVID-19 Pandemic, wildfire smoke mitigation measures to protect worker safety, and low water levels in the San Joaquin River. In total, 47.1% of 2300 scheduled seine hauls across all seine regions were completed without complications that could bias catch (e.g., twists in net, snagged net, etc.). The percentage of sampling completed varied by region - Lower Sacramento River: 61.5%; North Delta: 62.0%; Central Delta: 44.2%; South Delta: 8.6%; Lower San Joaquin River: 7.4%; Bay Seine: 51.7%. Given the significant restriction in sampling, we advise readers to take this into account and use caution when interpreting the results for 2021, especially for the South Delta and Lower San Joaquin River regions.

Results and Discussion

Hydrological Conditions - According to the California Department of Water Resources' (CDWR) Sacramento Valley water year (WY) index, WY 2021 is classified as a "critically dry" water-year type in both the Sacramento and San Joaquin valleys. Total Delta inflow in WY 2021 was 33% of the long-term average Delta inflow from 1995-2019 (3.32·107 ac ft) (Gartrell et al. 2022).

Hardhead (Mylopharodon conocephalus – native)

Hardhead (family Cyprinidae) are found in reservoirs and large low- to mid-elevation rivers and streams with low water velocities (≤25 cm·s-1), cool to warm thermal regimes (20-28°C maximum summer temperatures) and well-oxygenated waters (Knight 1985, Moyle 2002). They prefer non silted pool and run habitats and have trouble persisting in areas heavily populated by invasive species, particularly Centrarchid basses (Moyle 2002). This species exhibits strong site fidelity, leaving only to migrate to spawning pools during April and May (Grant and Maslin 1999). Hardhead mature in their third year when they typically reach 160-170 mm SL (Moyle 2002). Although considered abundant, some of their populations are showing decline or local extirpation, particularly in the San Joaquin drainage (Brown and Moyle 1993). This decline has caused the CDFW to list M. conocephalus as a Species of Special Concern.

Since 1996, we have sampled Hardhead ranging from 25-192 mm FL with a median FL of 46 mm (Figure 2). Juveniles (<160 mm FL; Moyle 2002) comprised 99.4% of the samples measured for size. Typically, the highest CPUE for Hardhead has been observed in the Sacramento River followed by lower abundance in the North Delta, Central Delta, Lower San Joaquin River, and South Delta respectively (Figure 3).

Standardized catch remained consistent in the Sacramento River between 1995 and 2018 before increasing in 2019, dropping to below average levels in 2020, and then

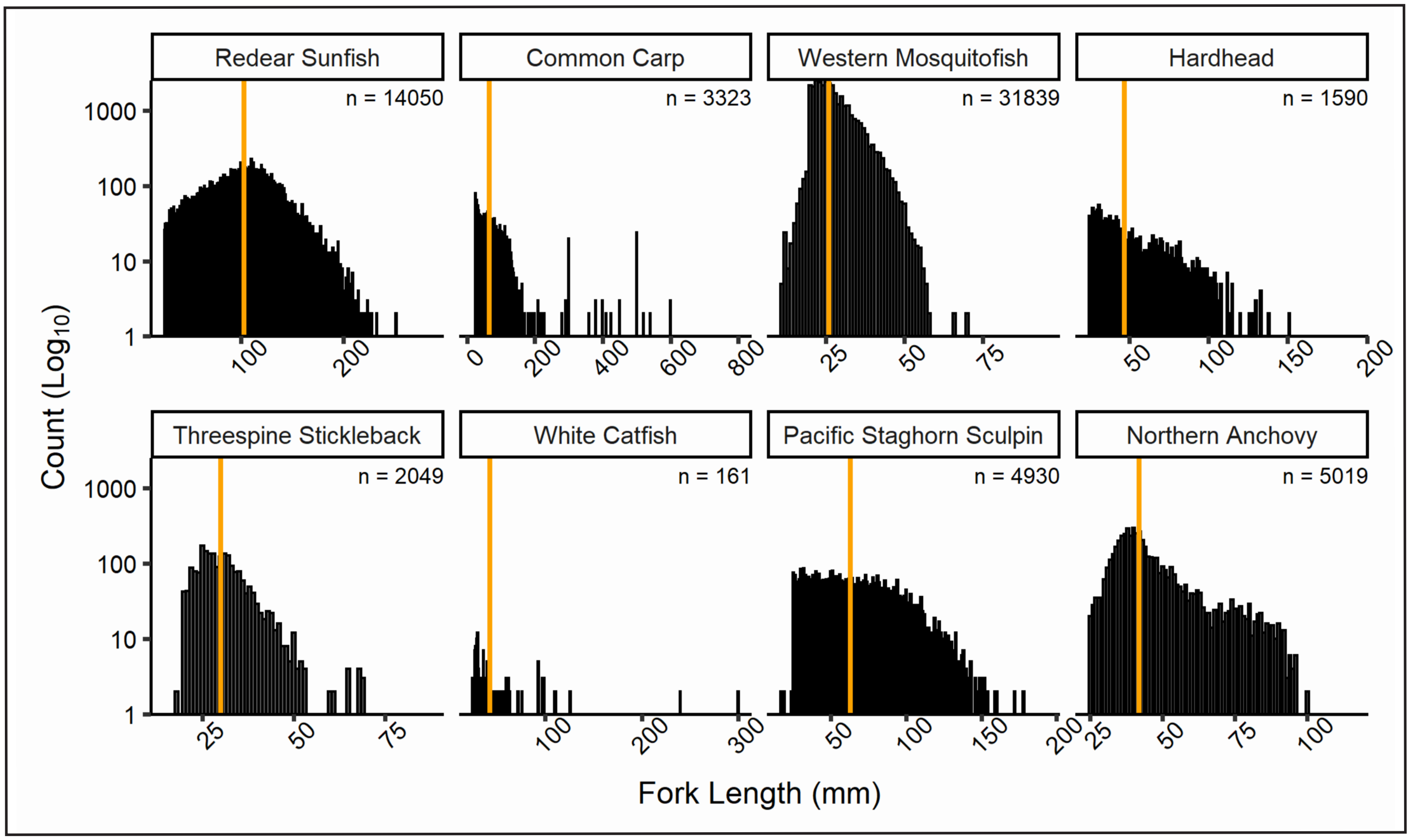

Figure 2: Size distribution of measured fish from 1995–2021 United States Fish and Wildlife Service Delta Juvenile Fish Monitoring Program beach seine surveys in the Sacramento-San Joaquin Delta and San Francisco Bay/Estuary. Median fork lengths are indicated with a vertical orange line.

dramatically increasing in 2021 (Figure 3). Hardhead are negatively impacted by reduced oxygen levels in warm water and it is likely that cold bottom-water reservoir releases in the Lower Sacramento River during summer provide habitat conditions that have allowed the species to maintain stable populations in this river (Moyle et al. 2015). The recent CPUE spike in Sacramento River region (Figure 3) is largely driven by elevated catch at a single site (Colusa State Park). It is important to note that this site was relocated from an off-channel area to a site on the mainstem Sacramento River in 2019. The new site has lower temperatures and other habitat features that are more favorable for the species. Hardhead, however, also increased in abundance between 2020 and 2021 in the North Delta (Figure 3) so the recent increase is observed in multiple regions.

Hardhead are rarely sampled in the San Joaquin River region. Only 20 have been captured since 1995; 10 individuals were captured in 2000 followed by six in 2006 and one in 2007, 2011, 2013, and 2019 (Figure 3). Factors that contribute to the low catch observed in the San Joaquin likely include competition with non-native species and habitat and hydrological modifications (Kaufman et al. 2013, Moyle et al. 2015). Because of these sensitivities, it is important to continue to monitor this species of conservation importance.

Threespine Stickleback (Gasterosteus aculeatus – native)

Threespine Stickleback (family Gasterosteidae) are widespread in the San Francisco Bay watershed. Threespine Stickleback life histories are diverse and taxonomy for this fish is complex. There are both inland and anadromous forms and they can persist in both fresh and salt water (Bell 1976). Threespine Stickleback may develop

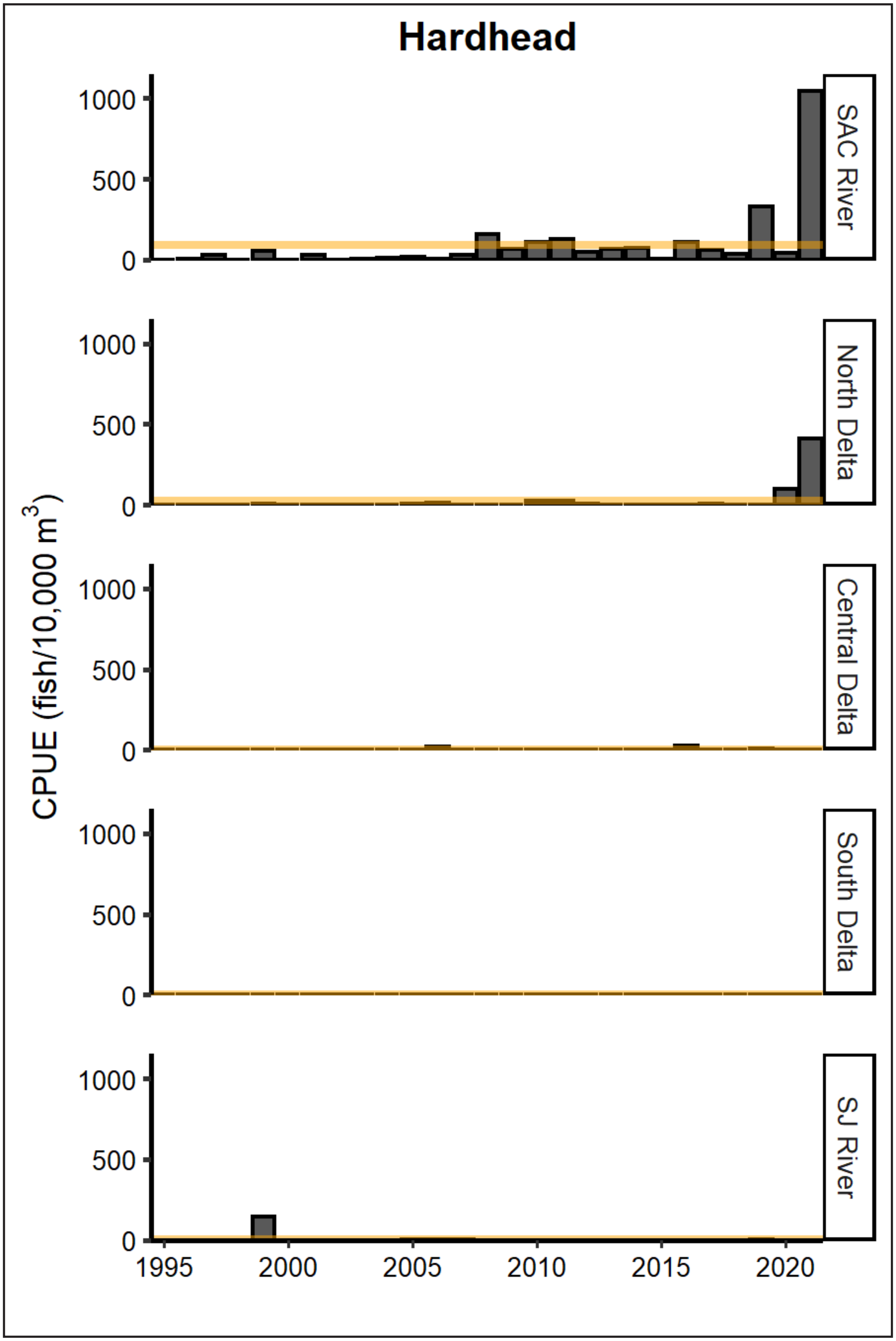

Figure 3: Annual catch-per-unit-effort (CPUE) of Hardhead (Mylopharodon conoceph-alus) in beach seine regions from 1995 to 2021. Horizontal orange lines indicate mean annual CPUE.

bony plates on their sides, the number of which is primarily determined by population genetics and linked to predation risks (Reimchen 1983, Bańbura and Bakker 1995). They may live for up to three years, but most Threespine Stickleback have annual life cycles (Moyle 2002). Both forms prefer cool (≤24°C) and clear pools with sand and gravel substrates in areas with extensive cover in the form of dense mats of floating and rooted aquatic vegetation (Leidy 1984, Moyle 2002). The anadromous form is often found just above the freshwater/tidal interface (Leidy 1984). They spawn from July through October in brackish or freshwaters (Wang 1986). Females deposit 50-300 eggs in several nests which are guarded by males (Moyle 2002). Incubation lasts approximately one week, and fry will remain in the nest for several days (Wang 1986). Threespine Stickleback aggregate in shoals throughout their rearing period and as non-breeding adults (Moyle 2002).

Since 1996, our seine surveys have captured Threespine Stickleback ranging from 20-87 mm TL with a median total length of 30 mm (Figure 2). Juveniles (<41 mm TL, Snyder and Dingle 1990) comprised 90.8% of all measured individuals. The highest CPUE for Threespine Stickleback has consistently occurred in the North Delta region (Figure 4). We observe an overall annual CPUE increase from 2009-2016 (Figure 4). Peak capture occurred in 2014 (Figure 4) but this observation may reflect the social behavior of Threespine Stickleback and the episodic nature of seine surveys; the majority of these individuals were captured in two seine hauls at a single site (Sherman Island) within the first two weeks of May 2014. Threespine Stickleback have never been captured during seine surveys on the San Joaquin River region and have rarely been captured in the South Delta (Figure 4). The Central Delta region has had lower and relatively consistent annual CPUE, while the Sacramento River has had low and intermittent annual catch (Figure 4). Although the species is likely present within all our survey regions, we may be limited in our ability to seine ideal habitat for this species, as they typically prefer heavily vegetated areas (Leidy 1984). Also, Threespine Stickleback distribution has become patchy in the San Joaquin and Sacramento River systems likely due, in part, to predation by invasive fishes (Leidy 1984, Moyle 2002).

Pacific Staghorn Sculpin
(Leptocottus armatus – native)

Pacific Staghorn Sculpin (family Cottidae) typically occur in salty and brackish waters but can also be found in freshwater (Moyle 2002). They reach maturity at 120 mm SL (Moyle 2002) and usually spawn in brackish or saltwater from October to April with peak larval hatching from January through March (Baxter et al. 1999, Wang 1986). Adults lay their eggs in estuarine habitats, choosing a substrate of either rock, sand or mud (Wang 1986). Pacific Staghorn Sculpin tend to decline in abundance as one moves upstream into freshwaters (Baxter et al. 1999). Pacific Staghorn Sculpin residing in saltwater have access to a variety of prey items, including amphipods, small fish, and decapods for juveniles, as well as the crabs, shrimp, and fishes that are preferred by adults (Moyle 2002). For freshwater residents, amphipods serve as the primary food source (Moyle 2002).

More than 80% of all Pacific Staghorn Sculpin sampled by the DJFMP since 1995 has occurred in the Bay. The temporal consistency of Bay catches (Figure 5) indicates population stability. Since 1995, our Seine surveys have sampled Pacific Staghorn Sculpin ranging from 25-193 mm FL with a median total length of 63 mm (Figure 2). Juveniles (<120 mm SL) comprise 95.7% of all measured individuals. Since 1995, we observe relatively high standardized catches during 1999, 2010, and 2011, relatively low catches in 1997-1998, 2001-2002, 2005-2006, and 2015-2017, and near average catches in other years (Figure 5). These patterns are consistent with expected

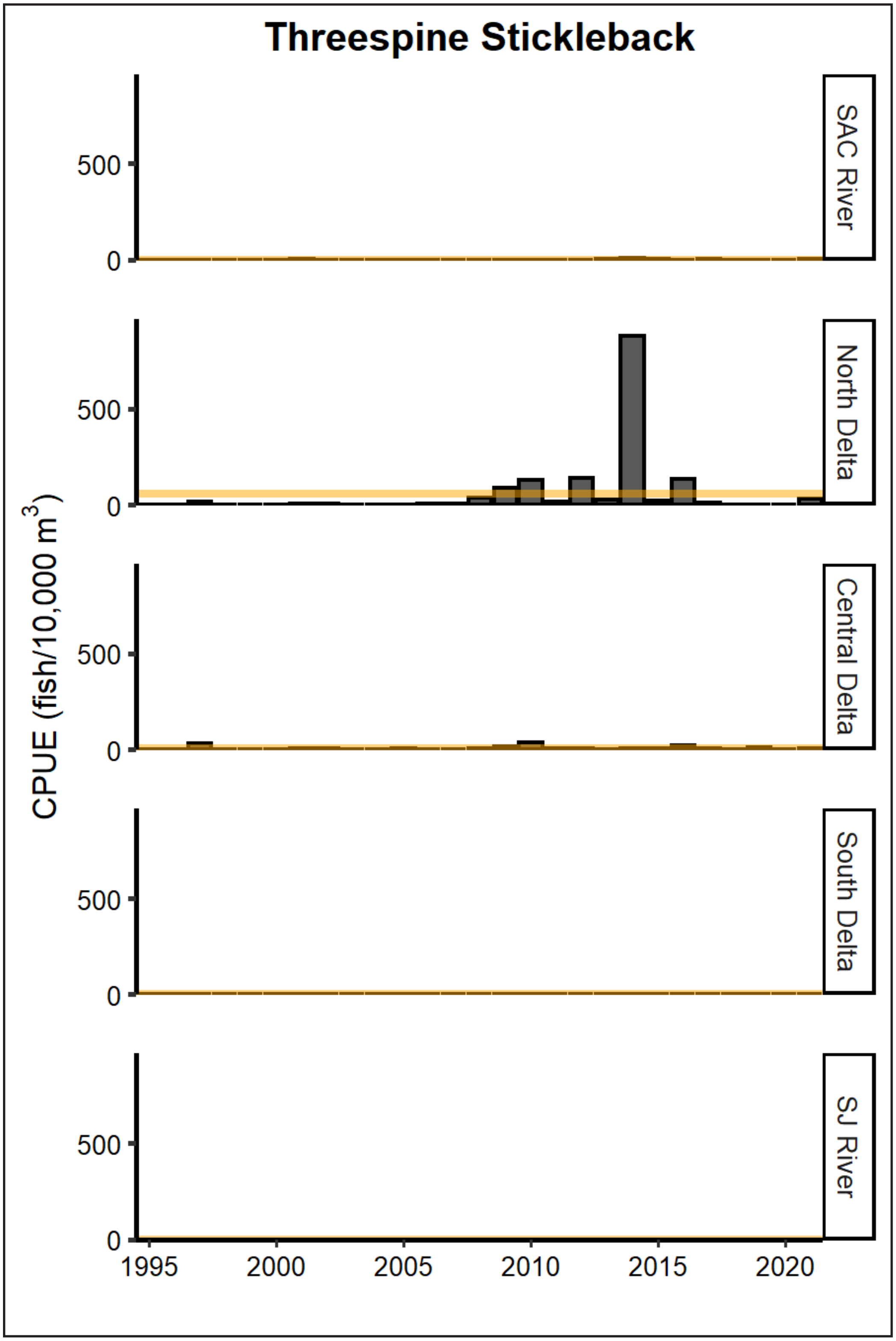

Figure 4: Annual catch-per-unit-effort (CPUE) of Threespine Stickleback (*Gasterosteus aculeatus*) in beach seine regions from 1995 to 2021. Horizontal orange lines indicate mean annual CPUE.

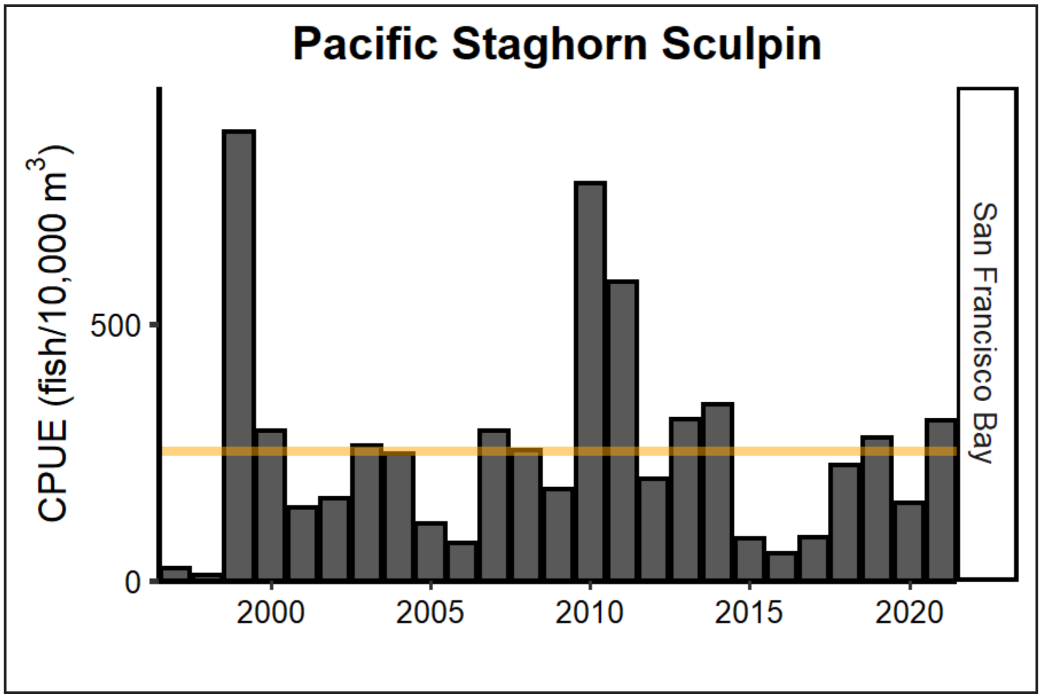

Figure 5: Annual catch-per-unit-effort (CPUE) of Pacific Staghorn Sculpin (Leptocottus armatus) in Bay seines from 1995 to 2021. This figure represents Pacific Staghorn Sculpin caught in San Francisco Bay. Horizontal orange lines indicate mean annual CPUE.

climatological and runoff effects of El Niño and La Niña events on Bay salinities.

Amongst all Pacific Staghorn Sculpin catch upstream of the Bay, most were captured in the North and Central Delta regions (Figure 6). These observations are expected given that Pacific Staghorn Sculpin are euryhaline fishes that prefer marine and estuarine environments. Adults are less tolerant of freshwater than juveniles (Jones 1962), so it is not surprising that zero adult-sized Pacific Staghorn Sculpin were captured upstream of the Bay. The median sizes (and ranges) of Pacific Staghorn Sculpin sampled in the Bay and upstream of the across all years are 73 mm (25-193 mm) and 43 mm (25-107 mm), respectively. These findings are consistent with those of Baxter et al. (1999), which describe how Pacific Staghorn Sculpin mature as they move downstream in the San Francisco Estuary.

There appears to be a loose correlation between dry periods and the capture of Pacific Staghorn Sculpin in the North and Central Delta. During the 2001-2002 drought, CPUE increased in the North and Central Delta compared to previous years (Figure 6). A similar trend during the 2007 to 2009 dry period is also observed (Figure 6). While this trend is less pronounced during the 2012-2016 severe drought, increased catch is observed in the North and Central Delta in 2013 and 2014 (Figure 6). Peak standardized catch in the North and Central Delta is observed during the "critically dry" conditions of WY 2021 (Figure 6). Concentrations of ocean-derived salts increase in the Delta during drought periods (Kimmerer et al. 2019); further investigation is needed to determine if the Pacific Staghorn Sculpin patterns described here are the result of physical habitat changes, tradeoffs between movement and survival, or both.

Northern Anchovy (Engraulis mordax – native)

Northern Anchovy (family Engraulidae) are neritic, epipelagic species that favor coastal upwelling regions throughout the northeastern Pacific Ocean. Juvenile Northern Anchovy are usually more abundant in nearshore habitats whereas adults prefer deeper water (Parrish et al. 1986). The San Francisco Bay region represents a transition zone between Northern and Central subpopulations (Schwartzkopf et al. 2022), so it is likely that individuals captured by DJFMP surveys belong to both groups. Northern Anchovies play a key ecological role as a prey species for a wide variety of aquatic and avian piscivores (NOAA 1978). Their populations have historically cycled through phases of peaks followed by collapse (MacCall et al. 2016), so our dataset has potential to contribute to understanding of key features San Francisco Estuary/Bay ecosystem functioning.

Since 1997, our Bay seine surveys have captured Northern Anchovy ranging from 25-116 mm FL with a median FL of 42 mm (Figure 2). Juveniles (< 96 mm SL; Hunter and Macewicz 1980) comprised 99.7% of measured individuals. Males and females usually mature at age-2 (Hewitt 1985, Picquelle and Hewitt 1983). Northern Anchovy are capable of spawning year-round in nearshore or inland areas. Peak spawning in the San Francisco Bay occurs from July through September (McGowan 1986). Prior to 2004, mean annual CPUE was relatively stable (Figure 7). Since 1997, mean annual CPUE for Northern Anchovy shows a variable pattern with a minor peak observed from 2001-2002 and a major peak observed from 2014-2016 (Figure 7). Larval and juvenile survival in Central and Southern California was high in 2015 (Zwolinski et al. 2017), leading to significant recovery of the Northern Anchovy population between 2015 and 2019 (Stierhoff et al. 2020, 2021). The recent recovery of the species may be linked to a marine heat wave that occurred between 2014 and 2016 (Thompson et al. 2019). This high survival may have contributed to our peak in juvenile catch in 2015 and 2016. Northern Anchovy were not captured in our beach seines outside the San Francisco Bay area.

Redear Sunfish (Lepomis microlophus – non-native)

Redear Sunfish (family Centrarchidae) are native to the Southeastern United States, the Rio Grande River, and lower Mississippi River drainage. The species was first introduced to California waters in 1948 or 1949 (Moyle 2002). They prefer warm lentic environments like ponds, lakes, river backwaters, and sloughs with abundant aquatic vegetation (Moyle 2002). Redear sunfish use their molar-like teeth to eat snails and other mollusks, including invasive species such as zebra mussels and rams-horn snails (French III and Morgan 1995). They prefer freshwater but can tolerate salinities up to 20 ppt (Peterson 1988). Redear sunfish mature at 3 or 4 years when they grow to lengths of 130-180 mm TL (Moyle 2002). They spawn during the summer when water temperatures reach 21-24°C (Emig 1966). Upon hatching, larvae exit nests and feed on plankton before settling on aquatic vegetation beds several weeks later (Wang 1986). They are less fecund than the closely related Bluegill sunfish and have been shown to benefit from harvest restrictions (Sammons et al. 2006).

Since 1995, our seine surveys have measured 14,149 Redear Sunfish ranging from 25-285 mm FL (Figure 2). Juveniles (<130 mm TL) comprised 78.8% of measured individuals. Catch-per-unit-effort for the Sacramento River and the North Delta has been lower than that for the Central Delta, Southern Delta, and San Joaquin River regions (Figure 8). The San Joaquin River basin is warmer than the Sacramento basin and heavily vegetated, which may favor Redear Sunfish reproduction and rearing. While catches throughout the Delta have been variable since 1995, standardized catch increased the most in the Central and Southern Delta. Region-specific increases in standardized catch first occurred in the Central and South Delta in 2011, followed by the North Delta in 2012 and Sacramento and San Joaquin rivers in 2014 (Figure 8). An overall decline in catch has occurred since 2018 at all sites except the San Joaquin River which spiked in in 2020 (Figure 8). The relatively high annual CPUE values in the 2010s coincides with a severe drought that began in water year 2012 (Swain et al. 2018).

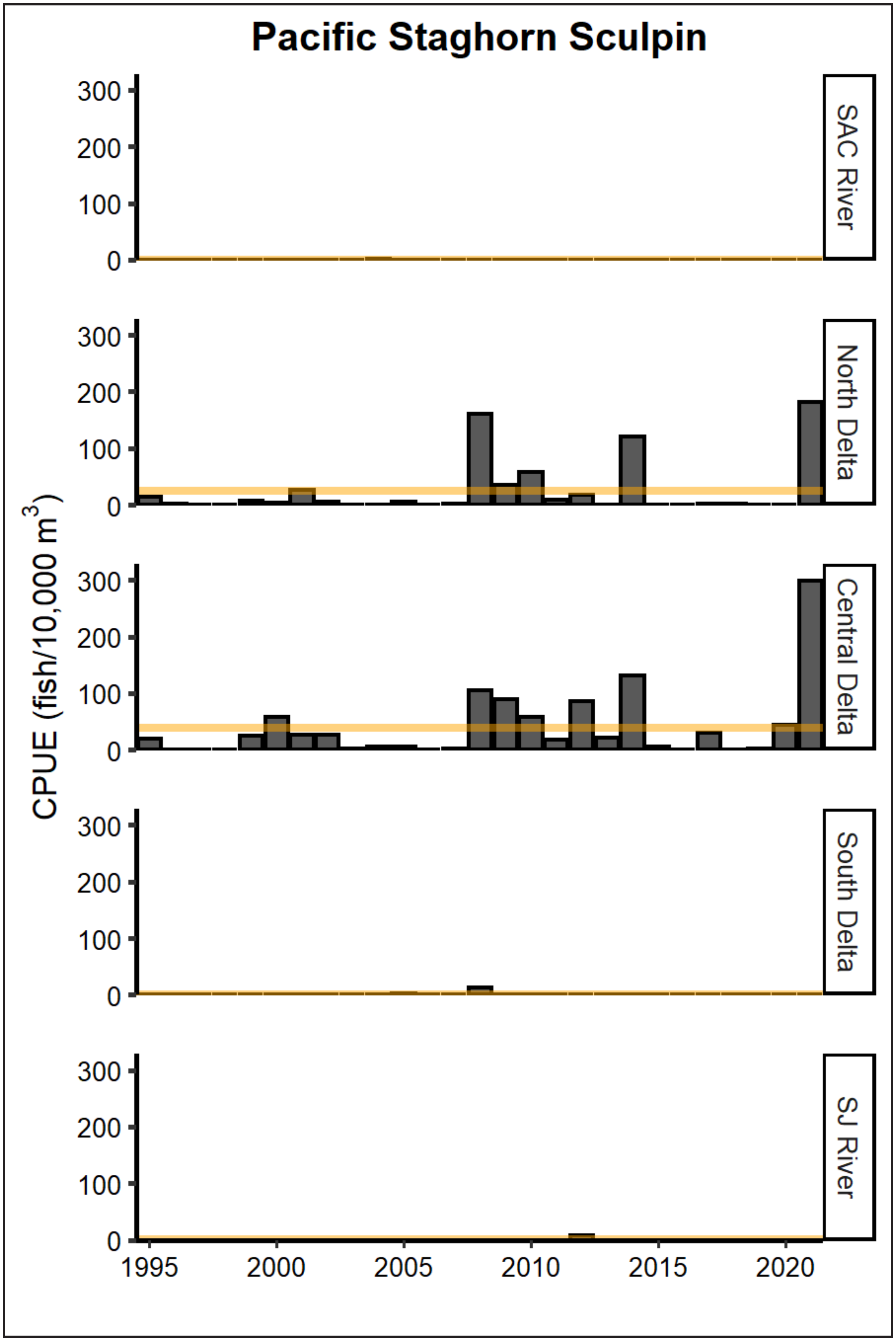

Figure 6: Annual catch-per-unit-effort (CPUE) of Pacific Staghorn Sculpin (Leptocottus armatus) captured in beach seines in the Sacramento and San Joaquin Rivers and the Delta from 1995 to 2021. Horizontal orange lines indicate mean annual CPUE.

Redear Sunfish, like other Centrarchids, thrive in vegetated areas and the 60% increase in submersed and floating aquatic vegetation from 7,100 ac to 11,360 ac in the Delta from 2008 to 2014 (Ta et al. 2017) may have facilitated L. microlophus population growth during that time. What's more difficult to explain is the subsequent CPUE reduction in 2017 and slow rebound since then (Figure 8). Total Delta Inflow in water year 2017 was 2.3 times greater than the average inflow from 1995-2016 ($3.22 \cdot 10^7$ ac ft) (Gartrell et al. 2022) and California's governor declared the drought over in April 2017 (Durand et al. 2020). It is possible that the increased flows in 2017 reduced submerged aquatic vegetation in the Delta which, in turn, may have had a negative effect on the Redear Sunfish population that year. Further investigation about the potential effects of the Delta's "ecological memory" (Schweiger et al. 2019) on Redear Sunfish abundance patterns is recommended. For example, what are the effects of accrued abiotic (e.g., drought, flow and thermal regimes) and biotic (e.g., submerged aquatic vegetation production, shifting fish assemblage structures) processes from past ecosystem dynamics on these and other Centrarchids?

Western Mosquitofish (Gambusia affinis – non-native)

Western Mosquitofish (family Poeciliidae) were introduced to California waters in 1922 as a method of controlling mosquitoes and have since been spread throughout the state by stocking and natural reproduction (Dill and Cordone 1997). They can survive in a wide range of habitats including brackish sloughs, salt marshes, and warm bodies of freshwater (Swanson et al. 1996). Western Mosquitofish prefer shallow and stagnant waters in ponds,

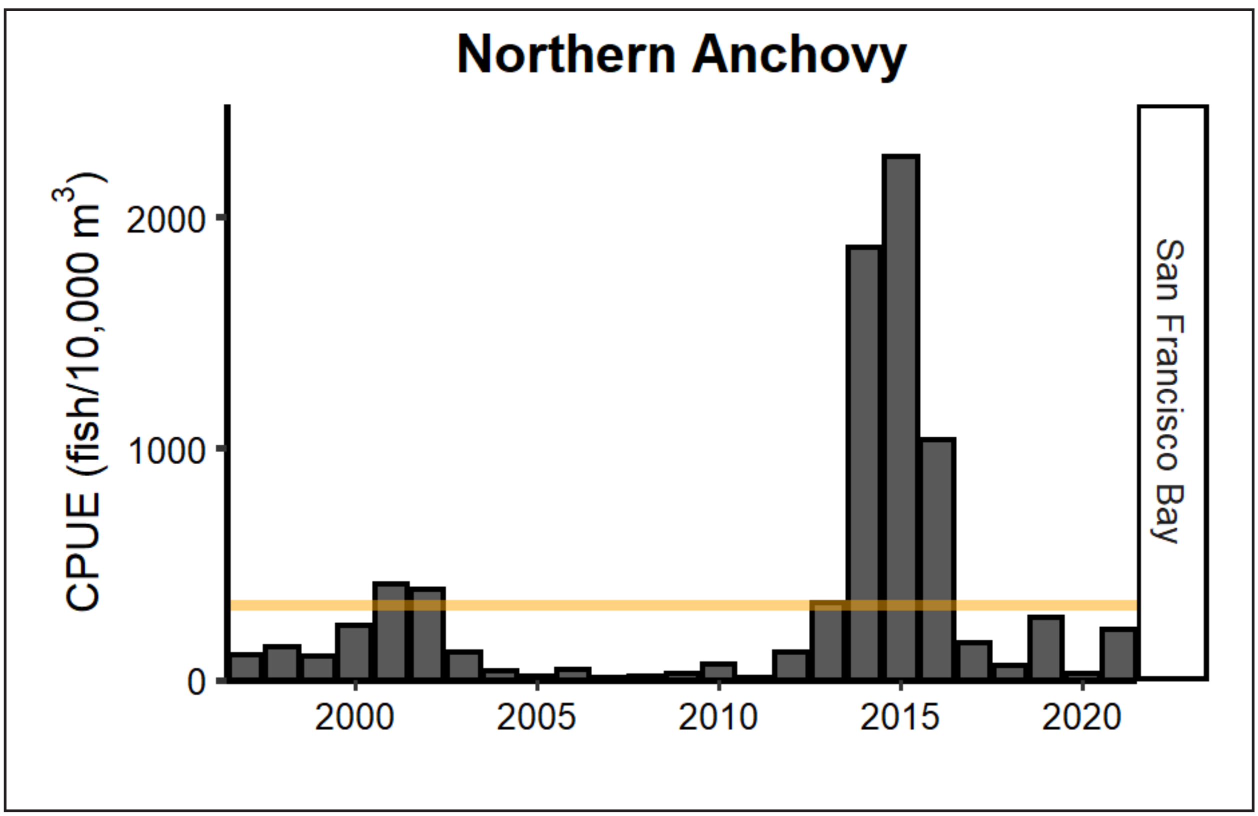

Figure 7: Annual catch-per-unit-effort (CPUE) of Northern Anchovy (Engraulis mordax) in beach seine regions from 1995 to 2021. Northern Anchovy were only captured in the San Francisco Bay region. Hori-

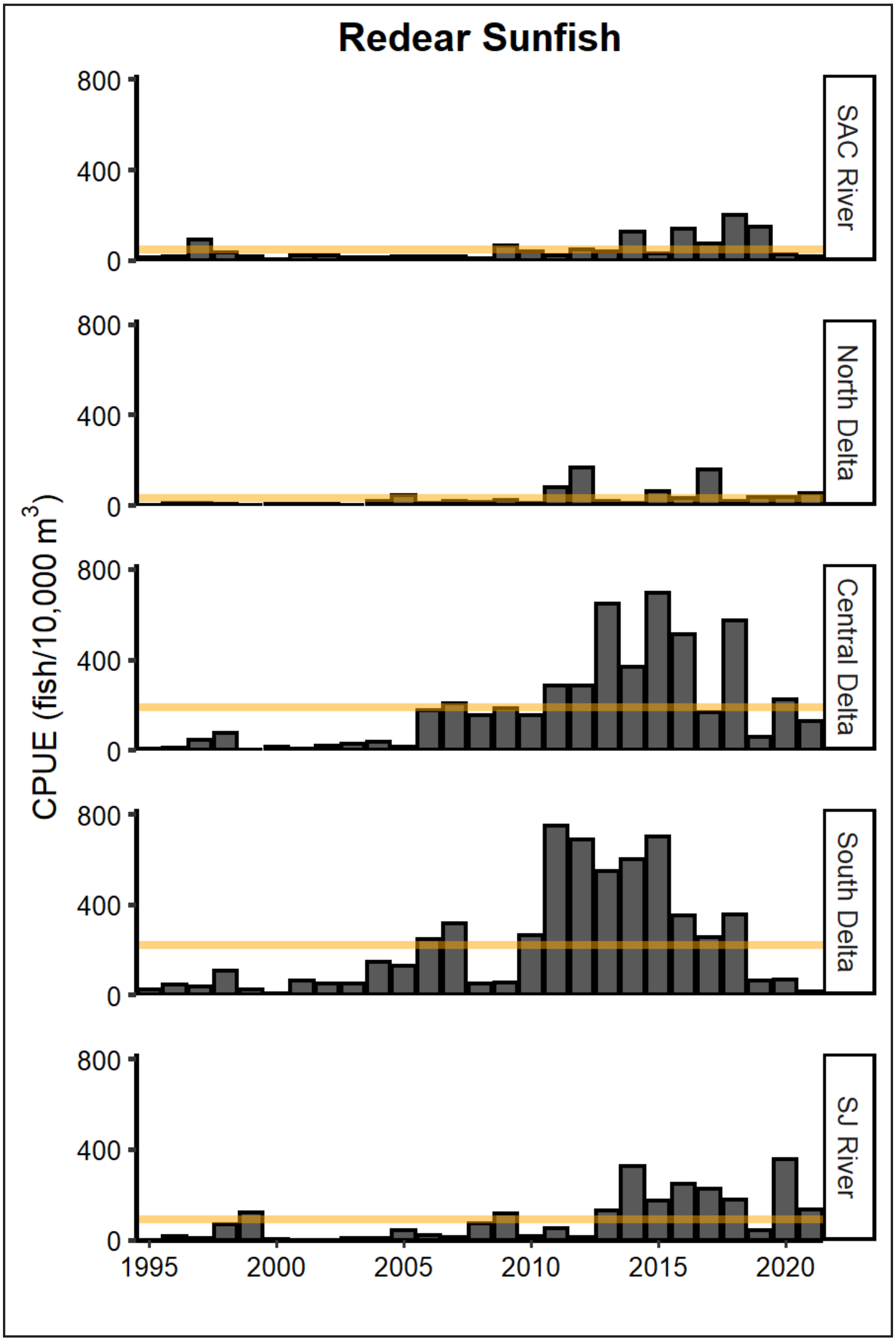

Figure 8: Annual catch-per-unit-effort (CPUE) of Redear Sunfish (Lepomis microlophus) in beach seine regions from 1995 to 2021. Horizontal orange lines indicate mean annual CPUE.

lake edges, and disturbed areas of low elevation rivers and streams (Swanson et al. 1996). They can tolerate water temperatures as low as 0.5°C and high as 42°C, pH levels from 4.7 to 10.2, and salinities up to 58 ppt. However, Western Mosquitofish prefer warm (25-30°C), neutral to alkaline (7-9 pH) fresh or brackish (<25 ppt) waters (Swanson et al. 1996). They are morphologically and physiologically adapted to tolerate hypoxic conditions; they have a flat head, small size, and their oblique mouth allows them to consume oxygen in the diffusion layer of the water surface (Cech et al. 1985). Male Western Mosquitofish mature at ~19-21 mm TL, females at ~24 mm TL (Moyle 2002). Poeciliids are livebearers and spawning in California occurs form April to September (Vondracek et al. 1988). Life expectancy is short and few live longer than 15 months (Krumholz 1948). Since sex is not determined for captured fish, we set the threshold maturity size at 21 mm TL.

Since 1995, we have measured 31,012 Western Mosquitofish ranging in size from 20-95 mm TL, with a median total length of 26 mm (Figure 2). Because these fish can mature at a small size, only 7.0% of fish caught were considered juveniles. The only region with consistent catch of Western Mosquitofish throughout the 27-year timeseries is the Sacramento River (Figure 9). Within this region, sites with high catches are historically off the main river where water is warmer than the main channel. Peak CPUE was observed in 2020 when 930 Western Mosquitofish were caught in the Central Delta region (Figure 9). The largest standardized catch occurred in backwater areas where water temperatures are elevated during summer and fall. Water temperatures were between 21 and 23°C.

Interestingly, a ~5-year cycle of Western Mosquitofish catch peaks were observed for the lower San Joaquin region with peak CPUEs occurring around 2005, 2010, and 2014 (Figure 9). These peaks are driven by elevated catches at three sites that are shallow and vegetated (Routh 132 site) or have sandy bottoms, high flows, and steep banks (Sturgeon Bend and North of Tuolumne sites).

There appears to be no trend in catch of Western Mosquitofish in the South Delta where CPUE was the lowest of all the regions (Figure 9). Given that the South Delta has relatively low flows and warm water temperatures, it is surprising that the catch rates were low. Further investigation is needed to determine if biotic controls (i.e., competition, predation) of Western Mosquitofish populations are stronger in the South Delta compared to other regions. For example, Bluefin Killifish (Lucania goodei) were first observed in the Delta in 2017 by the DJFMP (Mahardja et al. 2020). Subsequent monitoring indicates that L. goodei may be expanding their range in the Delta. Bluefin Killifish and Western Mosquitofish prefer similar habitats and both species have significant dietary overlaps (Taylor et al. 2001). Adult Western Mosquitofish have been known to feed on juvenile Bluefin Killifish in the Florida everglades (Taylor et al. 2001), so continued monitoring of both species in the Delta may help inform future hypothesis-driven scientific research in novel ecosystems.

White Catfish (Ameiurus catus – non-native)

Also known as White Bullhead (catfish is a misnomer; Moyle 2002), White Catfish (family Ictaluridae) were introduced to the San Joaquin River in 1874 and spread rapidly throughout the Central Valley (Dill and Cordone 1997). They inhabit deep lakes and reservoirs and slow-moving reaches of rivers and streams (Moyle 2002). In lotic habitats, they tend to move from deeper (>2 m) habitats during the day to shallow vegetated beds at night (Moyle 2002). In lentic environments during late spring and early summer, they congregate at approximately 3-10 m depth and disperse to deeper habitats during other seasons (Von Geldern 1964). By winter they may be found in water as deep as 30 m as long as temperatures are ≥21°C (Von Geldern 1964). Adults can survive temperatures as warm as 31°C (Kendall and Schwartz 1968) and

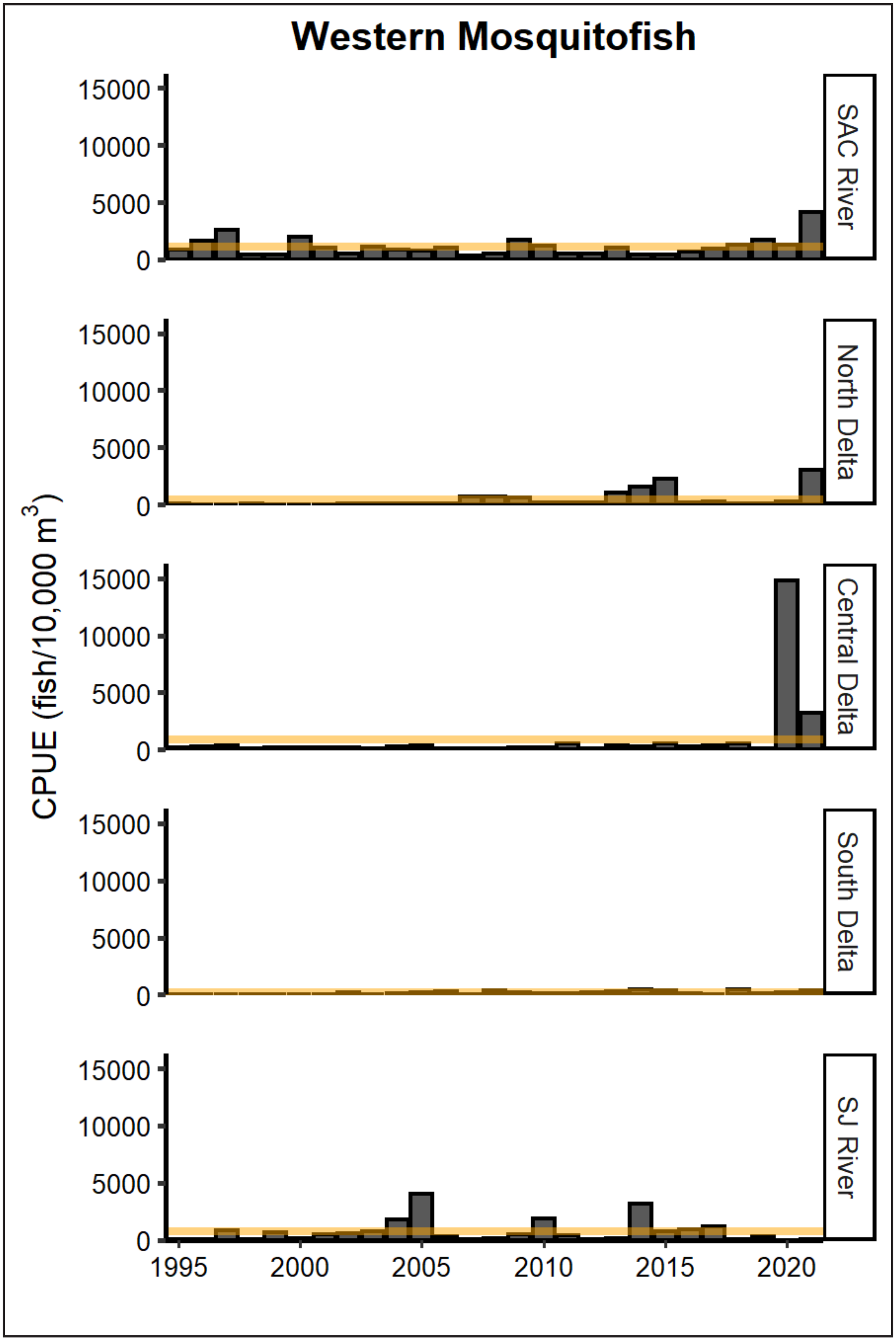

Figure 9: Annual catch-per-unit-effort (CPUE) of Western Mosquitofish (Gambusia affinis) in beach seine regions from 1995 to 2021. Horizontal orange lines indicate mean annual CPUE.

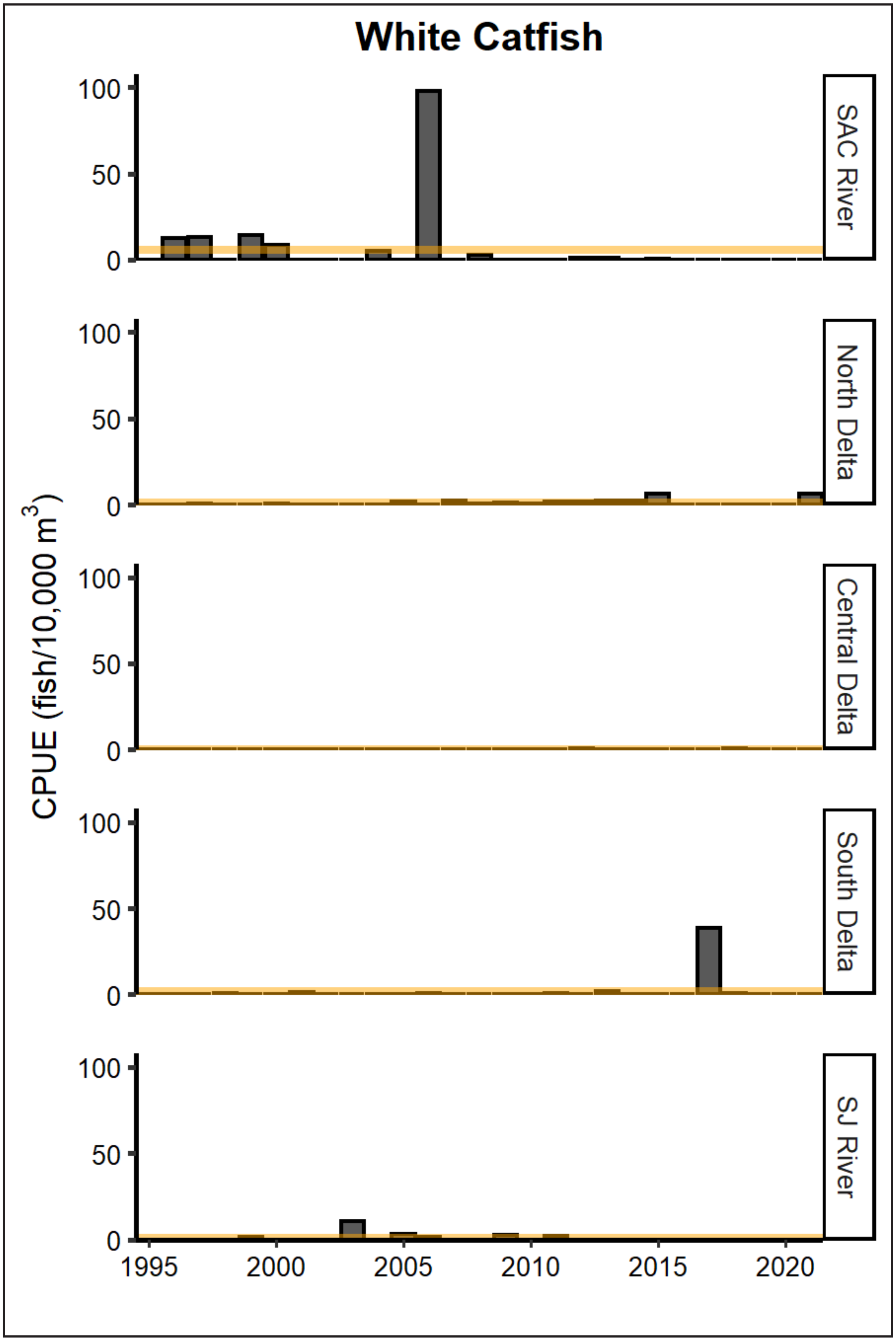

Figure 10: Annual catch-per-unit-effort (CPUE) of White Catfish (Ameiurus catus) in beach seine regions from 1995 to 2021. Horizontal orange lines indicate mean annual CPUE.

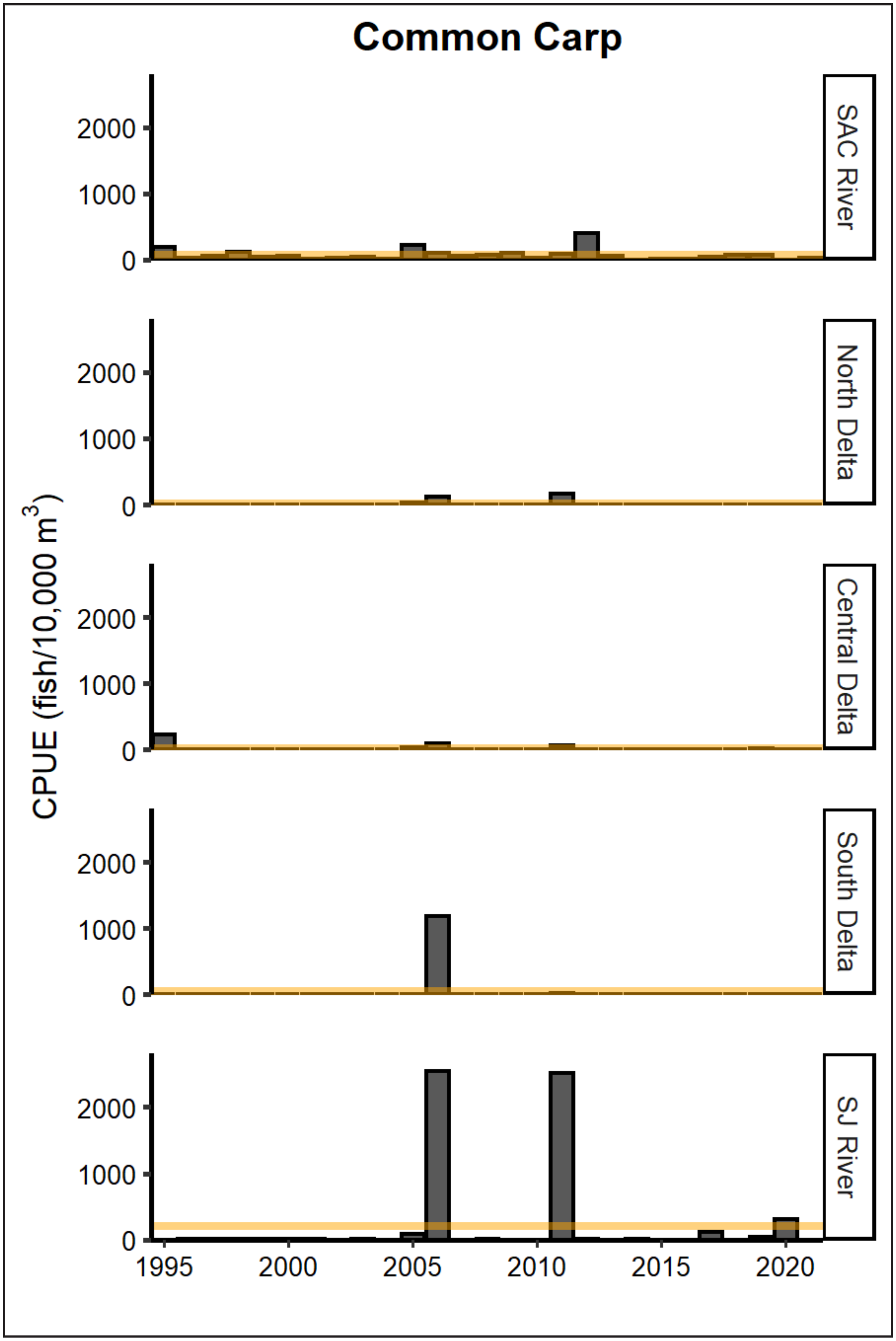

Figure 11: Annual catch-per-unit-effort (CPUE) of Common Carp (Cyprinus carpio) in beach seine regions from 1995 to 2021. Horizontal orange lines indicate mean annual CPUE.

tolerate salinities as high as 14.5 ppt (Ganssle 1966). White catfish mature at approximately 200-210 mm FL when they are 3-4 years old in California (Calhoun 1966). Spawning commences in June or July and can continue as late as September, as long as water temperatures are ≥21°C (Wang 1986). Males construct nests from sand or gravel near cover like that provided by vegetation or rocky areas (Wang 1986).

Since 1995, our seine surveys have captured White Catfish ranging from 25-390 mm FL (Figure 2). Juveniles (<200 mm FL) comprised 93.6% of measured individuals. Peak catch occurred In the Sacramento River in 2006 (Figure 10) due, in large part, to a catch of 138 juveniles (26-33 mm FL range) on 1-Jun 2006 at the Knight's Landing boat launch site. The boat launch is not located directly on the Sacramento River; instead, it connects through a short slough which is usually much warmer and slower moving than the main channel. Also, juveniles from the same brood school for some time after hatching (Simon and Wallus 2003). The slight CPUE increases in 1996-1997 and 1999-2000 (Figure 10) are also attributed to infrequent large catches at the Knight's Landing site. The relatively high catch in the North Delta in 2003 (Figure 10) is driven by the capture of 56 individuals (27-286 mm FL range) at Liberty Island between May and October. Since White Catfish mature at ~200 mm FL (Moyle 2002), only three of those captured in 2003 are classified as adults. The Liberty Island wetland is a 21 km2 freshwater perennial tidal wetland that was created by a levee failure in 1998 (Lehman et. al. 2010). A slightly higher standardized catch magnitude at Liberty Island compared to other Sacramento River sites is not surprising given that Liberty Island has slower moving water that fluctuates tidally. Moving south, White Catfish are rarely sampled in the South Delta; only 17 individuals have been captured in this region over the time period analyzed. The maximum number caught annually (n=3) occurred in 2017(Figure 9).

Common Carp (Cyprinus carpio – non-native)

Common Carp (family Cyprinidae) were first stocked in California waters (Sonoma Valley) in 1872. By 1896 they were widely distributed throughout the state (Moyle 2002). In lentic environments (e.g., lakes and sloughs) Common Carp prefer warm and turbid waters with silty substrates and both submerged and emergent vegetation (Moyle 2002). In rivers, they prefer turbid water and deep pools with soft substrates and high alkalinity (Brown 2000). They can tolerate temperatures ranging from 4-36°C, salinities up to 16 ppt, and dissolved oxygen levels as low as 0.5 ppm (McCrimmon 1968,Becker 1983). Consequently, they are common in eutrophic waters and are oftentimes the first to re-colonize an area after drought (Maiztegui et al. 2019). Common Carp commence reproduction during spring when temperatures rise above 15°C and peak spawning occurs between 19-23°C (Becker 1983). Eggs are deposited on aquatic plants and post-hatched larvae seek aquatic vegetation about two weeks later (Becker 1983). They remain concealed in vegetation until juveniles are approximately 70-100 mm long (Becker 1983). Common Carp can grow to large sizes due to their long life span (12-15 years on average) and rapid growth (~100-120 mm annually) (Moyle 2002).

From 1995 to 2021 DJFMP beach seine surveys have measured sizes for 3,255 Common Carp (Figure 2). Fork lengths ranged from 25-800 mm and the median was 65 mm (Figure 2). Of those captured, 99.5% were shorter than the length at maturity which is set at 540 mm TL (Mutethya et al. 2020). Note that beach seines are poorly suited for capturing large fish like adult Common Carp, so these data do not mean that few fish are reaching maturity. A visual inspection of Figure 11 reveals no obvious temporal CPUE trends. Elevated standardized catch is observed in nearly all regions in 2006 and 2011 (Figure 11). In early 2006, a series of large storms caused flooding and damage to levees. Common Carp spawn in shallow weedy areas and prefer areas that have recently flooded (Moyle 2002) and it is possible reproductive output in the Delta was high in 2006 due to the storms. Possible reasons for peak catch in in the San Joaquin River region in 2011 are less apparent, however that year is considered a “wet” year which means flooding into vegetated areas likely occurred. The vast majority of these fish (94.6%) were captured at a single site (Mossdale boat landing). This site is located in a section of the San Joaquin River were the river transitions from sandy beaches upstream to rip-rapped levees downstream where aquatic vegetation is abundant. It is possible that Common Carp spawning is concentrated above the Mossdale boat launch where flooding occurs regularly. Offspring would be expected to migrate to downstream vegetated areas for rearing and cover.

Conclusion

Since 1995, the DJFMP nearshore fish survey has documented the abundance and distribution of non-salmonid species year-round in nearshore habitats of the Delta, lower Sacramento and San Joaquin Rivers, and Bay. Here we examine the annual abundance patterns of four native and four non-native species captured in the Bay and Delta with beach seines from 1995 to 2021. Observed trends are linked to fish life histories, habitat preferences, regional habitat conditions, and climatic events. Data interoperability and free exchange of analyses provided by this and other Interagency Ecological Program monitoring efforts helps inform insightful and high quality science needed to reconcile the needs for a reliable and sustainable water supply and a functioning Bay-Delta ecosystem. Indeed, over 30 peer-reviewed scientific journal articles and over 50 grey literature reports have been published using DJFMP data. For example DJFMP data has enabled scientists to document species declines (Sommer et al. 2007), species introductions (Mahardja et al. 2020), and shifts in species assemblages (Majardha et al. 2017). Therefore, the DJFMP nearshore fish survey is useful to scientists studying novel ecosystem ecology and remains a critical component of California water and Bay-Delta adaptive management.

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2020 and 2021 Delta Juvenile Fish Monitoring Program Salmonid Annual Report

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Introduction

Intraspecific diversification of Pacific salmon (Oncorhynchus spp.) has occurred for the past six million years (Waples et al. 2008). At or near the southern end of their global distribution, California Central Valley salmonids have evolved complex life histories in response to the highly dynamic and variable environmental conditions in the Sacramento-San Joaquin Delta watershed including a fall, late-fall, winter, and spring run of Salmon (O. tshawytscha; Yoshiyama et al. 1998) and summer and winter steelhead runs (McEwan 2001). Due to a combination of habitat loss and degradation (especially blockage of historically available habitat, water diversions, and altered flow and water temperature regimes), harvest pressures, and introduced competitors, predators, and diseases since Euro-American colonization, only small fractions of historical population numbers currently remain of these iconic species (NMFS 2014). The summer steelhead (O. mykiss) run has been extirpated,.tThe Chinook Salmon winter-run Distinct Population Segment (DPS) is listed as endangered and both the spring-run Chinook Salmon DPS and winter-run steelhead DPS are listed as threatened under the federal Endangered Species Act. The Central Valley fall-run/late fall-run Chinook Salmon DPS is currently unlisted and supported heavily by hatchery supplementation (Huber and Carlson 2015, Sturrock et al. 2019).

California Central Valley Chinook Salmon and steelhead use the Sacramento-San Joaquin Delta (Delta) for rearing and migration. Juvenile salmonids must travel from upstream natal tributaries through the Delta before exiting the San Francisco Estuary and entering the Pacific Ocean through the Golden Gate. Approximately 27% of water flowing through the Delta is earmarked for the Central Valley Project (CVP) and State Water Project (SWP) to supply water to over 29.5 million Californians and 3.75 million acres of farmland (LAO 2008). These water deliveries have the potential to negatively affect salmonid rearing, survival, and migration pathways throughout the Delta (Kimmerer 2008, NMFS 2009, 2019). The impacts of these water operations depend on the timing and distribution of salmonids in the system which vary interannually (Munsch et al. 2019). Since 1976, the U.S. Fish and Wildlife Service's Delta Juvenile Fish Monitoring Program (DJFMP) has monitored the annual timing, distribution, relative abundance, and survival of juvenile salmonids and other fishes throughout the Delta to improve our understanding of salmonid ecology and mitigate the impacts of the CVP and SWP water export operations on their populations.

The purpose of this report is to summarize juvenile salmonid boat trawl and beach seine sample data obtained during the 2020 (Aug 2019 to Jul 2020) and 2021 (Aug 2020 to Jul 2021) DJFMP monitoring years (MYs); information for our non-salmonid catch trends can be found in the DJFMP Nearshore Fishes Annual Report also presented in this newsletter. We present status and trend information about: 1) immigration into the Delta from the Sacramento and San Joaquin Rivers; 2) residency within the Delta; and 3) emigration from the Delta into the San Francisco Bay. The complete DJFMP dataset, including 1) a complete description of sampling procedures, 2) non-salmonid catch data, and 3) environmental data not included in this report, is available at DJFMP's Environmental Data Initiative Data Portal (IEP et al. 2022).

Methods

Over the years as adaptive management information needs evolve, the DJFMP has used a variety of gear types and sample frequencies throughout the year to examine the temporal and spatial distribution of fishes in lower river mainstem in-channel habitats and Delta and San Francisco Bay littoral zones. A complete description of the historical and current methods is available at the DJFMP Environmental Data Initiative Data Portal (IEP et al. 2022). The technical report produced by Dekar et al 2013 contains detailed descriptions of sampling equipment used.

During the 2020 and 2021 monitoring years (MYs) the DJFMP used a combination of beach seine and surface trawls (mid-water [MWT] and Kodiak trawls [KDT]) sampling methods to monitor the distribution of juvenile salmonids (Table 1, Table 2, Figure 1). The DJFMP sampled at 58 beach seine sites and three trawl sitesand located throughout the Delta and Estuary (Table 1, Table 2, Figure 1). The beach seine sites were stratified into seven geographic regions, including the (1) Lower Sacramento Seine, (2) North Delta Seine, (3) Central Delta Seine, (4) South Delta Seine, (5) Lower San Joaquin Seine (Delta Entrance Seine from San Joaquin River), (6) Bay Seine (San Francisco and San Pablo Bays), and the (7) Sacramento Seine (Delta Entrance Seine from Sacramento River) (Table 1, Table 2, Figure 1). All monitoring was conducted year-round during daylight hours (between 06:00 and 18:00 PST). Trawl sites were located at the entry (Sherwood Harbor on the Sacramento River and Mossdale on the San Joaquin River) and exit (Chipps Island) points of the Delta (Figure 1). From 2002-2005 and 2009-2019 a total of 21 seine sites in the North Delta region were sampled at Liberty Island (Figure 1; see Steinhart et al. 2021 for more information).

Seine regions were delineated by proximity to canals or water bypasses where fish may be diverted from historical migration routes. We used a 15.2 m x 1.3 m beach seine net with a 3 mm delta square mesh, a 1.2 m bag in the center of the net, and a float line and lead line attached to 1.8 m tall wooden poles on each side. In general, beach seines were deployed from the shoreline by two crew members within unobstructed habitats including boat ramps, mud banks, and sandy beaches.

All seine sites were scheduled to be sampled once per week throughout the MY except for: (1) San Francisco and San Pablo Bay Seine sites (scheduled once every two weeks), and (2) Sacramento Seine sites (scheduled three times per week from 1-Oct through the last week of January; Table 21, Figure 1). The reason for the increased effort in the Sacramento region during fall and winter was to strategically monitor federal Endangered Species Act (ESA) endangered winter-run Chinook Salmon and inform Delta Cross Channel (DCC) operations.

The DJFMP exclusively used a MWT at the Chipps Island Trawl site and a KDT at the Mossdale Trawl site (Figure 1). The Sacramento River Trawl site used a KDT from October to March and a MWT for the remainder of each field season (Table1). The KDT was used in place of the MWT at the Sacramento site to maximize the capture of larger and less abundant runs of Chinook Salmon (Brandes et al. 2000). The USFWS conducts trawl samples from July to March and the California Department of Fish and Wildlife (CDFW) samples April through June (Table 1, Figure 1). The typical effort from May to June is to sample 5 days per week in April, May and first two to three weeks of June (Table 1). The increased sampling effort is required to adequately monitor juvenile salmon outmigration. Mossdale data collected from both DJFMP and CDFW monitoring programs are included in this report. Note that no trawl sampling occurred from April to June in MY 2020; In MY 2021, trawl sampling started in mid-May.

The Sacramento MWT net fished approximately 30-m behind the boat and was composed of six panels, each decreasing in mesh size towards the cod end.The stretched mesh size for each panel rangedfrom 20.3 cm at the mouth to 0.6 cm just before the cod end.The cod end was composed of 0.3 cm weave mesh. The fully extended mouth sizeis 4.15 m tall x5.00mwide. The MWT net used at the Chipps Island trawl site was different than the MWT net used at Sacramento.The Chipps MWT net fishedapproximately 45-m behind the boatThere were five panels, each with decreasing mesh size towards the cod end.The stretched mesh size rangedfrom 10.2 cm at the

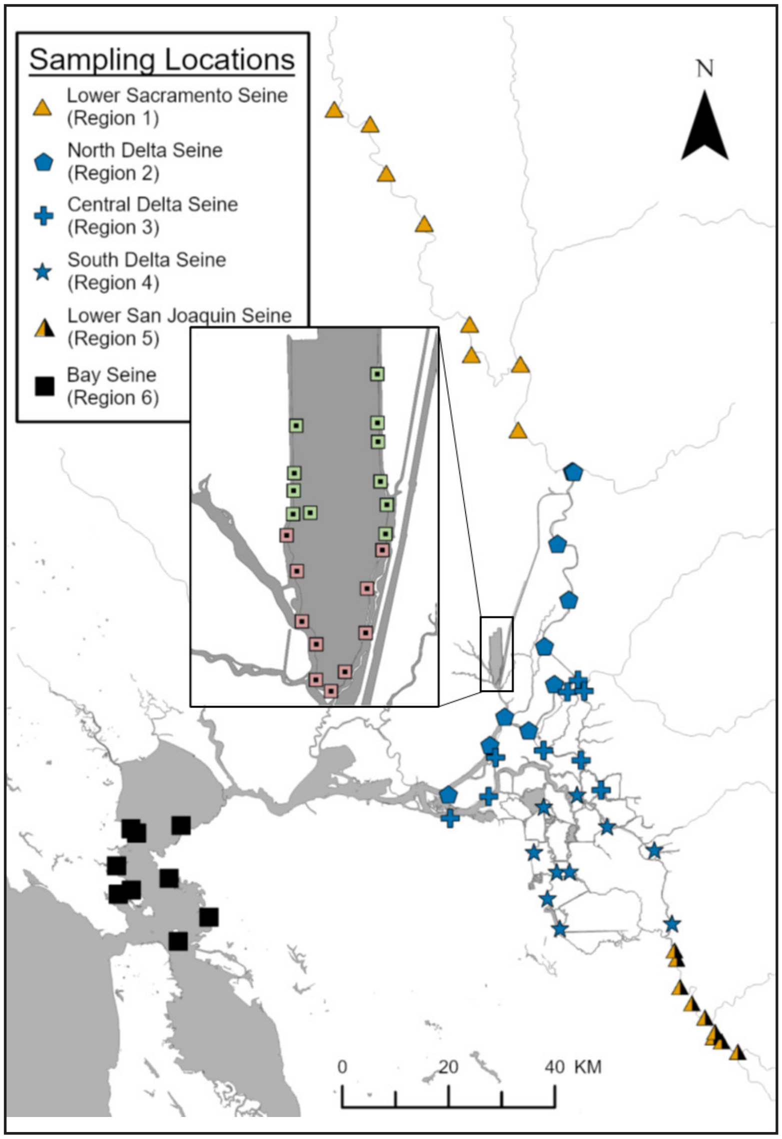

Figure 1: Map of the United States Fish and Wildlife Service (USFWS) Delta Juvenile Fish Monitoring Program (DJFMP) surface trawl and beach seine sampling sites and regions in the Sacramento-San Joaquin Delta and San Francisco Bay. Data from Liberty Island seine sites are in the North Delta region and included in this report for monitoring years 2002-2005 and 2009-2019.

mouth to 2.5 cm just before the cod end. The cod end mesh size for the Chipps Island MWT net was 0.79 cm and the fully extended mouth size was 7.64 m tall x 9.65 mwide. The KDT nets usedby the DJFMP at the Mossdale and Sacramento trawl sites fishedapproximately 31-m behind the boats and were composed of five panels, each decreasing in mesh size towards a live box at the cod end. The stretched mesh size for each panel rangedfrom 5.1 cm at the mouth to 0.6 cm just before the live box. The live box (36cm wide X36 cm tall x49cm long) was composed of 0.18cm thick aluminum perforated with numerous 0.46cm diameter holes. The KDT nets were connected to two boats using a 2.3 m rope bridle (2.4-cm diameter) attached to a 30.5 m tow rope (0.95cm diameter) on each side of the net.

We typically conducted a maximum of ten 20-minute tows at each trawl site. The distance traveled during each tow was recorded using a mechanical flow meter (General Oceanics, model 2030). All tows were performed facing upstream in the middle of the channel at the Sacramento and Mossdale Trawl sites, which have reach lengths of approximately 6.5 km and 3 km, respectively. In contrast, Chipps Island tows (~4 km reach length) were conducted facing both upstream and downstream in the north, south, and middle portions of the channel regardless of tidal stage. All channel lanes at Chipps Island are sampled each day but the order and number of tows per lane is randomly selected (two lanes receive three tows each and one lane receives four tows per day).

While not presented here, water quality variables (water temperature, conductivity, dissolved oxygen, and turbidity) were measured for each trawl or seine haul. Also, Secchi depths were measured for each trawl and substrate compositions and flow velocities were measured for each seine haul.

Sampled salmonids greater than or equal to 25 mm fork length (FL) were measured to the nearest millimeter. The race of all juvenile Chinook Salmon was determined using the river Length at Date Criteria (LDC) developed by Fisher (1992) and modified by Greene (1992), except for individuals captured in the San Joaquin River Basin (i.e., Mossdale trawl site and Lower San Joaquin River Seine Region; Table 1, Table 2, Figure 1). These individuals were classified as non-winter-run regardless of LDC since winter-run Chinook Salmon are not known to currently occur in the San Joaquin River watershed (Yoshiyama et al. 1998). If more than 50 individuals of a Chinook Salmon race were captured, a subsample of 50 individuals were randomly selected and measured for FL. The remaining fish were enumerated but not measured for size. All juvenile salmonids with adipose fin clips, pelvic fin clips (used to mark a specific broodstock of winter-run hatchery fish), and other forms of marks or tags (e.g., stain dye, disc tags, acoustic tags) were recorded as marked along with their respective marking and(or) tag type. All juvenile Chinook Salmon with adipose fin clips and intact pelvic fins were considered hatchery-origin and transported to the Lodi Fish and Wildlife Office for coded wire tag extraction and race and hatchery-origin determination (by cross-referencing data with the Regional Mark Information System database [RMIS 2022]). Juvenile Chinook Salmon with adipose and pelvic fin clips were recorded as hatchery-reared winter-run and released. Adipose fin-clipped juvenile steelhead were recorded as hatchery-origin and released soon after capture.

To compare the timing, distribution, and relative abundance of juvenile salmonids, we calculated mean monthly and annual catch-per-unit-effort (CPUE, catch per water volume sampled by seine haul or trawl tow) values for each seine region and trawl site. Before estimating CPUE, we excluded fish count data that were obtained during incomplete sampling procedures or technical difficulties like net twists or major cod-end blockages (i.e., gear condition code >2 in the DJFMP dataset [IEP et al. 2022]) or flow meter technical difficulties. For seine surveys, we removed samples (n=32 out of total of 43,122 samples) with missing volume estimates and volume outliers that were identified by the exceedance of the standard minimum and maximum seine net dimensions set by the DJFMP standard operating procedure for seine surveys. For trawls, volume outliers (n=238 out of a total of 104,139 samples) were identified as values outside of the normal volume range of DJFMP trawls (1,000-50,000 m3). All adipose fin-clipped juvenile salmonids were treated as marked hatchery fish in our dataset. Salmonids used for special studies that possessed other marks or tags (e.g., stain dye, disc tags, acoustic tags), were excluded from our analyses (n=6 fish total). Since 1998 (brood year 1997), all juvenile winter-run Chinook Salmon and steelhead from Central Valley hatcheries have been adipose fin-clipped so all unmarked individuals from these taxa were classified as natural-origin (USFWS 2011, NMFS 2014). For juvenile Chinook Salmon identified as non-winter-run, we estimated the number of hatchery- and natural-origin juveniles using the methods detailed in Graham et al. (2018) since hatchery-origin individuals are not all marked.

Calculations of mean monthly and annual CPUE values were performed in a manner to avoid overweighting sampling sites due to differences in sampling frequencies. First, we calculated CPUE values for each taxon and origin type (e.g., hatchery-origin winter-run Chinook Salmon, natural-origin winter-run Chinook Salmon, hatchery-origin steelhead, natural-origin steelhead) by dividing the total number of individuals captured by seine or trawl survey by the total water volume sampled:

$$\text{Sample CPUE}_{ij} = \frac{\text{Count}_{ij}}{\text{Sample Volume (m}^3\text{)}}$$

$$\text{Seine Volume}\left(\text{m}^3\right) = \text{Seine Width(m) x Seine Length(m) x Seine Depth (m)x 0.5}$$

where i indexes species and j indexes sites.

We then calculated mean monthly CPUE values within sampling sites:

$$\text{Monthly CPUE}_{ij} = \frac{\sum_{\text{site:month}} \text{Sample CPUE}_{ij}}{N}$$

where i indexes species, j indexes sites, and N equals then number of samples per site.

We then averaged the mean monthly CPUE values for seine sites across their respective sampling region or trawl site within each month, to obtain the mean monthly CPUE for each seine region and trawl site:

$$\text{Monthly CPUE}_{ik} = \frac{\sum_{\text{region:month}} \text{Monthly CPUE}_{ij}}{N}$$

where i indexes species, j indexes sites, k indexes seine regions or trawl sites, and N equals the number of regions sampled

Next, we calculated mean annual CPUE values for each seine region and trawl site by averaging monthly CPUE values for each seine region and trawl site across months within each MY. For data presentation purposes, mean annual CPUE values were converted to fish per 10,000 m3 by multiplying the mean monthly CPUE by 104

$$\text{Annual CPUE}_{ik} = \frac{\sum_{\text{region:year}} \text{Monthly CPUE}_{ik}}{N} \text{ x 10,000}$$

$$\text{Trawl Volume}(m^3) = \text{Flow Meter Revolutions} \times 0.026873(m/\text{revolution}) \times \text{Net Mouth Area}(m^2)$$

where i indexes species. k indexes seine regions or trawl sites, and N equals the number of calendar months sampled.

Results and Discussion

Monitoring Disruptions - Implementation of COVID-19 workplace safety policies (beginning March 2020), unhealthy air quality from wildfire smoke, and low water levels in the San Joaquin River curtailed monitoring activities. The 2021 MY was more disrupted than MY 2020 and monitoring in the San Joaquin River Basin was disrupted more than in the Sacramento River Basin. For MY 2020 (Aug 2019 to Jul 2020), 63% and 10% of scheduled beach seine and trawl surveys were cancelled, respectively. For MY 2021 (Aug 2020 to Jul 2021), 65% and 33% of scheduled beach seine and trawl surveys were cancelled, respectively. Mossdale trawl surveys were suspended from 16-Mar until the end of the MY (31-Jul, 2020) and San Joaquin seine surveys were canceled from 17-Mar to 1-Jul, 2020. Bay seine surveys were conducted for 23 days in MY 2020 and 17 days in MY 2021 (52 days per MY is normally scheduled). The last day that Bay sites were surveyed in MY 2020 was 9-Mar due to implementation of safety protocols. In MY 2021, Bay seine sampling was paused again from 17-Nov to 11-May due to safety concerns.

Hydrological Conditions - According to the California Department of Water Resources' Sacramento Valley water year (WY) index, WY's 2020 and 2021 are classified as dry and critically dry types, respectively, in both the Sacramento and San Joaquin valleys, Total Delta inflow was 40% (WY 2020) and 32% (WY 2021) of the long-term average Delta inflow from 1995-2018 (3.40·107 ac ft) (Gartrell et al. 2022). It is important to note that WY 2019, the brood year for age-1 salmonids captured in 2020, was classified as a wet water year type in both valleys.

Delta Immigration from the Sacramento River Basin - During the 2020 and 2021 MYs, we documented winter-run juvenile Chinook Salmon (according to LDC) entering the Delta from the Sacramento River(Sherwood Harbor trawl site; Figure 1) from 30-Sep to 27-Feb and 9-Nov to 18-Mar, respectively (Figures 2 and 3). A strong association exists between the onset of significant juvenile winter run sized Chinook salmon outmigration and the first day of 400 m3s-1 measured at Wilkins Slough (rkm 190) (del Rosario et al. 2013).

Table 1. Scheduled monthly sampling matrix schedule indicating number of sampling days per week for trawls (a value of 0.5 indicates one sample every two weeks). Sampling methods include mid-water trawl (MWT) and Kodiak trawl (KDT) in the Sacramento River (Sac R), San Joaquin R (SJR), and at Chipps Island (Delta) which is located downstream of the confluence of the Sacramento and San Joaquin Rivers. . See text for details about monitoring disruptions.

Trawl Region/Site	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Sac R/Sherwood MWT	0	0	0	5	5	3	3	3	3	0	0	0
Sac R/Sherwood KDT	5	5	5	0	0	0	0	0	0	3	3	5
Delta/Chipps Island MWT	5	5	5	5	5	2	3	3	3	3	3	5
SJR/Mossdale KDT1	3	3	3	5	5	3-5	3	3	3	3	3	3

Table 2. Scheduled monthly sampling matrix schedule indicating number of sampling days per week for beach seines. Beach seine hauls were conducted in the Lower Sacramento River (SR1), North Delta (SR2), Central Delta (SR3), South Delta (SR4), San Joaquin River (SR5), San Francisco Bay (SR6) and Sacramento Region (SR7). See text for details about monitoring disruptions.

Seine Region/Site	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
SR 1/Lower Sac R Seine	1	1	1	1	1	1	1	1	1	1	1	1
SR 2/North Delta Seine	1	1	1	1	1	1	1	1	1	1	1	1
SR 3/Central Delta Seine	1	1	1	1	1	1	1	1	1	1	1	1
SR 4 /South Delta Seine	1	1	1	1	1	1	1	1	1	1	1	1
SR 5 /SJR Seine	1	1	1	1	1	1	1	1	1	1	1	1
SR 6 /Bay Seine	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
SR 7/Sac Seine	1	0	0	0	0	0	0	0	0	3	3	3

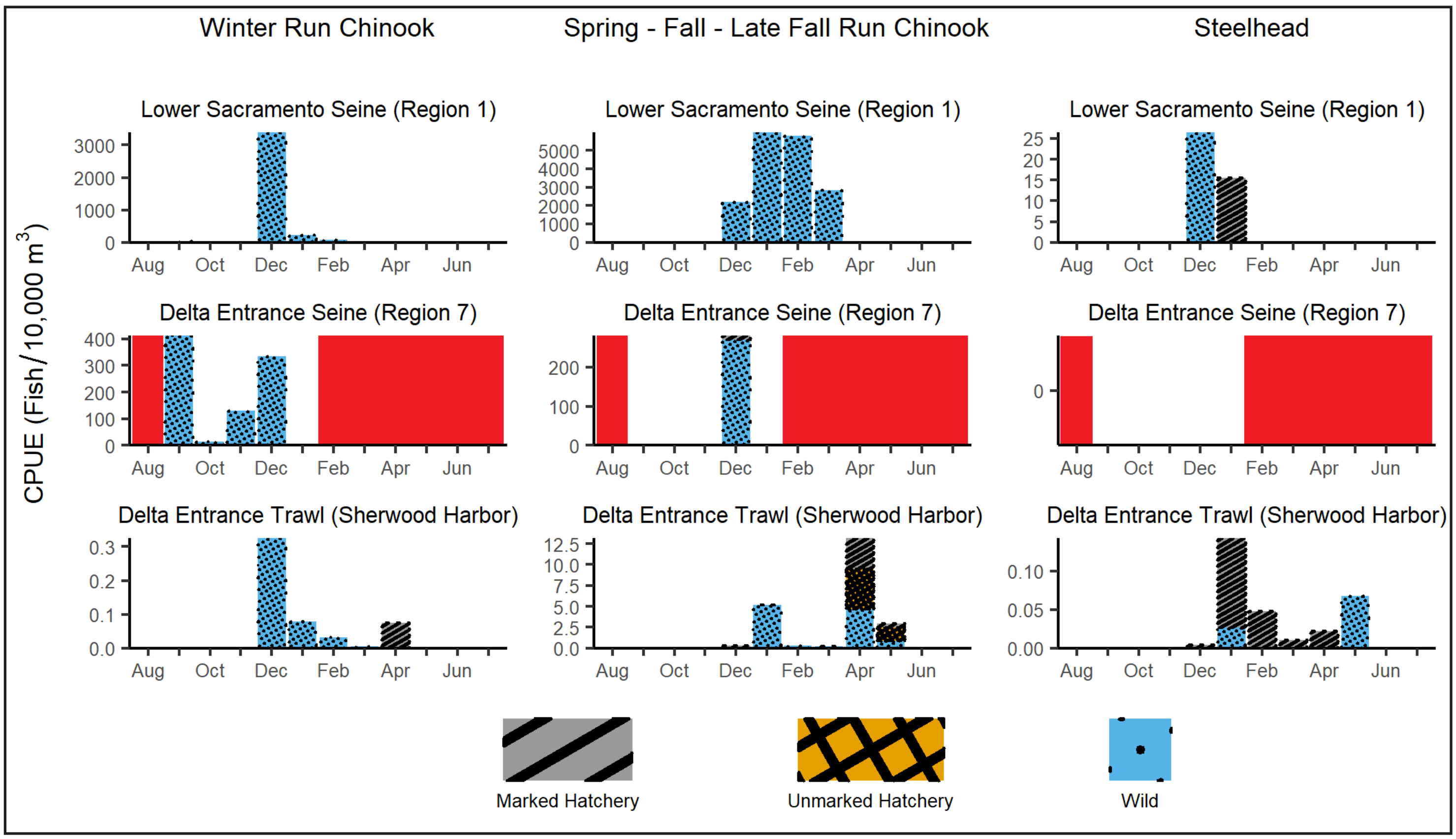

Figure 2: Monthly catch-per-unit-effort (CPUE) for hatchery- and natural-origin juvenile salmonids entering the Sacramento-San Joaquin Delta from the Sacramento River basin during the 2020 monitoring year (August 2019 to July 2020). The red shaded areas indicate periods of no sampling.

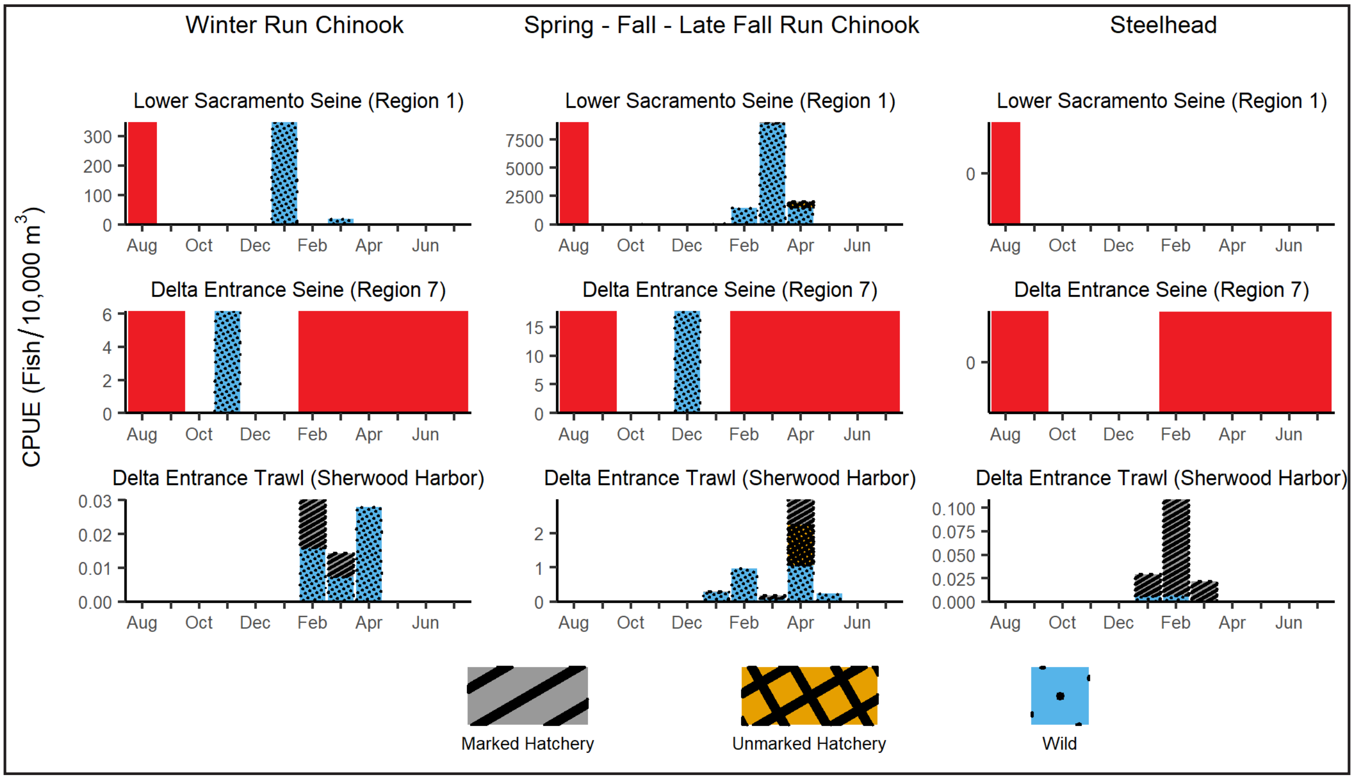

Figure 3: Monthly catch-per-unit-effort (CPUE) for hatchery- and natural-origin juvenile salmonids entering the Sacramento-San Joaquin Delta from the Sacramento River basin during the 2021 monitoring year (August 2020 to July 2021). The red shaded areas indicate periods of no sampling.

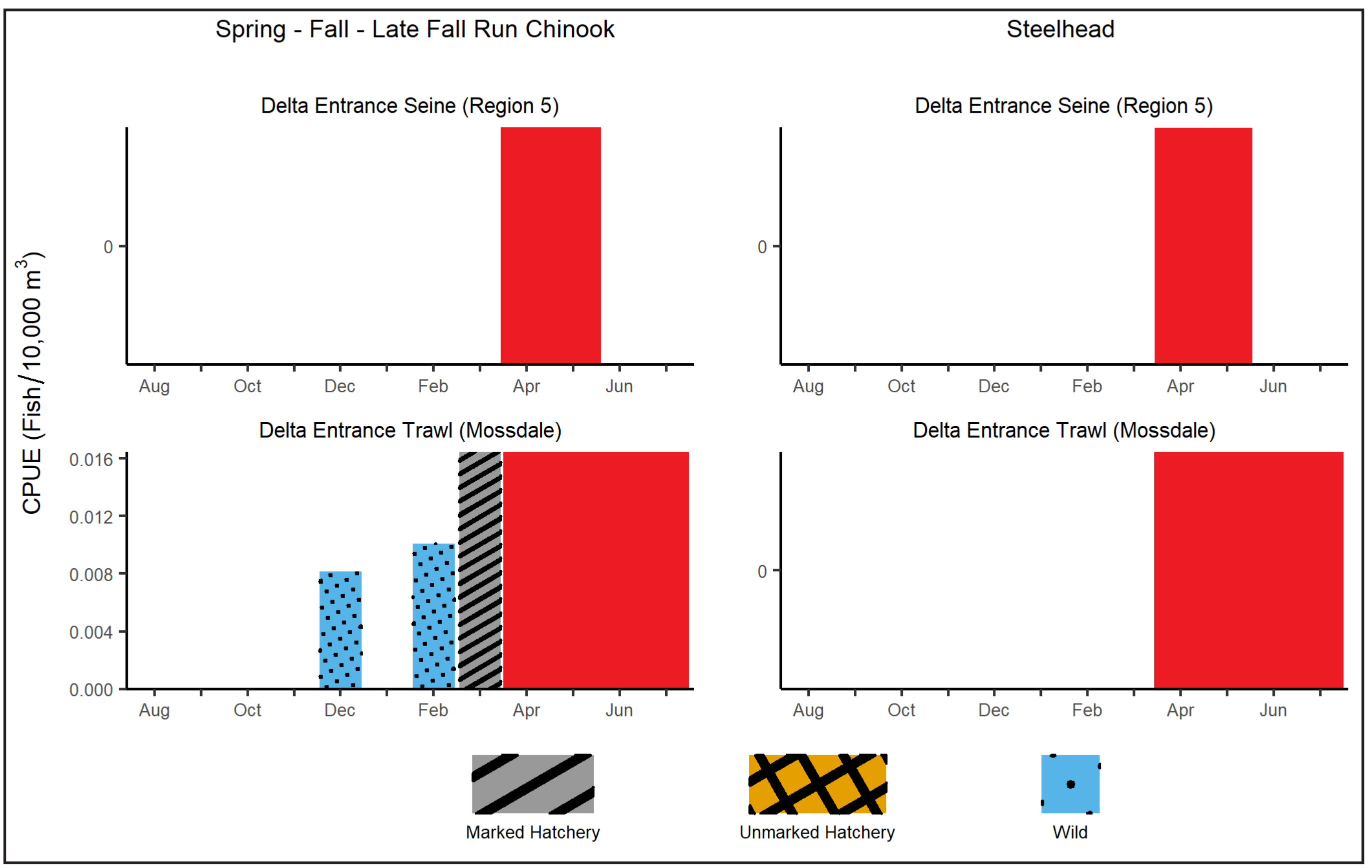

Figure 4: Monthly catch-per-unit-effort (CPUE) for hatchery- and natural-origin juvenile salmonids entering the Sacramento-San Joaquin Delta from the San Joaquin River basin during the 2020 monitoring year (August 2019 to July 2020). The red shaded areas indicate periods of no sampling.

Consistent with our peak catch in December for MY 2020 (Figure 2), this flow value was initially surpassed in early December 2019 (peak of 421.9 m3s-1 on 9-Dec). The threshold flow was never reached in MY 2021; however, flows surpassed 300 m3s-1 in late January and early February 2021 (peak of 345.5 m3s-1 on 30-Jan) which is consistent with peak winter run Chinook Salmon catch in February for MY 2021 (Figure 31). Peak Delta entrance seine survey catch occurred earlier than that observed for trawl surveys (Figures 2 and 3) which is not surprising since less smolts and more fry and parr are consistently sampled by seines.

Winter-run Chinook Salmon hatchery releases occurred in March for MY 2020 (RMIS 2022) and were detected in the Delta during March and April (Figure 2). For MY 2021 winter-run Chinook Salmon hatchery releases occurred in February and March and were detected in the Delta during those same months only (Figure 3). We observed a higher proportion of hatchery fish caught in trawls compared to seines for both MYs (Figures 2 and 3). This trend has been observed across multiple years in this region and might be the result of body size and habitat use differences between natural- and hatchery-origin fish (Huber and Carlson 2015, Roegner et al. 2016).

Spring-, fall-, and late fall-run juvenile Chinook Salmon (according to LDC) were detected from 8-Nov to 19-Jun during the 2020 MY (Figure 2) and from 20-Oct to 3-Jun during the 2021 MY (Figure 3). At seine sites (Figure 1), peak relative abundance for MY 2020 was observed in January and February; trawl relative abundance peaked in April (Figure 2). For MY 2021 peak relative abundance at seine sites (Figure 1) occurred in March and trawl relative abundance peaked in February and April (Figure 3). For MY 2020 the proportion of hatchery-origin fish in trawl catches (Figure 3) coincided with the timing of hatchery releases, which mostly occurred from the months of December through May (RMIS 2022). For MY 2021 trucked hatchery releases above the Delta mostly occurred from January to April (RMIS 2022).

Juvenile steelhead were detected from 12-Dec to 22-May during MY 2020 (Figure 2) and from 29-Dec to 11-May during MY 2021 (Figure 3). In MY 2020, their relative abundance peaked in December for the Lower Sacramento River seine sites and in January for the Delta entrance trawl surveys (Figures 1, 2). For the 2021 MY, steelhead were not captured at the lower Sacramento River seine sites or Delta entrance seine sites (Figures 1 and 3). However, O. mykiss were captured at the Delta entrance trawl site from the Sacramento River (Sherwood Harbor, Figure 1) where relative abundance peaked in Jan 2022 (Figure 3). In MY 2020 natural-origin steelhead accounted for 21.0% of 71 total steelhead captured at the Lower Sacramento River seine sites and Sherwood Harbor trawl site (Figure 1) and in 2021 natural-origin steelhead in the same locations accounted for only 6.9% of 86 total steelhead captured. The scarcity of natural-origin steelhead sampled by the DJFMP from the Sacramento Basin, especially during the critically dry year of 2021, highlight the relatively poor condition of wild Central Valley O. mykiss populations (NMFS 2016).

Delta Immigration from the San Joaquin River Basin - For the 2020 MY only two(both natural-origin) Chinook Salmon and one marked Chinook Salmon were captured at the Delta entrance from the San Joaquin River (Mossdale trawl site; Figure 1); single individuals were caught on 4-Dec, 2019 and 7-Feb, 2020 (Figure 4). However, springtime is typically the peak season for juvenile salmon outmigration from the lower San Joaquin River so no inferences about the population's condition can be inferred from Aug 2019 to Jul 2020 due to monitoring disruptions (see above; Figure 4). No Chinook Salmon were detected by San Joaquin seine surveys during the 2020 salmon season; however, sampling effort was also curtailed (Figure 4). During the MY 2021, 82 Chinook Salmon (all natural-origin) were

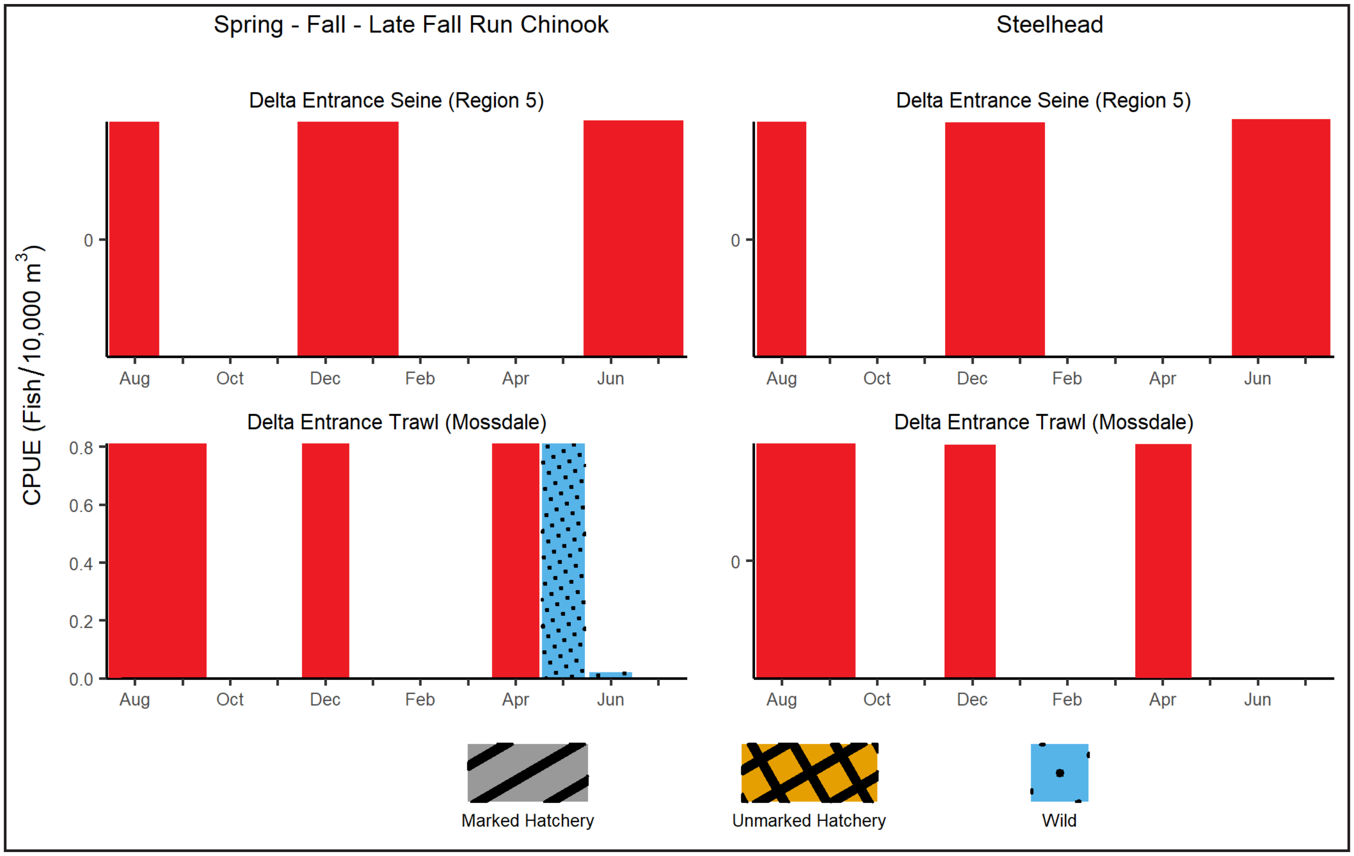

Figure 5: Monthly catch-per-unit-effort (CPUE) for hatchery- and natural-origin juvenile salmonids entering the Sacramento-San Joaquin Delta from the San Joaquin River basin during the 2021 monitoring year (August 2020 to July 2021). The red shaded areas indicate periods of no sampling.

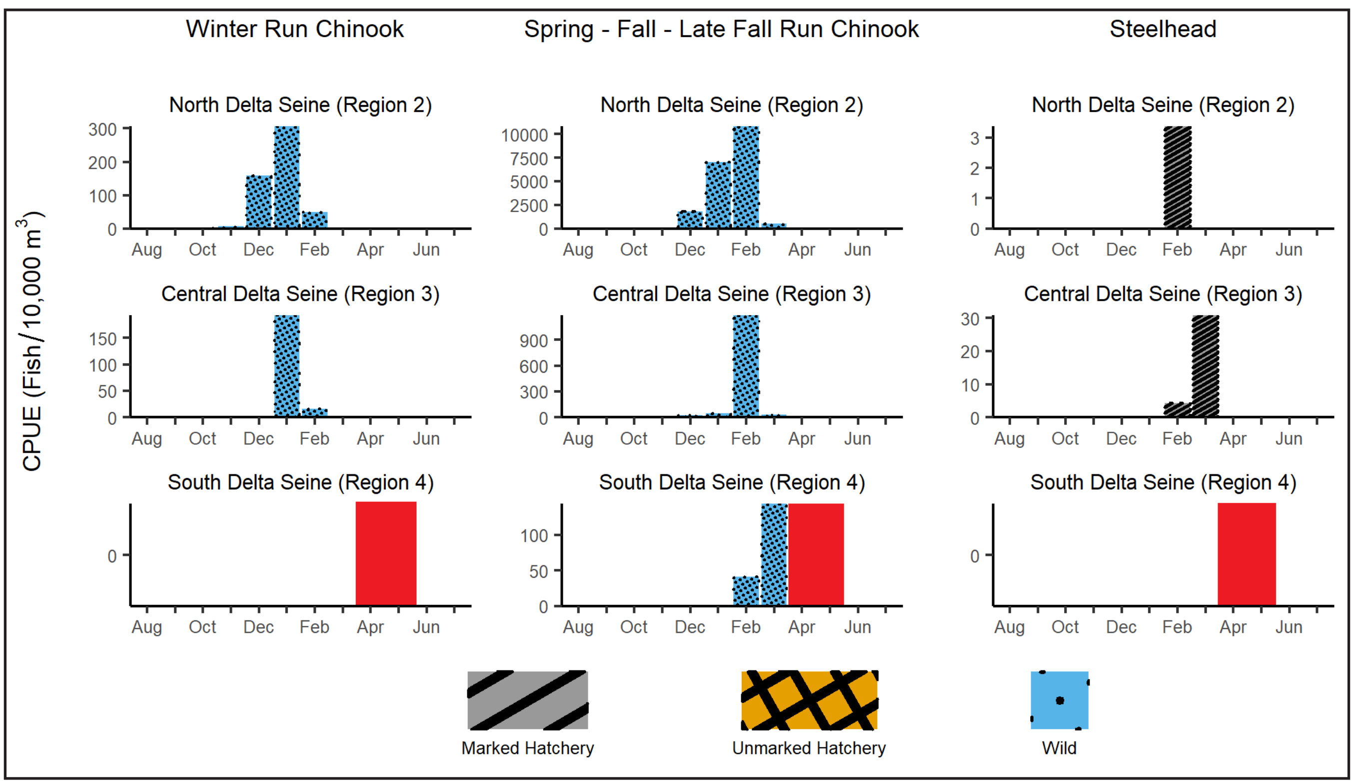

Figure 6: Monthly catch-per-unit-effort (CPUE) for hatchery- and natural-origin juvenile salmonids in Delta littoral zones sampled by beach seines during the 2020 monitoring year (August 2019 to July 2020). The red shaded areas indicate periods of no sampling.

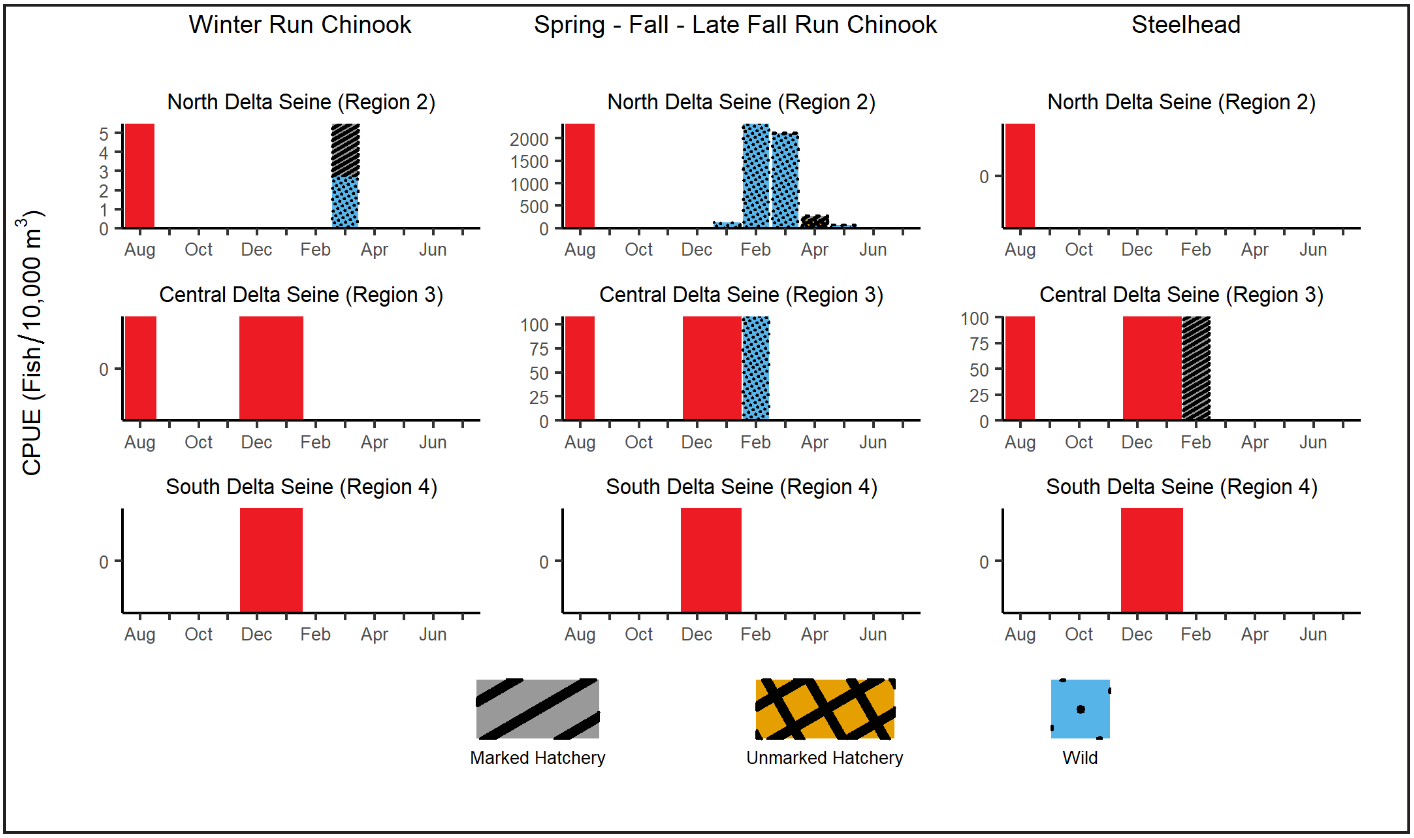

Figure 7: Monthly catch-per-unit-effort (CPUE) for hatchery- and natural-origin juvenile salmonids in Delta littoral zones sampled by beach seines during the 2021 monitoring year (August 2020 to July 2021). The red shaded areas indicate periods of no sampling.

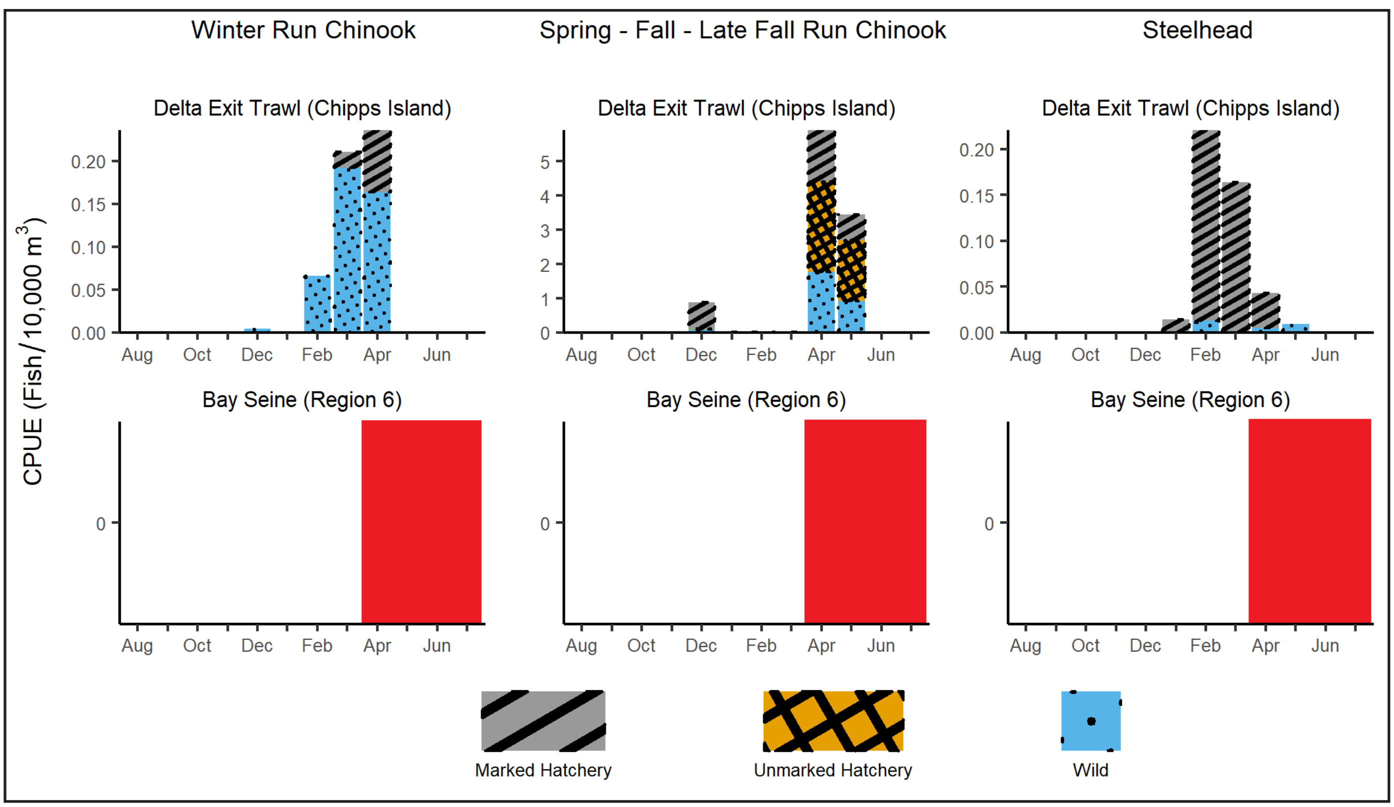

Figure 8: Monthly catch-per-unit-effort (CPUE) for hatchery- and natural-origin juvenile salmonids entering the San Francisco Estuary/Bay from the Sacramento-San Joaquin Delta during the 2020 monitoring year (August 2019 to July 2020). The red shaded areas indicate periods of no sampling.

captured by CDFW Mossdale trawl surveys between 10-May and 14-Jun (nine of the captures were spring-run and the remainder were fall-run according to LDC; Figure 5). No steelhead were captured by the Mossdale trawl surveys during the 2020 and 2021 MYs (Figures 4 and 5). Low catch of steelhead in the San Joaquin River during the 2020 and 2021 is consistent with previous years; indeed, only 10 O. mykiss were caught by Mossdale trawl surveys from 2017-2019.

Delta Residency - We observed winter-run juvenile Chinook Salmon (according to LDC) in the North Delta Region from 10-Oct to 27-Feb for MY 2020, with a peak relative abundance occurring in January (Figure 6). Winter-run fish were also captured in the Central Delta between 2-Jan and 12-Feb during MY 2020 (Figure 6). No winter-run individuals were sampled in the South Delta during MY 2020 (Figure 6). For MY 2021, the DJFMP captured winter-run juvenile Chinook Salmon in the North Delta region on 9-Mar and 17-Mar, 2021 (Figure 7). Zero Chinook Salmon were sampled in the Central Delta or South Delta that season (Figure 7).

Spring-, fall-, and late-fall juvenile Chinook Salmon (according to LDC) were observed in the North Delta during the 2020 MY from 8-Nov to 17-Mar with a peak relative abundance observed in January (Figure 6). During the following MY, spring-, fall-, and late-fall juvenile Chinook Salmon were observed in the North Delta from 26-Jan to 20-May with a peak relative abundance occurring in February (Figure 7). In the Central Delta for MY 2020, juvenile Chinook Salmon were sampled from 18-Dec to 17-Mar with a peak in February (Figure 6). In the Central Delta during the 2021 MY only one juvenile Chinook Salmon (fall-run based LDC) was captured (25-Feb; Figure 7). For the 2020 MY we observed fall- and spring-run juvenile Chinook Salmon in the South Delta from 20-Feb to 17-Mar, with peak catch occurring in March (Figure 6). Zero Chinook Salmon were captured in the South Delta during MY 2021 (Figure 7).

Only one juvenile steelhead (hatchery-origin) was captured in the North Delta region during the 2020 MY (27-Feb; Figure 6). No steelhead were captured in the North Delta during MY 2021 (Figure 7). Two steelhead were captured in the Central Delta region during MY 2020 - one on 27-Feb and the other on 17-Mar, 2020 (both were hatchery-origin; Figure 6). For MY 2021, one juvenile hatchery-origin steelhead was captured in the Central Delta on 24-Feb (Figure 7). No juvenile steelhead were captured in the South Delta region for MYs 2020 and 2021 (Figures 6 and 7).

Delta Emigration - Winter-run juvenile Chinook Salmon (according to LDC) exited the Delta between 20-Dec and 13-Apr during MY 2020, with peak emigration observed in April (Figure 8). In MY 2021, winter-run juvenile Chinook Salmon exited the Delta between 2-Feb and 25-Apr, with a peak detected in March (Figure 9). No winter-run were detected in the Bay region seine surveys during the 2020 (Figure 8) and 2021 MY (Figure 9), which is consistent with data from previous years (Figure 10).

During MY 2020, spring-, fall-, and late fall-run juvenile Chinook Salmon (according to LDC) exited the Delta between 20-Nov and 1-Jun, with peak emigration observed in AprilMay (Figure 8). For MY 2021, these runs exited the Delta between 9-Nov and 3-Jun, with peak emigration detected in MayApril (Figure 9). During MYs 2020 and 2021, spring-, fall-, and late fall-run juvenile Chinook Salmon were not captured by Bay region seine surveys (Figures 8 and 9). These observations are largely inconsistent with previous years (Figure 10) and likely influenced by reduced sampling during the pandemic (see above).

Juvenile steelhead exited the Delta during MY 2020 between 25-Jan and 11-May, with peak emigration observed in February (Figure 8). For MY 2021 juvenile O. mykiss exited the Delta between 20-Jan and 4-May, with a peak emigration also observed February (Figure 9). The total catch was dominated by hatchery-

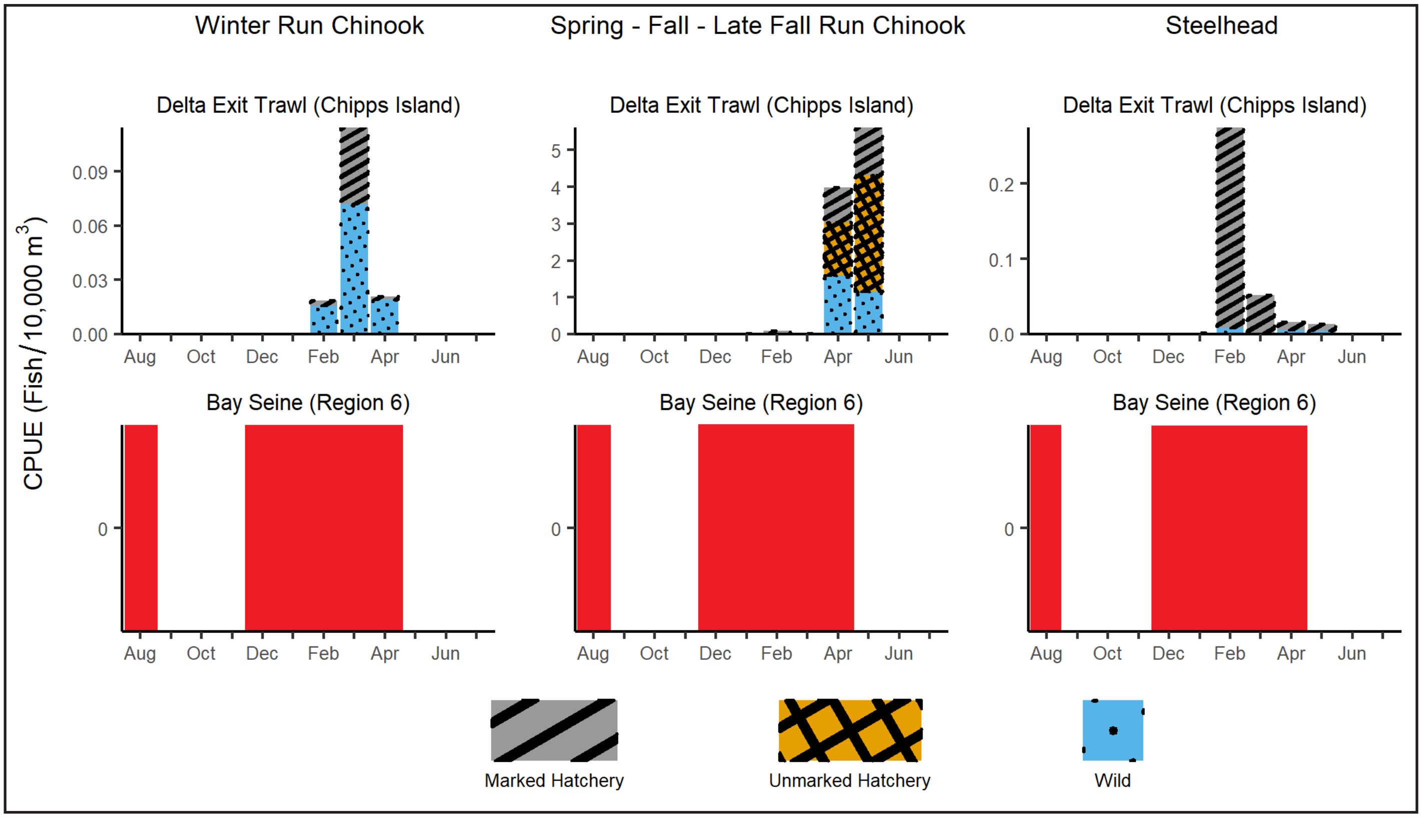

Figure 9: Monthly catch-per-unit-effort (CPUE) for hatchery- and natural-origin juvenile salmonids entering the San Francisco Estuary/Bay from the Sacramento-San Joaquin Delta during the 2021 monitoring year (August 2020 to July 2021). The red shaded areas indicate periods of no sampling.

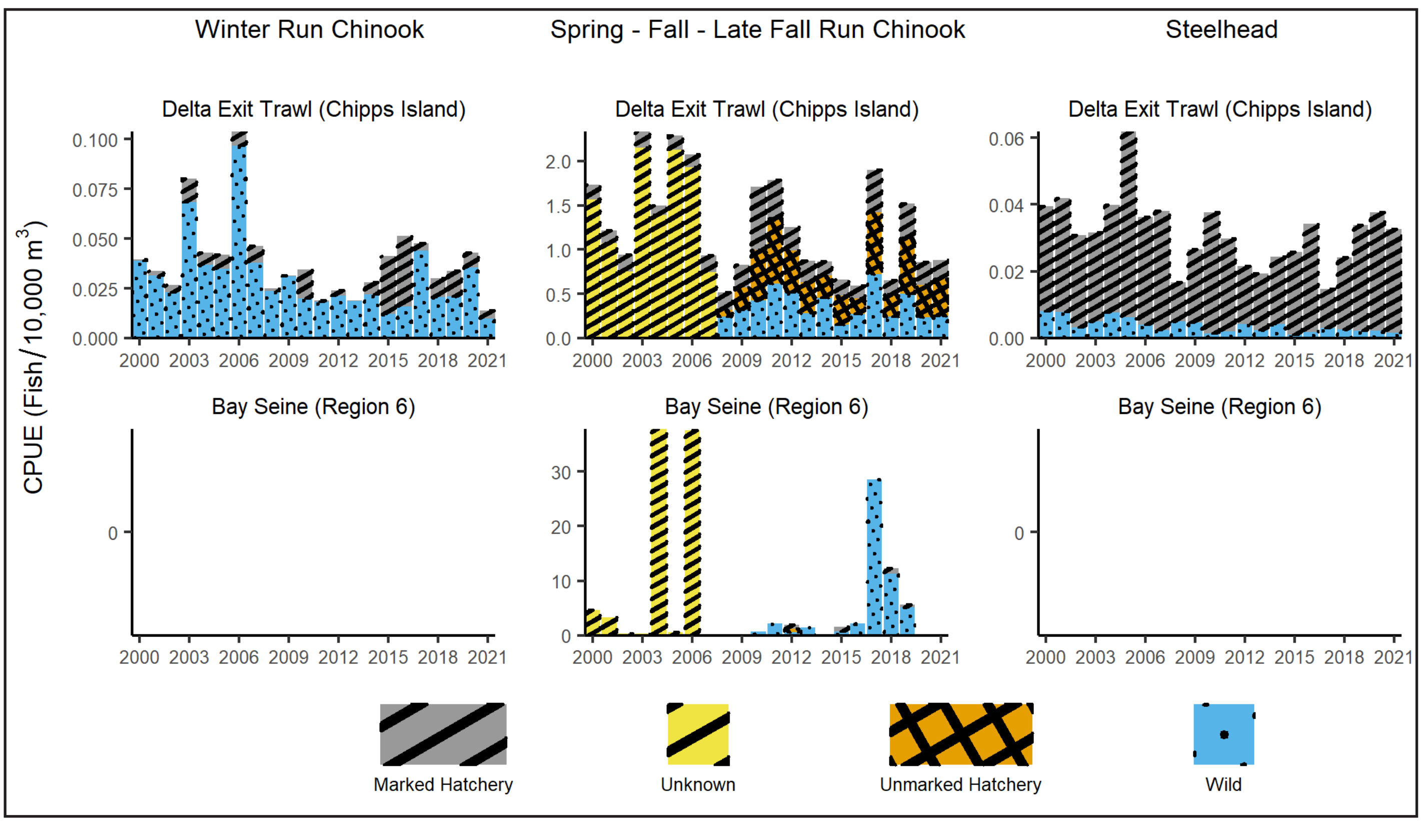

Figure 10: Monthly catch-per-unit-effort (CPUE) for hatchery- and natural-origin juvenile salmonids entering the San Francisco estuary from the Sacramento-San Joaquin Delta from 2000 to 2021.

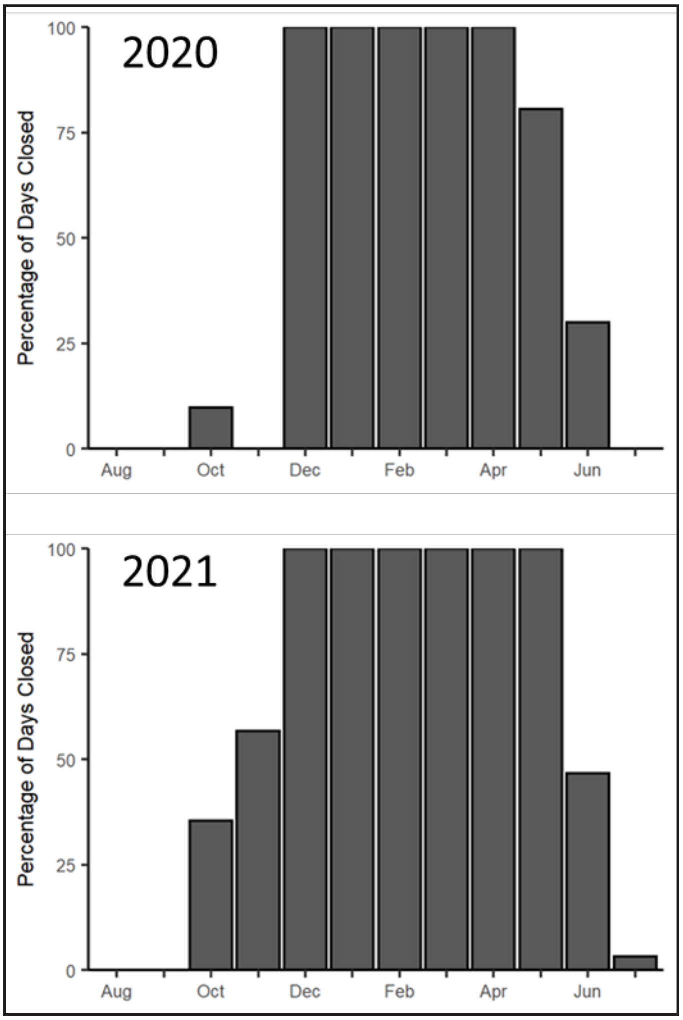

Figure 11: Delta Cross Channel operations as percentage of days closed per month during the 2020 (August 2019 to July 2020) and 2021 (August 2020 to July 2021) monitoring years.

origin fish; natural-origin O. mykiss represented only 4.6% and 4.2% of the catch during MYs 2020 and 2021, respectively (Figures 8 and 9). These observations of hatchery dominance of the population complex are consistent with previous years. No steelhead were detected in the Bay seine samples in MYs 2020 and 2021 (Figures 8 and 9) which is consistent with data from previous years (Figure 10).

Delta Cross Channel (DCC) Operation - The main purpose of the Delta entry seine survey is to detect winter-run and larger juvenile Chinook Salmon before reaching the Delta Cross Channel. The timing and duration of the DCC gate closures (Figure 11) corresponded with our detection of juvenile salmonids in the South Delta (Figures 6 and 7). This indicates that efforts to limit entrainment at the CVP (C.W. Bill Jones Pumping Plant) and SWP (Harvey O. Banks Pumping Plant) pumping facilities were likely effective.

Conclusion

Since 1976, the U.S. Fish and Wildlife Service's Delta Juvenile Fish Monitoring Program (DJFMP) has monitored the annual timing, distribution, and relative abundance of juvenile salmonids throughout the Delta. The rich long-term DJFMP dataset informs hypothesis-driven science and adaptive water and conservation management, including mitigation of Central Valley Project (CVP) and State Water Project (SWP) water export operations on salmonid populations.

Here we document the status and trends of juvenile salmonids migrating and rearing in the Delta and Bay during dry (2020) and critically dry (2021) water year types following a wet (2019) water year.

Salient findings include:

• Spring-, fall-, and late fall-run juvenile Chinook Salmon were observed to be entering the Delta from the Sacramento River about 2-3 weeks earlier during monitoring year (MY) 2021 compared to MY 2020. This pattern could be related to interannual differences in spawning and emergence timing, growth rates, and(or) flow regimes.

• Relatively few salmonids entered the Delta from the San Joaquin River in MY 2021; due to the timing of pandemic-related monitoring disruptions no assessment can be made for MY 2020.

• Less winterrun Chinook salmon were sampled in North and Central Delta in MY 2021 compared to MY 2020.

• Spring-,/fFall-, and/lLate fFall-run Chinook salmon were sampled in the South Delta in MY 2020 but not in MY 2021.

• No winter-run Chinook salmon or steelhead were sampled in the South Delta in both MYs.

• Steelhead were sampled in the North Delta in MY 2020 but not MY 2021.

• No natural-origin steelhead were sampled by seine in both MYs.

The full DJFMP dataset, including environmental data not included in this report and a description of sampling procedures are available at DJFMP's Environmental Data Initiative Data Portal (IEP et al. 2022).

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2019-2020 Yolo Bypass Fisheries Monitoring Status and Trends Report

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Introduction

The California Department of Water Resources (DWR) has operated the Yolo Bypass Fish Monitoring Program (YBFMP), largely supported by the Interagency Ecological Program (IEP), since 1998. The program collects baseline data on hydrology, water quality, lower trophic metrics (phytoplankton, zooplankton, and aquatic and terrestrial insects), and juvenile and adult fishes. The YBFMP, mandated under DWR's 2020 Incidental Take Permit (Section 3.13.1, CDFW 2020), has provided critical information regarding the significance of seasonal floodplain habitat to native fishes (Sommer et al. 2004a). As the largest remnant floodplain of the Sacramento River, the Yolo Bypass has been identified as a high restoration priority by the National Marine Fisheries Service's Biological Opinion (NMFS 2019), California EcoRestore (CDWR 2021a), and the California Natural Resources Agency Delta Smelt (CNRA 2016) and salmon resiliency strategies (CNRA 2017). As such, the baseline data provided by the YBFMP are critical for evaluating the success of current and future restoration projects. Moreover, for over two decades, data acquired from this monitoring effort have increased our understanding of the crucial role that the Yolo Bypass plays in the San Francisco Estuary ecosystem (e.g., Sommer et al. 1997; Sommer et al. 2001; Feyrer et al. 2006a; Lehman et al. 2007; Frantzich et al. 2018; Goertler et al. 2018; Mahardja et al. 2019). This report describes the fisheries sampling effort for water year (WY) 2020 (October 1, 2019 – September 30, 2020), including a summary of water quality metrics and fish catch by species and gear type.

In this report, we also highlight the impact of the COVID-19 global pandemic's effect on YBFMP monitoring efforts. In WY 2020, YBFMP suspended all fish monitoring from March 18th through the end of the water year in compliance with the California State of Emergency stay-at-home order issued by the governor. We investigated the impact of this suspension on the Catch Per Unit Effort (CPUE) for WY 2020 and compared CPUE of all monitoring methods to similar historic WY types between 2000 to 2020.

Methods

Study Site

Sampling occurred in the Toe Drain, a perennial riparian channel on the eastern edge of the Yolo Bypass (Figure 2). The 2020 water year was characterized as "dry" according to the California Data Exchange Center's Water Supply Index (CDWR 2021b).

Water Quality

Field crews concurrently collected several discrete water quality parameters using a YSI Pro DSS handheld instrument and Secchi disc during each fish sampling event, which occur weekdays October – June and once every other week in the summer (Figure 1). These parameters included: water temperature (°C), specific conductivity (µS/cm), dissolved oxygen (mg/L), pH, turbidity (FNU), and Secchi depth (m). Additionally, a multi-parameter YSI 6600 Sonde (Yellow Springs Instruments) located at Lisbon Weir and a YSI EXO2 Sonde at Hood, CA on the Sacramento River collected dissolved oxygen, turbidity, conductivity, pH, temperature, and chlorophyll-a (µg/L) at 15-minute intervals year-round.

Larval Fishes

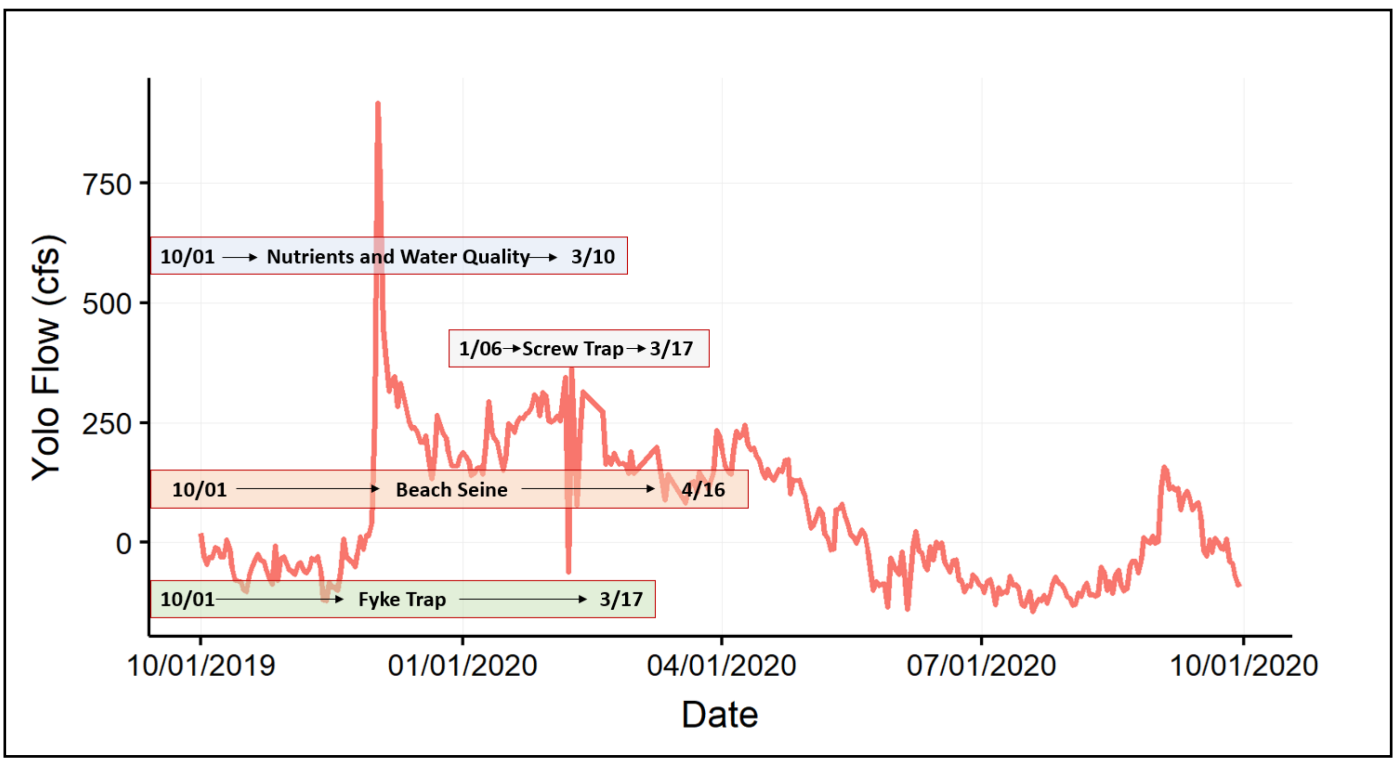

Figure 1. Fishing effort by gear type summarized against average daily flow for WY 2020 at Lisbon Weir (CDWR 2020a, Yolo Dayflow).

A survey for the general composition and timing of larval fishes in the Toe Drain has been conducted since 1999. Sampling is conducted about 6 inches below the surface of the water through a 2 m long, 500 µm mesh net with a 0.65 m diameter opening for 10 minutes during ebb tide. A single tow is taken every other week between January and June at the rotary screw trap location (Figure 1). Samples are preserved in 10% formalin on site and transported back to the lab. Samples are then transferred into 70% ETOH within two weeks of collection and sent to a contractor for identification and enumeration. In WY 2020, due to the pandemic, the tows were only conducted from 1/7/2020 – 3/10/2020.

Juvenile and Adult Fishes

Small adult (e.g. Delta Smelt) and juvenile fish have been sampled with a 2.44m diameter rotary screw trap (RSTR) located in the Toe Drain of the Yolo Bypass approximately 14.5km south of the Lisbon Weir (Figure 2) since 1998. The rotary screw trap generally operates five days a week from January – June. Circumstances that prevent fishing the trap a full five days per week

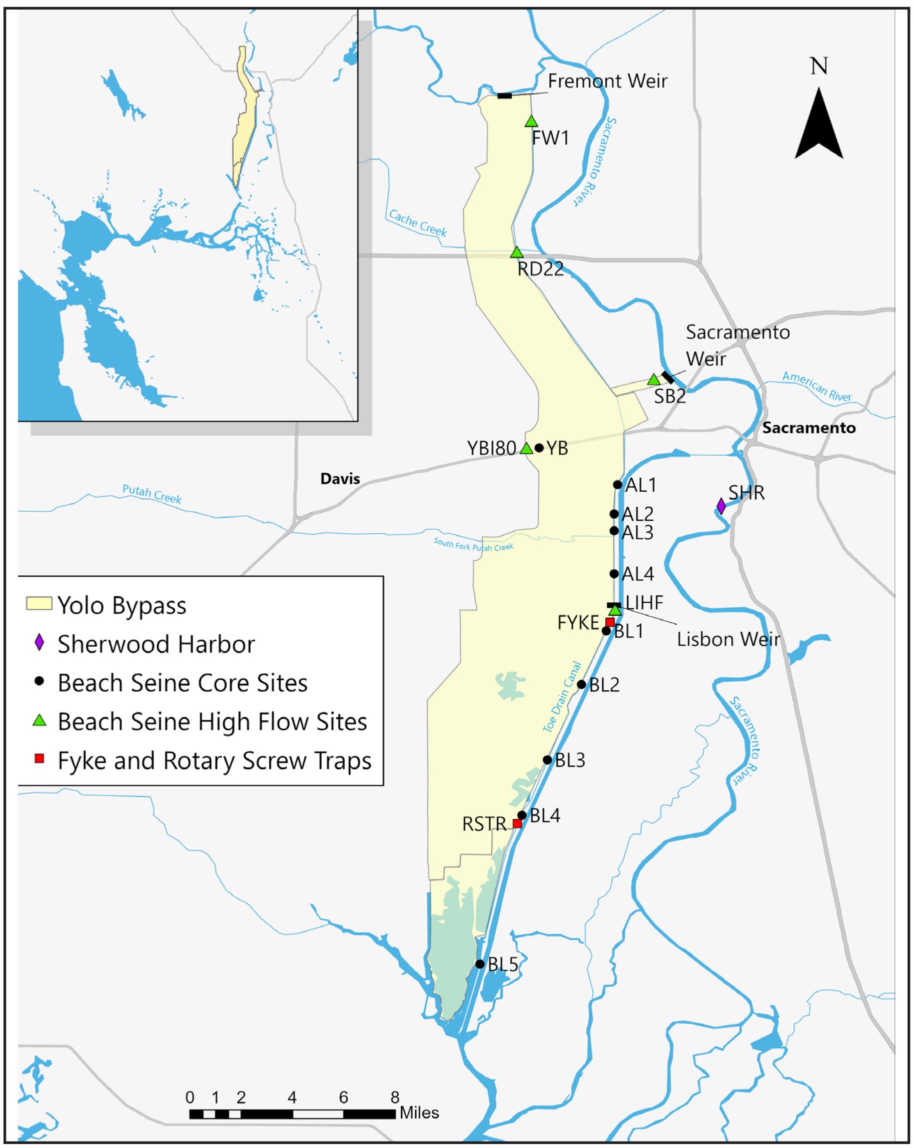

Figure 2. Map of Yolo Bypass showing the various sampling locations of the YBFMP.

include obstruction by large debris or strategic avoidance of high debris flow periods. In WY 2020, due to the pandemic, the screw trap was only operated from 1/7/2020 – 3/17/2020 (Figure 1).

Every other week throughout the year, we supplement the collection of small adult and juvenile fish in the Yolo Bypass by conducting beach seine surveys at various locations along the Toe Drain (Figure 1,2). A 7.6 m wide by 1.2 m tall seine net with 0.32 cm mesh was used. The spread of Water Hyacinth (Eichhornia crassipes), Brazilian Waterweed (Egeria densa), and Coontail (Certophyllum demersum) in the Toe Drain occasionally precluded beach seine sampling at station BL5. During periods of inundation, we sample an additional 5 sites that are only accessible during flooding. In WY 2020, due to the pandemic, beach seines were only conducted from 10/10/2019 – 3/16/2020.

The YBFMP has seasonally deployed a 3.15 m diameter steel-framed fyke trap since 1999 to monitor upstream migrations of large adult fish in the Toe Drain. The trap is located 1.2 km below Lisbon Weir and 21 km north of the terminus of the Toe Drain (Figure 2). The fyke trap is operated five days a week during the months of October – June (Figure 1, 2) and is checked once every 24 hours. In WY 2020, due to the pandemic, the fyke trap was only operated from 10/8/2019 – 3/17/2020 (Figure 1). Data for all fish catch, along with associated water quality data, can be accessed online as part of the Environmental Data Initiative (IEP 2019; IEP 2020). For all methods, proportion of catch was calculated using the following equation:

$$x = \frac{\text{total count of specific species by gear type}}{\text{total count of all species by gear type}} \times 100$$

Results and Discussion

Hydrology

The Sacramento River watershed experienced a “dry” water year with below

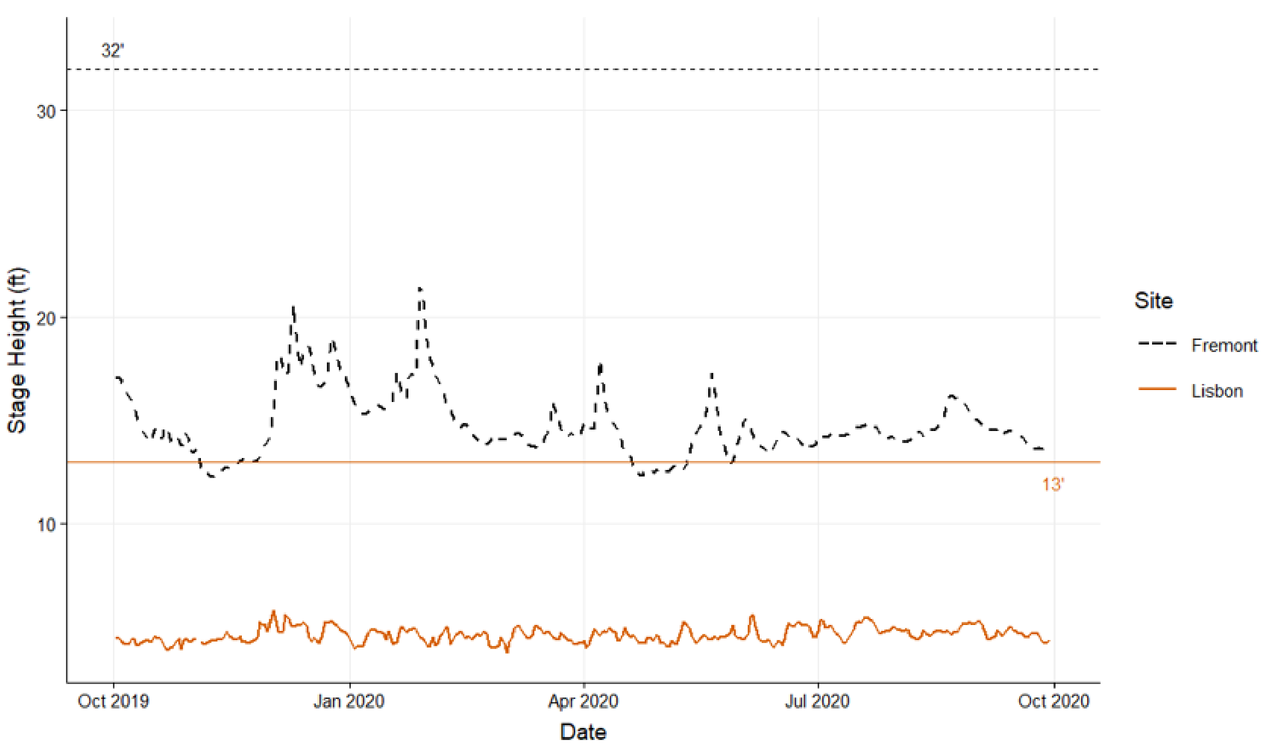

Figure 3. Stage heights of Lisbon and Fremont Weir and corresponding inundation threshold.

average precipitation during WY 2020 (CDWR 2020b). The Yolo Bypass had an average daily flow of 54.7 cfs (cubic feet per second), with a peak flow of 1,137 cfs on December 2nd, 2019 (Figure 1, CDWR). This is less than a tenth of the average daily flow of the most recent previous “dry” year, WY 2013. Historically, the Yolo Bypass floods two out of three years (Schemel et al. 2004). The last flooding event occurred in WY2019, when the floodplain was inundated for 73 days between February and April of 2019 (Kwan et al. 2021). Flooding events occur when the water levels of the Sacramento River at Fremont Weir exceed their monitoring stage height of 32 feet and spill into the Yolo Bypass (Figure 3). Localized flooding occurs when water levels from the upper Toe Drain (Above Lisbon) at Lisbon Weir exceed 13 feet and spill into the lower Toe Drain (Below Lisbon)(Figure 3). WY 2020 saw zero days of bypass inundation, as neither weir overtopped. Inundation events are important to the aquatic habitats and resident fish populations of the Yolo Bypass as they drive food web production and provide spawning and rearing habitat for native fish species (Harrell and Sommer 2003; Kwan et al. 2019) such as the Chinook Salmon (Oncorphynchus tshawytscha; Takata et al. 2017), Sacramento Splittail (Pogonichthys macrolepidotus), Sacramento Blackfish (Orthodon microlepidotus), and Delta Smelt (Hypomesus transpacificus).

Water Quality

In WY 2020, conductivity in the Yolo Bypass (216.5 – 980.7 µS/cm) was far more variable than in the Sacramento River (105.2 – 217.4 µS/cm; Figure 4A). The extreme variability in the bypass can be attributed to its unique hydrologic complexity, as conductivity is a key indicator of significant changes in water source input and water chemistry (Schemel et. al. 2004). This complexity is affected by tidal flow, residence time, salinity, and sediment transportation/deposition (Frantzich et. al. 2018). The Yolo Bypass is hydrologically complex as it receives water from several sources including adjacent tributaries, agricultural drainage, seasonal flooding, and tidal flows, which also contribute to conductivity fluctuations (Sommer et al. 2004b). The lowest conductivity measurements in the Yolo Bypass coincided with observed spikes in daily flow. Conversely, the highest conductivity measurements were observed during the early spring, in which there was a sharp decrease in water entering the system from upstream sources and water temperatures began increasing.

Turbidity can be an essential part to the health and function of an estuarine habitat as it determines the depth of the euphotic zone, which is the area where primary production can establish and help create valuable pelagic fish habitat (Morgan-king and Schoellhamer 2013; Frantzich et al. 2018). Turbidity in the Yolo Bypass is typically higher and more variable than in the Sacramento River. Similar to previous years, we saw this trend continue with higher levels of turbidity in the Yolo Bypass in water year 2020. However, during the winter months of WY 2020, two notable spikes in turbidity occurred in the Sacramento River (Figure 4B). The first major increase in turbidity is usually a product of sediments dislodged and/or mobilized from the first big winter storm, while subsequent increases are often associated with heavy rainstorms that transport large pulses of sediment through the watershed (Morgan-King and Schoellhamer 2013). The highest turbidity recorded in the Yolo Bypass during WY 2020 was 45.82 FNU, compared to 47.71 FNU in the Sacramento River.

Water temperatures in the Yolo Bypass are generally higher but more variable than in the Sacramento River (Goertler et al. 2018), although both locations follow typical seasonal trends with peak temperatures in the summer and coolest temperatures in the winter. The shallow and broad topography of the inundated Yolo Bypass floodplain results

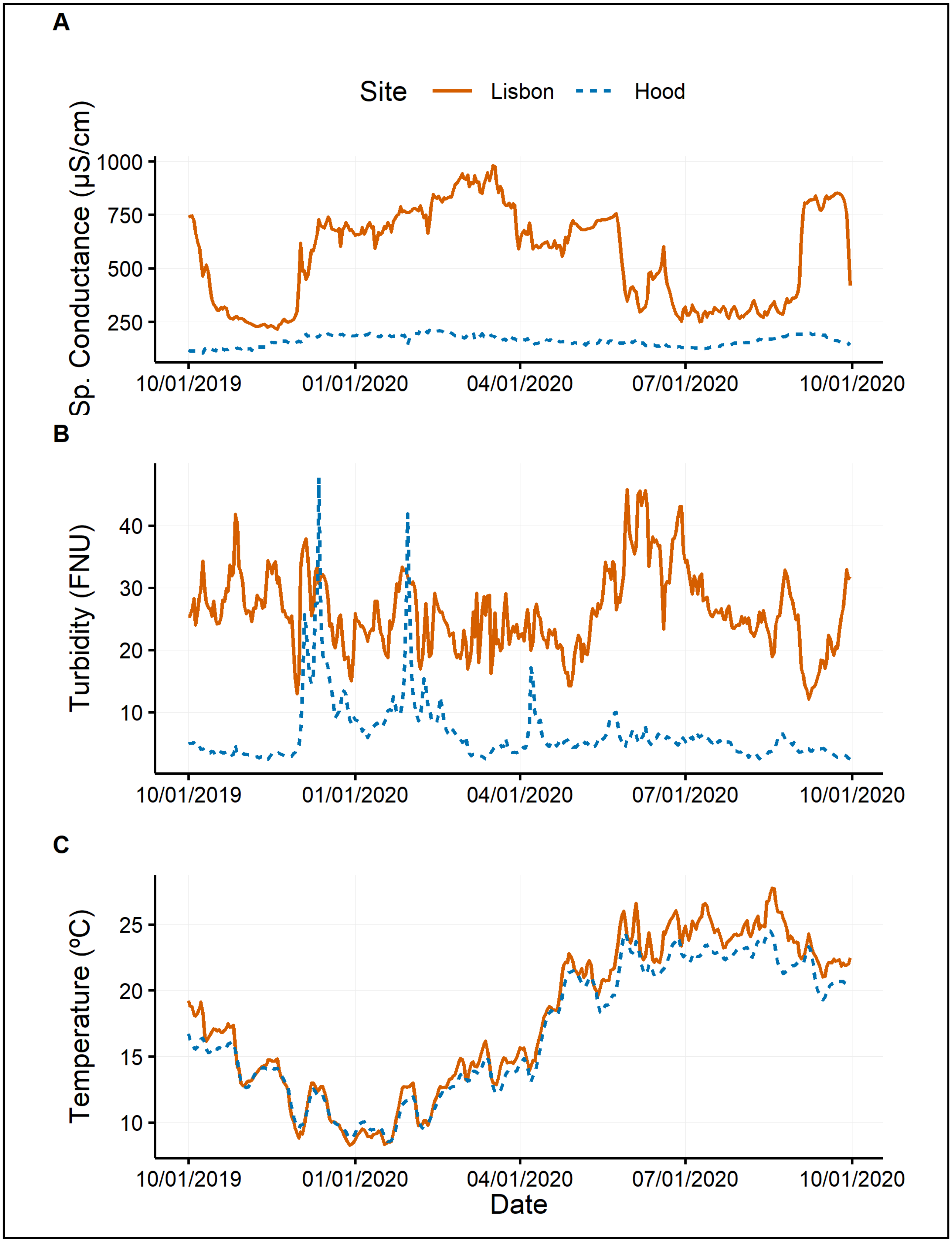

Figure 4. Time series plots for turbidity, specific conductivity, and water temperature at Lisbon Weir in the Yolo Bypass and Hood Station in the Sacramento River.

in more extreme temperature variability throughout the year (Sommer et al. 2004a). In WY 2020, the highest water temperature in the Yolo Bypass at Lisbon Weir occurred on August 18th, 2020, at 27.77 °C, while the Sacramento River at Hood (henceforth: Sacramento River; Figure 1) peaked at 24.52 °C on August 17th, 2020 (Figure 4C). The lowest water temperature recorded in the bypass and Sacramento River was 8.30 °C and 8.57 °C, respectively. Water temperature plays a significant role not only for lower trophic food production (Lehman et al. 2007) but also for the timing of outmigration from the floodplain (Takata et. al. 2017) and increased size diversity of juvenile Chinook Salmon (Goertler et al. 2018).

Fishes

Due to the COVID-19 pandemic, larval fish sampling was suspended on March 17, 2020. Sampling occurred for only three months from January 2020 through March

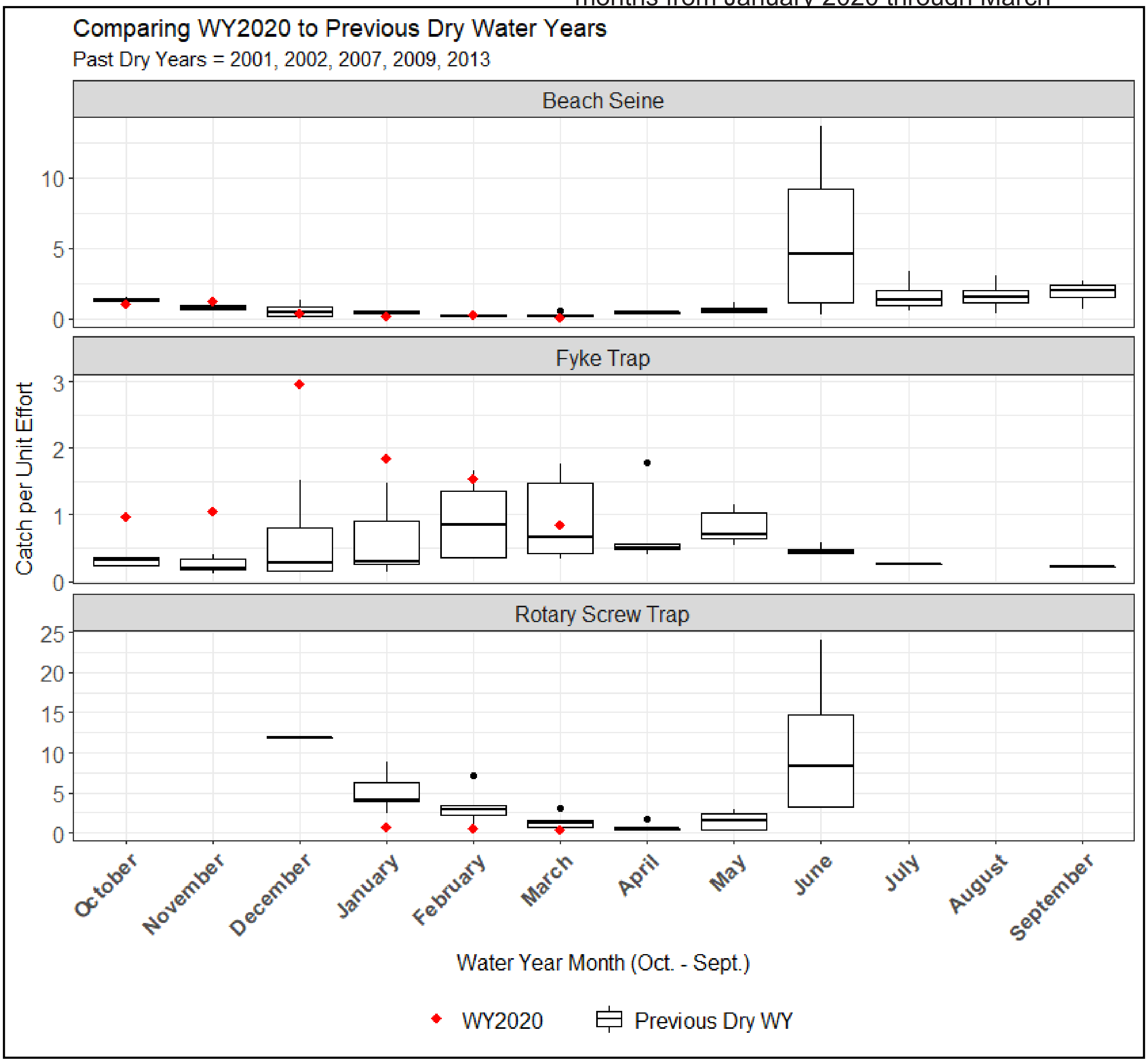

Figure 5. Boxplot of average monthly CPUE from the past 5 "dry" water years compared to WY 2020 monthly CPUE.

2020, rather than the usual seven months from January through July. Due to the limited time frame, larval fish were only sampled on five days (1/6/20, 1/27/20, 2/10/20, 2/24/20, and 3/10/20). During those five sampling occasions, Prickly Sculpin (Cottus asper) were the only larval fish species detected with 11 individuals caught on 1/27/20 and 1 individual caught on 2/24/20. We surmise that due to suspended sampling, we potentially missed the recruitment times of other species that spawn in the spring and early summer months. This below normal species catch and diversity was also reflected in the catch totals of our other fish community sampling methods.

A total of 31 fish species were collected in the shortened WY 2020 sampling period; 8 of which are native to the Sacramento-San Joaquin River Delta (Table 1). Mississippi Silverside (Menidia beryllina) were the most prevalent species by count in both the beach seine (72.65%) and rotary screw trap (75.14%) sampling methods. White Catfish (Ameiurus catus) were the most prevalent species by count using the fyke trap sampling method (73.42%). Both species are nonnative and made up a significant portion of the catch for WY 2020. Mississippi Silversides made up a total of 43.87% of all catch across sampling methods, and White Catfish followed closely behind at 30.16% of all catch. As a comparison to our high nonnative fish count, the highest native fish count was the Sacramento Splittail (Pogonichthys macrolepidotus) in the fyke (1.65%), Hitch (Lavinia exilicauda) in beach seine sampling (0.78%), and Chinook salmon (Oncorhynchus tshawytscha) from the rotary screw trap (2.52%). All three of these species were individually below 1% of the total catch for WY 2020 across all sampling methods.

While Sacramento Splittail and Chinook salmon have both been at the top of the native species percentages in the past, Hitch have never been the top native species collected for a gear type in the history of YBFMP fish catch. In fact, the highest total catch of Hitch over a year of sampling was in WY 2019 with 46 total individuals, however, that count only made up 0.35% of beach seine catch for that year (Kwan et al. 2021). WY 2011 had the next highest with a total of 42 Hitch, but that count made up even less (0.17%) of the total beach seine catch for that water year (Frantzich et al. 2013). The 29 Hitch collected in WY 2020 made up such a high percentage of the total beach seine sampling most likely due to the canceled sampling of the latter half of the water year, which is typically when higher counts of other native species are caught (Kwan et al. 2019, Kwan et al. 2021, Frantzich et al. 2013).

WY 2020 Highlight: Impacts of the COVID-19 pandemic on YBFMP monitoring efforts

The YBFMP monitors juvenile and adult fish within the Yolo Bypass across specific periods throughout the water year to better understand the movements of resident and migratory fish that utilize the Yolo Bypass (Harrell and Sommer 2003). As a result of the statewide emergency stay at home order due to the COVID-19 pandemic, the YBFMP had to suspend all monitoring efforts from March 17, 2020, to September 30, 2020; a little over half of WY 2020. This prompted the question: what impact did this suspension have on CPUE from our monitoring methods for WY 2020 and how does the resulting CPUE compare to other water years?

We first compiled all catch data from 2000-2020 and calculated monthly CPUE for our rotary screw trap (RSTR), fyke trap (FKTR) and beach seine (BSINE) monitoring methods. Rotary screw trap and fyke trap CPUE is calculated using sampling time (total hours based on set, check, and pull times) divided by catch to get catch per hour as the volume of water sampled is unknown. Beach seine CPUE is calculated by multiplying the length, width, and depth of a seine and then dividing by the fish catch. WY 2020 was

Scientific Name	Common Name	Beach Seine Catch	Beach Seine Percent	Fyke Catch	Fyke Percent	Screw Trap Catch	Screw Trap Percent	Total
Menidia beryllina	Mississippi Silverside	2717	72.65%	54	1.82%	417	75.14%	3188
Ameiurus catus	White Catfish	0	0.00%	2182	73.42%	10	1.80%	2192
Lepomis macrochirus	Bluegill	342	9.14%	8	0.27%	0	0.00%	350
Dorosoma petenense	Threadfin Shad	237	6.34%	52	1.75%	18	3.24%	307
Pomoxis nigromaculatus	Black Crappie	84	2.25%	156	5.25%	2	0.36%	242
Morone saxatilis	Striped Bass	3	0.08%	204	6.86%	3	0.54%	210
Percina macrolepida	Bigscale Logperch	168	4.49%	6	0.20%	0	0.00%	174
Cyprinus carpio	Common Carp	4	0.11%	107	3.60%	2	0.36%	113
Micropterus salmoides	Largemouth Bass	55	1.47%	3	0.10%	0	0.00%	58
Gambusia affinis	Western Mosquitofish	39	1.04%	0	0.00%	17	3.06%	56
Lavinia exilicauda	Hitch	29	0.78%	21	0.71%	2	0.36%	52
Pogonichthys macrolepidotus	Sacramento Splittail	0	0.00%	49	1.65%	2	0.36%	51
Ameiurus nebulosus	Brown Bullhead	0	0.00%	33	1.11%	3	0.54%	36
Notemigonus crysoleucas	Golden Shiner	5	0.13%	4	0.13%	25	4.50%	34
Lucania parva	Rainwater Killifish	4	0.11%	0	0.00%	28	5.05%	32
Ictalurus punctatus	Channel Catfish	2	0.05%	23	0.77%	2	0.36%	27
Pimephales promelas	Fathead Minnow	24	0.64%	0	0.00%	3	0.54%	27
Oncorhynchus tshawytscha	Chinook salmon	4	0.11%	8	0.27%	14	2.52%	26
Ameiurus melas	Black Bullhead	0	0.00%	25	0.84%	0	0.00%	25
Catostomus occidentalis	Sacramento Sucker	1	0.03%	21	0.71%	0	0.00%	22
Lepomis microlophus	Redear Sunfish	9	0.24%	8	0.27%	0	0.00%	17
Tridentiger bifasciatus	Shimofuri Goby	2	0.05%	1	0.03%	5	0.90%	8
Micropterus punctulatus	Spotted Bass	6	0.16%	0	0.00%	0	0.00%	6
Pomoxis annularis	White Crappie	2	0.05%	2	0.07%	0	0.00%	4
Ptychocheilus grandis	Sacramento Pikeminnow	1	0.03%	2	0.07%	0	0.00%	3
Lepomis cyanellus	Green Sunfish	2	0.05%	0	0.00%	0	0.00%	2
Alosa sapidissima	American Shad	0	0.00%	0	0.00%	1	0.18%	1
Cottus asper	Prickly Sculpin	0	0.00%	1	0.03%	0	0.00%	1
Oncorhynchus mykiss	Rainbow Trout (Steelhead)	0	0.00%	1	0.03%	0	0.00%	1
Hypomesus nipponensis	Wakasagi	0	0.00%	0	0.00%	1	0.18%	1
Acipenser transmontanus	White Sturgeon	0	0.00%	1	0.03%	0	0.00%	1

Table 1. Fish species catch data and percent (species catch/overall catch) summarized by gear type for WY2020, sorted in descending order of total abundance.

classified as a “dry” water year, according to the California Data Exchange Center – Water Year Hydrologic Classification Indices (CDWR 2020b), so we chose to compare CPUE across similarly classified water years. Over the 20-year span, 2001, 2002, 2007, 2009, and 2013 were also classified as “dry” water years (CDWR 2020b). Focusing on these “dry” years, we plotted the monthly average CPUE of all species, facetted by gear type, to observe what months generally have the highest CPUE (Figure 5). Finally, in order to compare monthly CPUE within and between water years, we visualized the data by both gear type and water year (Figure 6).

Through this exploratory plotting, we observed differences in total monthly CPUE and maximum monthly CPUE between previous “dry” years and WY 2020 (Figure 5). Previous “dry” water years had the highest

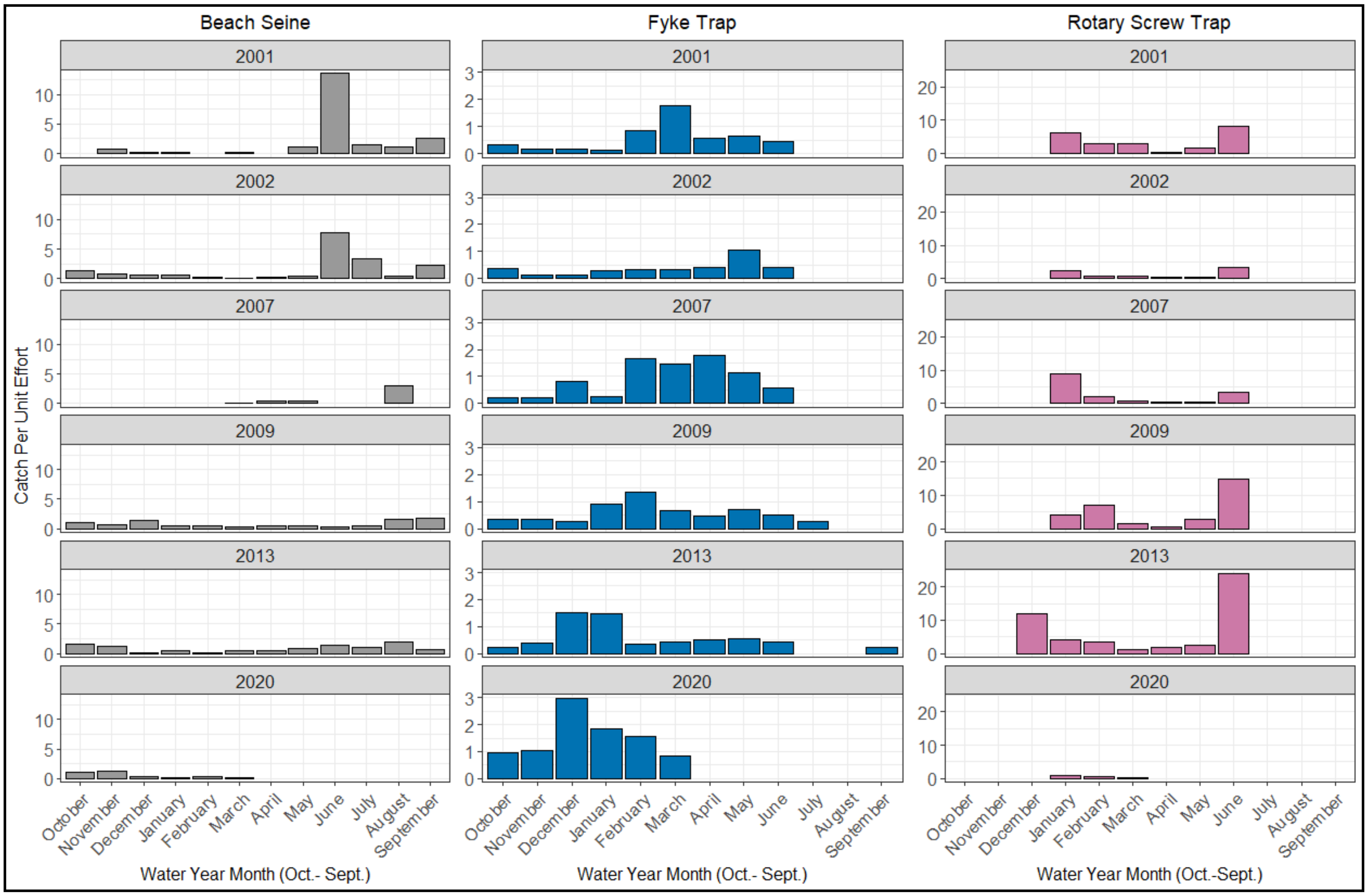

Figure 6. Stacked barplots for each sampling method of monthly CPUE for water year 2020 and 5 past "dry" water years.

median beach seine (4.56) and rotary screw trap (8.32) CPUE in June and the highest median Fyke (0.84) CPUE in February. In WY 2020, we observed the highest beach seine CPUE (1.23) in November, the highest rotary screw trap CPUE (0.78) in January and the highest Fyke CPUE (2.97) in December. Beach seine CPUE in WY 2020 was similar to previous "dry" water years for the months sampled, however, rotary screw trap CPUE had decreased from previous "dry" water years and the fyke trap saw significantly increased CPUE from previous "dry" water years for months which were sampled. Comparing WY 2020 to previous similar water years gives a general understanding of average historical trends, but to understand how each year affects those averages we compared CPUE from year-to-year.

Looking at year-to-year comparisons between similar water years highlights the variation of CPUE of sampled fish communities. As shown in Figure 6, WY 2020 fyke trap CPUE in December was about two times higher than the previous highest December CPUE in WY 2013. These comparisons also show what was potentially missed due to the shutdown, based on catch during previous water years. For example, June tends to have the highest CPUE for the rotary screw trap (Figure 6) and WY 2013 had the highest recorded CPUE for all months in all "dry" water years. Since June was not sampled in WY 2020, we potentially missed some of the highest CPUE of the water year. Observing and comparing trends across similar water years gives the YBFMP insight to the changes in CPUE and perspective on outliers of sampled fish communities even with complications like reduced sampling.

Summary

WY 2020 was one of the least sampled water years in the program's history due to the COVID-19 statewide emergency and stay-at-home order. Peak turbidity, electrical conductivity, and water temperature were higher in the Yolo Bypass than in the Sacramento River reference site. Larval tows caught only one species, the Prickly Sculpin. Nonnative Inland Silverside made up the highest proportion of catch in both beach seining and rotary screw trap, while nonnative White Catfish made up the highest proportion of catch in the fyke trap. Hitch made up the highest proportion of catch of native species in beach seining, Chinook salmon made up the highest proportion of catch of native species in the rotary screw trap, and Sacramento Splittail made up the highest proportion of native species catch in the fyke trap. Our comparison of CPUE between WY 2020 and historically similar water years highlighted the need to consistently sample fish communities to accurately assess the changes in CPUE for our monitoring methods. Additionally, using multiple methods to compare data between, as well as within, water years provides better perspective on changes in the sampled fish communities through time. Overall, WY 2020 provides insight on the importance of consistent sampling to better understand monthly and annual changes in fish CPUE.

Acknowledgements

The Yolo Bypass Fish Monitoring Program would not be possible without the support from IEP. We'd like to thank the following WY 2020 YBFMP field staff: Naoaki Ikemiyagi, Mallory Bedwell, Catarina Pien, Jesse Adams, Haley Hudson, Amanda Casby, Craig Stuart, and Terrence Jarrell, as well as our volunteers. We also acknowledge Dr. Ted Sommer for pioneering scientific research in the Yolo Bypass.

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Fish Salvage at the State Water Project's and Central Valley Project's Fish Facilities during the 2021 Water Year

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Introduction

Two fish protective facilities reduce fish losses associated with water export by the federal Central Valley Project (CVP) and California's State Water Project (SWP). The CVP's Tracy Fish Collection Facility (TFCF) and the SWP's Skinner Delta Fish Protective Facility (SDFPF) salvage fish (fish are removed from exported water and released back to the Delta) from water exported from the southern end of the Sacramento-San Joaquin Delta located in Byron, California (Aasen 2013). Salvage reporting is required by contract with the California Department of Water Resources and the United States Bureau of Reclamation to report to stakeholders such as the Smelt Working Group and the Salmon Monitoring Team for near real time management of listed species. Both facilities use louver-bypass systems to divert fish from the exported water. The salvaged fish are periodically loaded into tanker trucks and transported to fixed release sites in the western Delta. Export and salvage operations began in 1957 at the TFCF and in 1968 at the SDFPF.

This report summarizes salvage information from the 2021 water year (10/1/2020-9/30/2021; WY) for both the TFCF and the SDFPF while examining data from WY's 1981 to 2021 for salvage trends over time, emphasizing recent years. The following species were given individual consideration including listed species: Chinook Salmon (Oncorhynchus tshawytscha), steelhead (O. mykiss), Delta Smelt (Hypomesus transpacificus), Longfin Smelt (Spirinchus thaleichthys), and Green Sturgeon (Acipenser medirostris). Striped Bass (Morone saxatilis) was included as an apex predator, Delta Smelt (Hypomesus transpacificus), Longfin Smelt (Spirinchus thaleichthys), Sacramento Splittail (Pogonichthys macrolepidotus) was included as a species of special concern, and Threadfin Shad (Dorosoma petenense) as an important forage fish., and Green Sturgeon (Acipenser medirostris).

Methods

Systematic sampling was used to estimate the numbers and species of fish salvaged at both facilities. The data was reported by CVP and SWP. In 2021, bypass flows into the fish-collection buildings were sub-sampled generally once every 1 or 2 hours for 10 to 30 minutes at the SDFPF and generally once every 2 hours for 30 minutes at the TFCF. Fish with a fork length (FL) of 20 mm or larger were identified, counted, and measured. These fish counts were expanded to estimate the total number of fish salvaged in each 1 to 2 hour period of water export. For example, a subsample duration of 30 minutes over an export period of 120 minutes gives an expansion factor of 4, which is then multiplied by the number of fish per species collected during the fish count. These incremental salvage estimates were then summed across time to develop monthly and annual species-salvage totals for each facility.

The loss of Chinook Salmon is estimated from the number of juvenile Chinook Salmon entrained by the facility less the number of Chinook Salmon that survive salvage operations (California Dept. of Fish and Wildlife 2013). Salmon salvage and loss were summarized by origin (i.e., hatchery fish defined as adipose fin clipped or wild fish defined as non-adipose fin clipped) and run (fall, late-fall, winter, or spring). Runs of Chinook Salmon were initially determined by the Delta criteria based on length at date of salvage (California Dept. of Fish and Wildlife 2014). WhenIf coded wire tag (CWT) information becamewas available, the run of hatchery Chinook Salmon was updated based on run associated with the CWT. WhenIf DNA information becamewas available, the run of wild Chinook Salmon was updated based onafter genetic resultswere returned. The Delta length at age criteria used is a modified version of the Fisher Model with expanded boundaries for winter-run Chinook Salmon since juvenile fork length ranges from runs were not segregated and empirical fork lengths trends for all runs did not exhibit the constant apparent growth rates used to generate Length-at-date size criteria The Delta length at date criteriawas created by the U.S. Fish and Wildlife Service who modified the California Department of Water Resourcesmodified version of the Fisher Model by changing the upper and lower boundaries for winter-run ChinookSalmon(Harvey and Stroble 2013). HoweverConsequently, apparent growth rates and size ranges vary among runs leading to potential misclassification with the Delta length at date criteria (Harvey and Stroble 2013). Consequently,a change was made to use CWT-determinedrun in WY 2017and DNA-determinedrunin 2018.

Hence, a change was made to use CWT-determined run in WY 2017 to present and DNA-determined run in 2018 to present.

Larval fish were also collected and examined for the presence of Delta Smelt and Longfin Smelt less than <20 mm FL. Smelt less than 20 mm FL are historically reported as detections rather than numbers to avoid any confusion with salvage since fish less than 20 mm FL are not included in salvage. Larval sampling in WY 2021 ran from February 22 through May 31 at the SDFPF and from February 15 through June 1 at the TFCF. These dates were selected based on optimum water temperature for spawning early in the year and lack on larva in samples at the end of the season. Larval samples were generally collected once for every 1-6 hours of water export. The TFCF sampled every 6 hours while the sampling interval at SDFPF varied due to facility shutdown from low water exports. The duration of larval sampling was the same as for counts30 minutes. To retain these smaller fish, the fish screen used in the routine counts was lined with a 0.5 mm Nitex mesh. Larval fish from the TFCF were identified to the species level by TFCF personnel, while larval fish from the SDFPF were identified to the lowest possible taxaspecies level or Centrarchidae at SDFPF

Results

Water Exports

The SWP in WY 2021 (drought year) exported a record low 0.71 billion m3 of water which represented 8.6% of outflow (Medellín-Azuara et al. 2021). This was a large decrease from WYs 2015-2020 (1.38-4.4486 billion m3), WY 2019 (3.48 billion m3), WY 2018 (2.63 billion m3), WY 2017 (4.44 billion m3), and drought years WY 2016 (2.43 billion m3), WY 2015 (1.38 billion m3) and . Tthe previous record low exports occurred in WY 2014 (1.12 billion m3; Figure 1). The CVP in WY 2021 exported 1.14 billion m3 of water which represented 13.0% of outflow. This was a decrease from WYs 2016-2020 (1.68-3.312.43 billion m3), WY 2019 (2.91 billion m3), WY 2018 (2.83 billion m3), WY 2017 (3.31 billion m3), WY 2016 (1.68 billion m3), but a smalln increase from drought year WY 2015 (0.86 billion m3, a record low) and almost equal WY 2014 (1.17 billion m3). Total export in WY 2021 at SWP was well below the WYs 1981-2020 average (3.05 billion m3) and was also below average at CVP (2.79 billion m3).

Exports at the SWP peaked in November 2020 to February 2021 (Figure 2). During this period, the SWP exported 523.6 million m3, which represented 73.8% of the total annual export which represented 6.0% of outflow. Exports at the CVP peaked in October 2020, February 2021, and September 2021. The cumulative water export for those months was 538.3 billion m3, which represented 42.9% of the annual export which represented 6.1% of outflow. SWP monthly exports ranged from 11.3 to 146.76 million m3. CVP monthly exports ranged from 44.8 to 239.3 million m3. The pattern of monthly export at both facilities generally follow the same trend year-to-year with the lowest exports occurring in spring. Although in WY 2021, the lowest exports occurred both in spring and summer at both facilities.

Total Salvage and Prevalent Species

Total fish salvage (all fish species combined) at the SDFPF in WY 2021 was a record low at 164,423 (Figure 3). This was a large decrease from WYs 2016-2020 (435,541-2,832,631)), WY 2019 (660,001) and a marked decrease from WY 2018 (1,041,003), WY 2017 (2,104,742), and WY 2016 (2,832,631). WY 2021 salvage was even a marked decrease from drought years WY 2015 (347,882) and the previous record low in WY 2014 (236,688). Total fish salvage at the TFCF in WY 2021 was 381,373. This was a large decrease from WYs 2016-2020 (1,432,489-1,679,609). , WY 2019 (1,463,817), WY 2018 (1,432,489), and WY 2016 (1,437,551). WY 2021 salvage at TFCF was an small increase from drought years WY 2015 (295,854) and the record low in WY 2014 (160,681). In general, total fish salvage has been influenced by exports in recent years (i.e., higher salvage at higher exports). However, this trend was not found at the SDFPF in WY 2016 when higher salvage was found than in WY's 2017-2019 despite lower exports. Also, salvage in WY 2020 increased at TFCF despite being a drought year with decreased exports.

Threadfin Shad was the most-salvaged species at both the SDFPF and TFCF (Figure 4 and Table 1). Bluegill and Inland Silverside were the 2nd and 3rd most-salvaged fish at SDFPF, respectively. Bluegill and Largemouth Bass were the 2nd and 3rd most-salvaged fish at TFCF, respectively. Native species comprised 6.2% of total fish salvage at SDFPF and 2.9% of total fish salvage at TFCF. This was a large increase from WY 2020 at the SDFPF (3.3%) but a small decrease at the

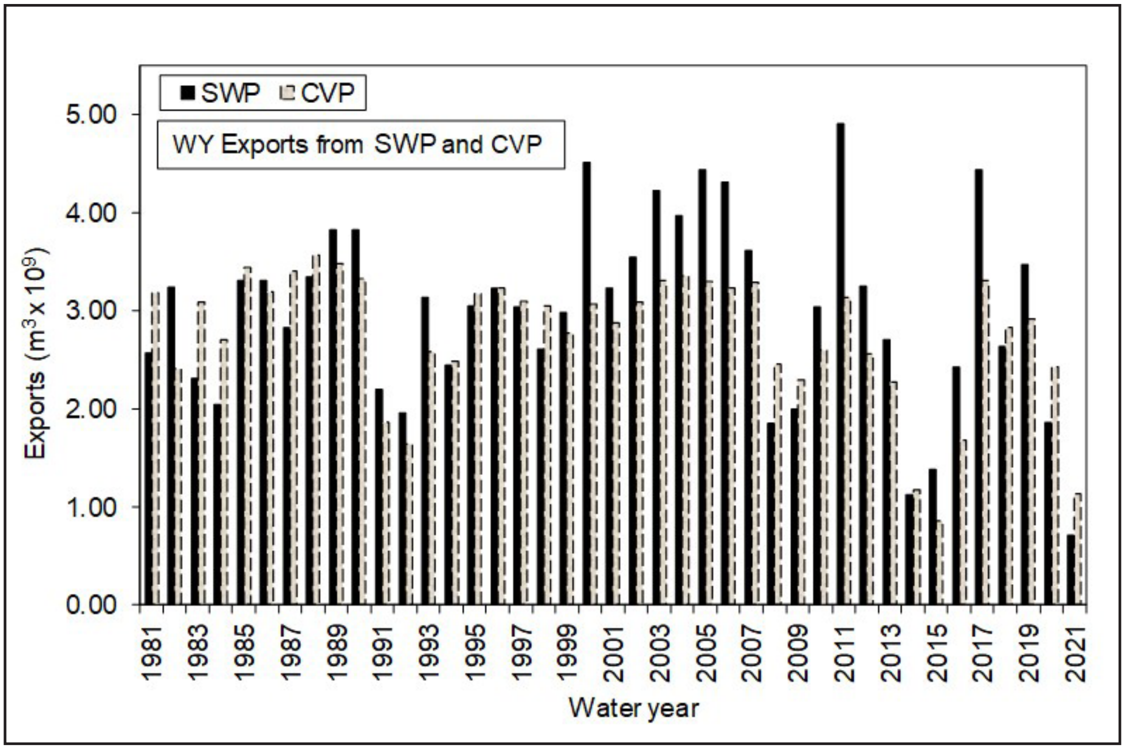

Figure 1 Annual water exports in billions of cubic meters for the State Water Project and the Central Valley Project, Water Years 1981 to 2021.

TFCF (3.2%). Relatively few listed species (i.e. Chinook Salmon, steelhead, and Longfin Smelt) were salvaged at the SDFPF (0.6% combined of total fish salvage). This was equal to WY 2020 when listed species comprised 0.6% of salvage. Relatively few listed species including Chinook Salmon, steelhead, and Longfin Smelt were salvaged at the TFCF (0.3% combined of total fish salvage). This was also equal to WY 2020 when these species and Green Sturgeon (which were salvaged in WY 2020) also comprised 0.3% of salvage.

Chinook Salmon

Annual salvage estimates of Chinook Salmon (all runs and origins combined) at both facilities in WY 2021 (a drought year) were low and similar to the trend seen during drought years 2012-2016 (Figure 45). Salvage of juvenile (80-249 mm FL) Chinook Salmon (302) at SDFPF in WY 2021 was far less than that in WYs 2017-2020 (1,187-23,118), WY 2019 (4,253), WY 2018 (5,964) and WY 2017 (23,118), but similar to WY 2016 (362)and WY 2015 (221). The record low occurred in WY 2014 (64). Mean salvage for Chinook Salmon in WYs 2001-2021 at SDFPF was only 8.0% of the mean salvage in WYs 1981-2000. The same trend was seen for salvage of juvenile Chinook Salmon (38-250 mm FL) at the TFCF in WY 2021 (892) which was a large decrease from WYs 2017-2020 (3,690-23,633),, WY 2019 (9,083), WY 2018 (14,315) and WY 2017 (23,633), but low as in WY 2016 (970) and the record low in WY 2015 (187).. The record low occurred in WY 2015 (187). Mean salvage for WYs 2001-2021 was only 9.9% of the mean salvage for WYs 1981-2000.

Wild Chinook Salmon salvaged at the SDFPF were primarily wild fall run fish, which comprised 98.2% of wild fish, followed by wild spring run fish (Table 2). Salvaged wild Chinook Salmon at the TFCF were primarily wild fall run fish, which comprised 98.4% of wild fish caught, followed by wild spring and winter run fish. At the SDFPF, the majority of wild fall run fish were salvaged in April (58) and wild fall run fish were most frequently salvaged in May (296) at the TFCF.

Annual loss of Chinook Salmon (all origins and runs) was higher at the SDFPF (1,296)

Table 1. Annual fish salvage and percentage of annual fish salvage (%) collected from the State Water Project and the Central Valley Project, Water Year 2021.

Common Name	Scientific Name	TFCF Salvage	TFCF Percent	SDFPF Salvage	SDFPF Percent
Threadfin Shad	Dorosoma petenense	228,915	60.0	35,980	21.9
Bluegill	Lepomis macrochirus	58,912	15.4	32,684	19.9
Largemouth Bass	Micropterus salmoides	17,696	4.6	13,422	8.2
Shimofuri Goby	Tridentiger bifasciatus	14,234	3.7	3,295	2.0
White Catfish	Ameiurus catus	13,054	3.4	671	0.4
Striped Bass	Morone saxatilis	12,567	3.3	13,939	8.5
Inland Silverside	Menidia beryllina	10,572	2.8	24,037	14.6
Prickly Sculpin	Cottus asper	7,412	1.9	9,035	5.5
American Shad	Alosa sapidissima	5,026	1.3	16,637	10.1
Rainwater Killifish	Lucania parva	2,546	0.7	357	0.2
Lamprey Unknown	Lampetra	1,768	0.5	60	<0.1
Yellowfin Goby	Acanthogobius flavimanus	1,667	0.4	536	0.3
Western Mosquitofish	Cyprinus carpio	1,456	0.4	4	<0.1
Channel Catfish	Ictalurus punctatus	944	0.2	142	<0.1
Chinook Salmon	Oncorhynchus tshawytscha	892	0.2	302	0.2
Redear Sunfish	Lepomis microlophus	874	0.2	15	<0.1
Golden Shiner	Notemigonus crysoleucas	776	0.2	13	<0.1
Pacific Lamprey	Entosphenus tridentatus	567	0.1	0	0
Black Crappie	Pomoxis nigromaculatus	528	0.1	1332	0.8
steelhead	Oncorhynchus mykiss	197	<0.1	69	<0.1
Longfin Smelt	Spirinchus thaleichthys	188	<0.1	677	0.4
Red Shiner	Lepomis microlophus	144	<0.1	0	0
Bigscale Logperch	Percina macrolepida	140	<0.1	8,879	5.4
Threespine Stickleback	Gasterosteus aculeatus	76	<0.1	0	0
Brown Bullhead	Ameiurus nebulosus	54	<0.1	5	<0.1
Warmouth	Lepomis gulosus	48	<0.1	11	<0.1
Sacramento Splittail	Pogonichthys macrolepidotus	32	<0.1	58	<0.1
Black Bullhead	Ameiurus melas	25	<0.1	5	<0.1
Blue Catfish	Ictalurus furcatus	13	<0.1	0	0
River Lamprey	Lampetra ayresii	8	<0.1	0	0
Tule Perch	Hysterocarpus traskii	8	<0.1	0	0
Common Carp	Cyprinus carpio	5	<0.1	2,249	1.4
Fathead Minnow	Pimephales promelas	4	<0.1	0	0
Green Sunfish	Lepomis cyanellus	4	<0.1	0	0
Sacramento Sucker	Catostomus occidentalis	4	<0.1	0	0
Shokihaze Goby	Tridentiger barbatus	4	<0.1	0	0
Smallmouth Bass	Micropterus dolomieu	4	<0.1	0	0
Spotted Bass	Micropterus punctulatus	4	<0.1	1	<0.1
Wakasagi	Hypomesus nipponensis	4	<0.1	0	0
Goldfish	Carassius auratus	0	0	4	<0.1
Hardhead	Mylopharodon conocephalus	0	0	4	<0.1
Total	Total	381,372			

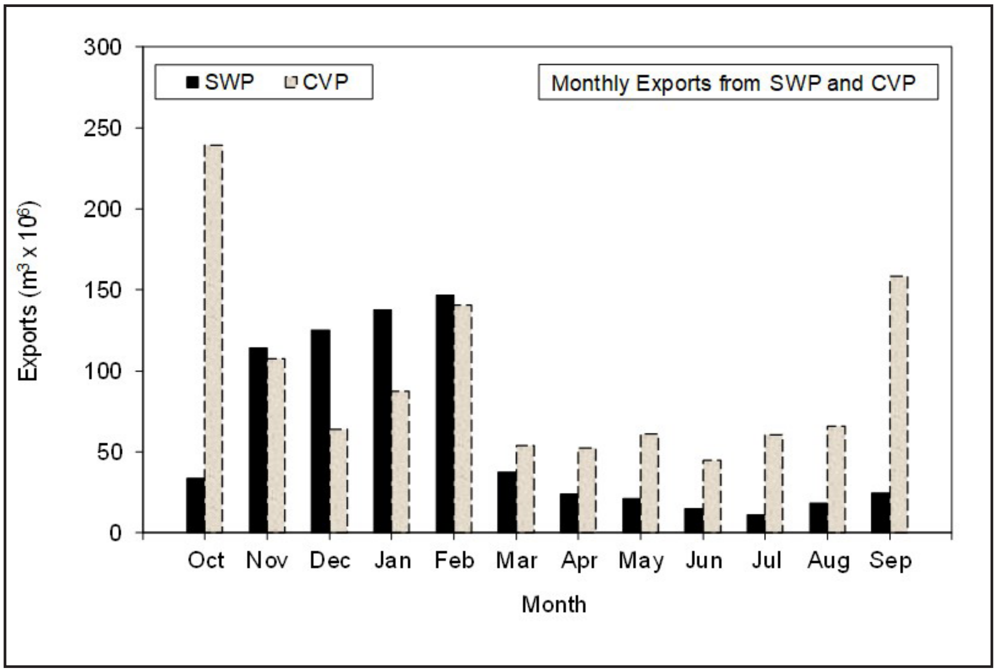

Figure 2 Monthly water exports in millions of cubic meters for the State Water Project and the Central Valley Project, Water Year 2021.

than at the TFCF (751; Table 2). Greater entrainment loss at the SDFPF than at the TFCF was attributable to greater pre-screen loss occurring in Clifton Court Forebay (California Dept. of Fish and Wildlife 2013).

Steelhead

Salvage of steelhead (both wild and hatchery-born) continued the pattern of low salvage observed since WY 2005 (Figure 56). SDFPF salvage of juvenile (198-332 mm FL) and adult (440 mm FL) steelhead in WY 2021 was a record low (69) and decreased from WYs 2018-2020 (244-1,562) , WY 2019 (1,562) WY 2018 (1,111), and the previous record low in WY 2017 (78). The salvage composition for juvenile Steelhead was 513 hatchery and 16 wild fish with most wild steelhead salvaged in May (7)(Figure 7). Two adult hatchery steelhead were salvaged in March.

At the TFCF in WY 2021, salvage of juvenile (205-315 mm FL) steelhead (197) was a drastic decrease from WYs 2018-2020 (488), WY 2019 (725), and WY 2018 (-740), but a largen increase from the record low in WY 2017 (30). Most wild steelhead were salvaged

Table 2. Chinook Salmon annual salvage, percentage of annual salvage, race and origin (wild or hatchery), and loss at the State Water Project and the Central Valley Project, Water Year 2021.

Facility	Origin	Race	Salvage	Percentage	Loss
SDFPF	Wild	Fall	110	98.2	471
SDFPF	Wild	Late-fall	0	0	0
SDFPF	Wild	Spring	2	1.8	9
SDFPF	Wild	Winter	0	0	0
SDFPF	Total Wild		112		480
SDFPF	Hatchery	Fall	18	9.5	75
SDFPF	Hatchery	Late-fall	12	6.3	51
SDFPF	Hatchery	Spring	157	82.6	677
SDFPF	Hatchery	Winter	3	1.6	13
SDFPF	Total Hatchery		190		816
SDFPF	Grand Total		302		1,296
TFCF	Wild	Fall	500	98.4	410
TFCF	Wild	Late-fall	0	0	0
TFCF	Wild	Spring	4	0.8	3
TFCF	Wild	Winter	4	0.8	4
TFCF	Total Wild		508		417
TFCF	Hatchery	Fall	8	2.1	6
TFCF	Hatchery	Late-fall	40	10.4	35
TFCF	Hatchery	Spring	332	86.5	290
TFCF	Hatchery	Winter	4	1	3
TFCF	Total Hatchery		384		334
TFCF	Grand Total		892		751

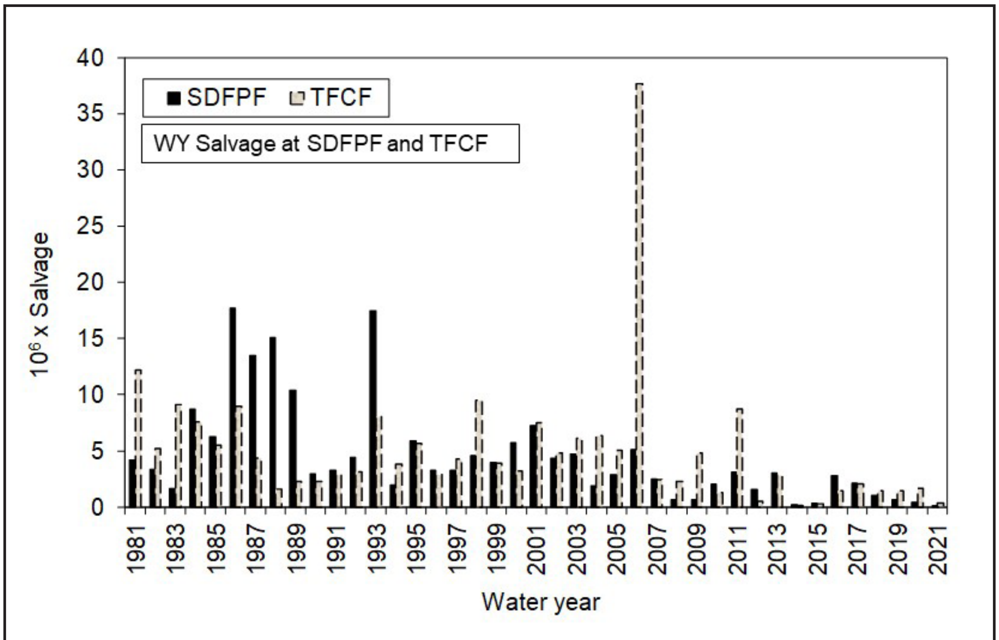

Figure 3 Annual salvage of all fish taxa combined at the State Water Project and the Central Valley Project, Water Years 1981 to 2021.

in March-May (8 fish each) and the salvage composition was 165 hatchery and 32 wild fish(Figure 7).

Striped Bass

Salvage in WY 2021 of juvenile, sub-adult, and adult Striped Bass (20-621 mm FL) at the SDFPF was a record low (13,939) and a large decreased from WYs 2015-2020 (32,508-396,161). , WY 2019(89,675),and WY 2018 (40,283),anddecreasedmarkedlyfrombothWY 2017(396,161) and WY 2016 (224,967)but was similar toWY 2015 (35,070).Salvage in WY 2021 of juvenile, sub-adult, and adult Striped Bass (20-372 mm FL) at the TFCF (12,567) was also a decrease fromWY WYs 2015-2020 (21,398-74,759). The record low salvage of Striped Bass at TFCF occurred in WY 2014 (5,933). , 2019 (44,584),WY 2018 (44,481), WY 2016 (61,787), but was similar to WY 2015 (21,398). Salvage at the SDFPF and the TFCF continued a declining trend observed since the midlate-198090s (Figure 68). Prior to WY 19951990, annual Striped Bass salvage estimates were generally above 1,000,000 fish.

Most Striped Bass salvage at the SDFPF occurred with peaks in November-January and June(Figure 9). Salvage at the SDFPF in November (3,927), December (2,753), January (2,769), and June (2,262) accounted for 84.0% of total WY salvage. At the TFCF, salvage in May (6,065) and June (5,008) accounted for 88.1% of total WY salvage. Striped Bass were salvaged every month at both the SDFPF and the TFCF, with the lowest monthly salvages occurring in September at the SDFPF (55) and in April at the TFCF (4).

Delta Smelt

Salvage of Delta Smelt continued the pattern of mostly low salvage observed since WY 2005 (Figure 710). The only exception occurred in WY 2008 when Delta Smelt salvage was 1,009at the TFCF and at the SDFPF in 2007 (2,360),2012 (1,999), and 2013 (1,701). No Delta Smelt were salvaged at the TFCF in WY 2021 (a record low). The last incidence of Delta Smelt salvage at TFCF was in WY 2019 (8). as in WY 2020, which follows a steep decreasing trend since WY 2013 (300). No Delta Smelt were salvaged at the SDFPF in WY 2021. The last incidence of Delta Smelt salvage at SDFPF was in 2017 (25).as in WY 2020, WY 2019, and WY 2018, but a decrease from WY 2017 (25). The absence of Delta Smelt at the SDFPF is particularly notable as 1,701 fish

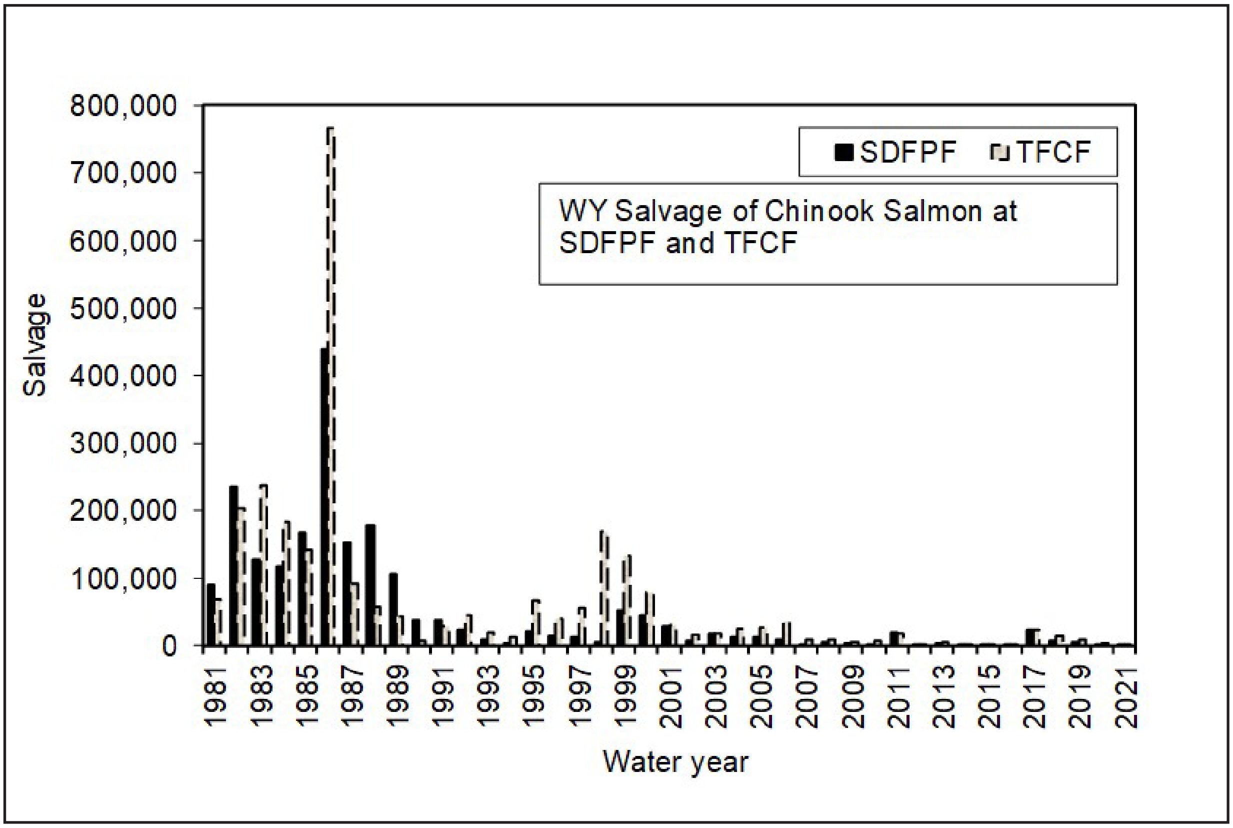

Figure 4 Annual salvage of Chinook Salmon (all races and wild and hatchery origins combined) at the State Water Project and the Central Valley Project, Water Years 1981 to 2021.

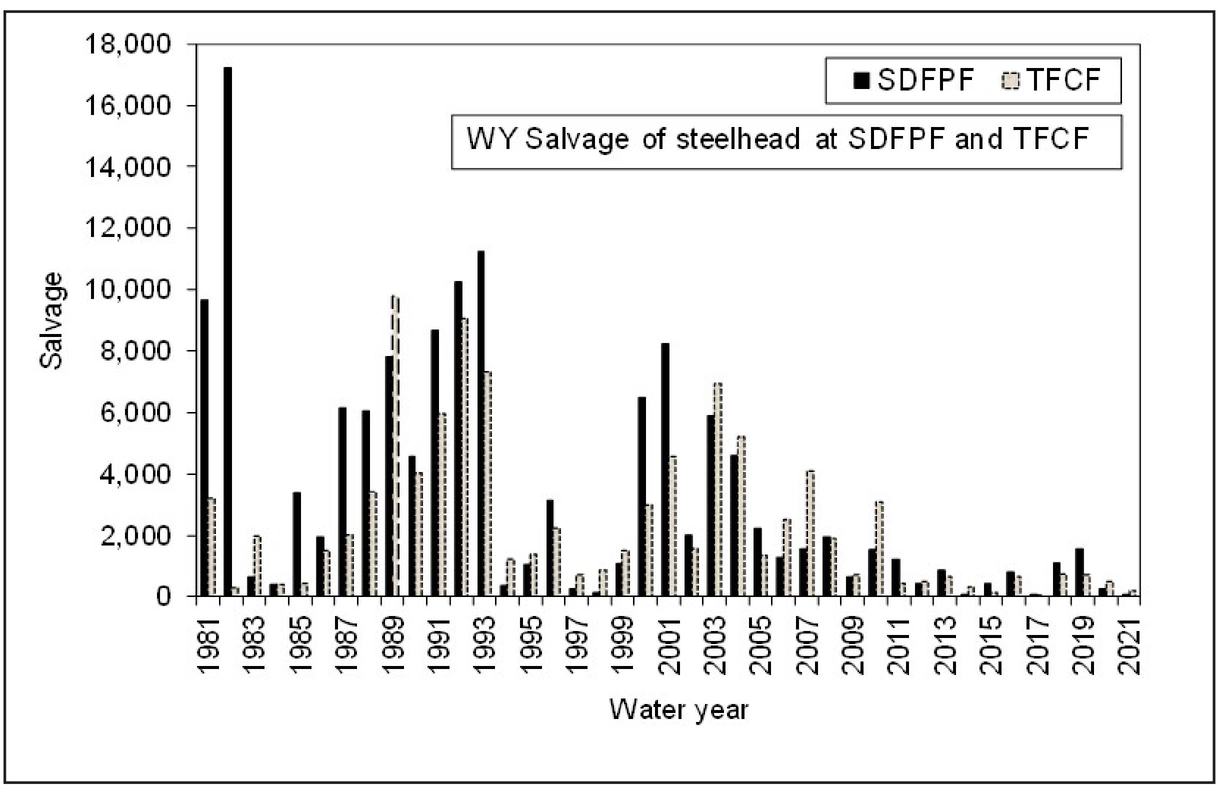

Figure 5 Annual salvage of steelhead (wild and hatchery origins combined) at the State Water Project and the Central Valley Project, Water Years 1981 to 2021.

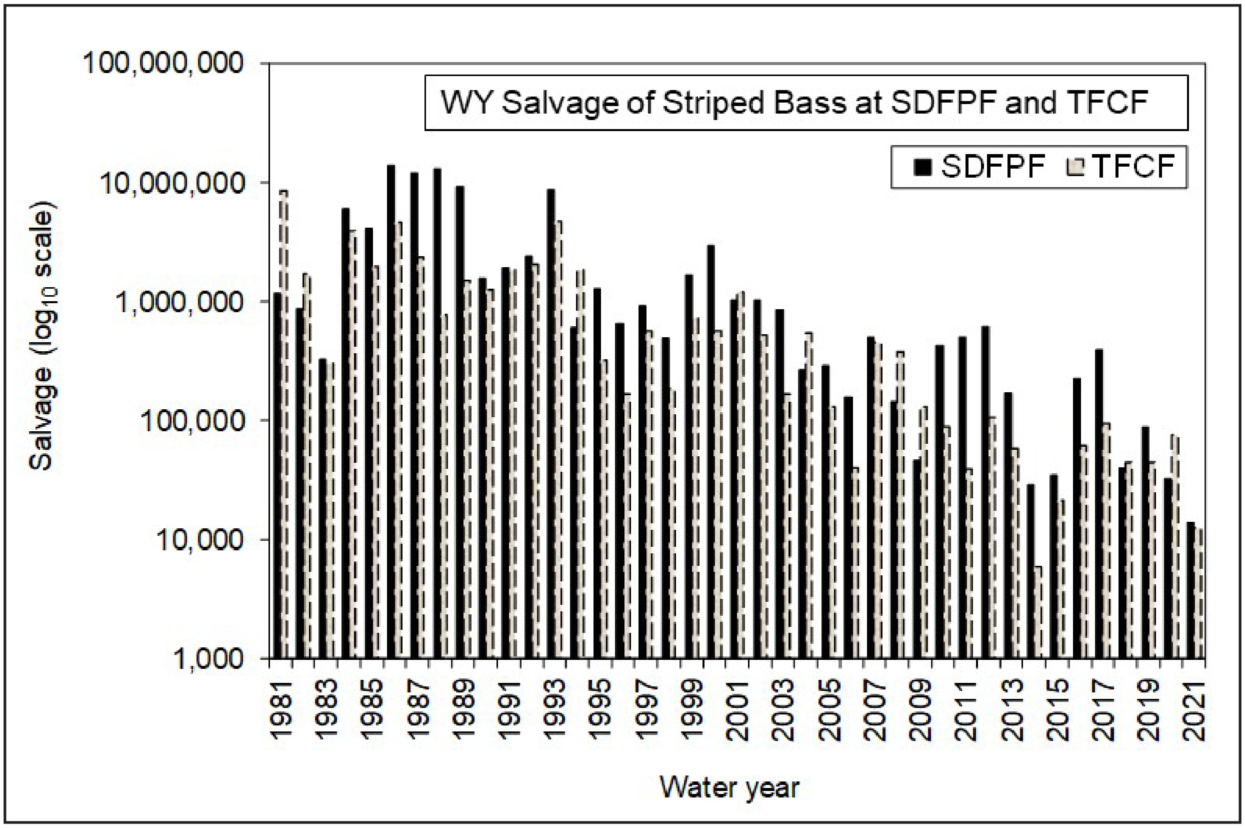

Figure 6 Annual salvage of Striped Bass at the State Water Project and the Central Valley Project, Water Years 1981 to 2021. The logarithmic scale is log10.

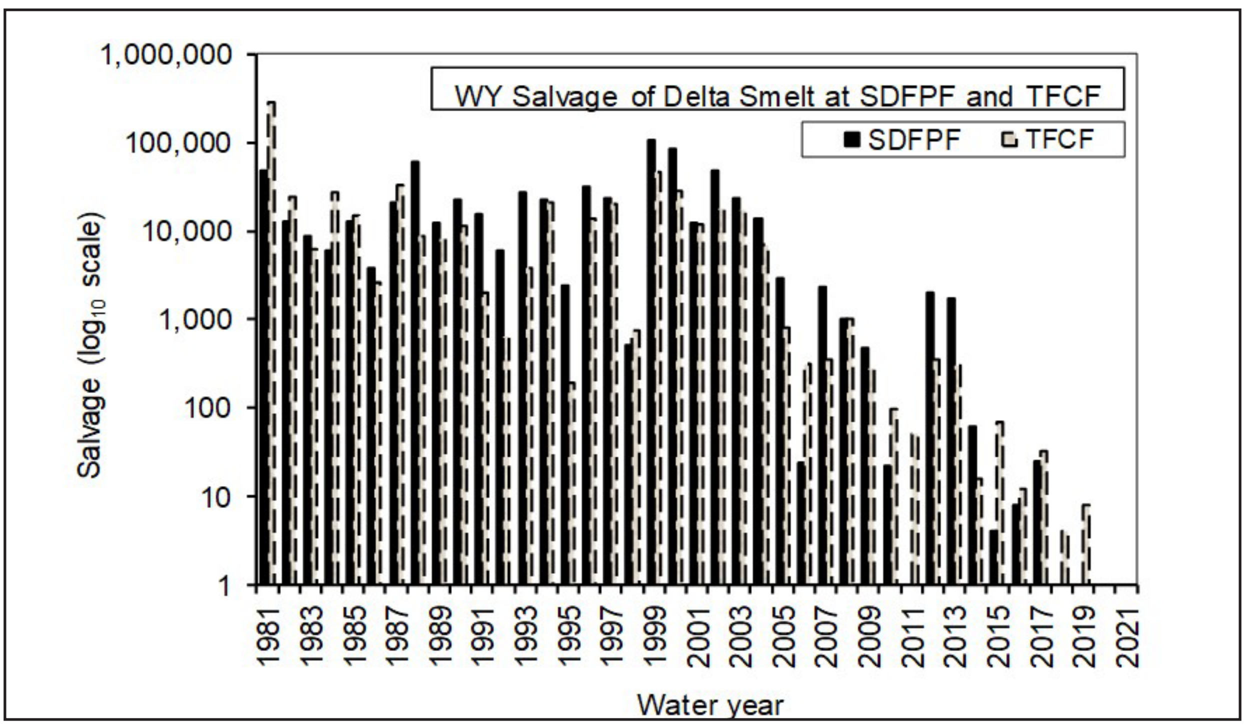

Figure 7 Annual salvage of Delta Smelt at the State Water Project and the Central Valley Project, Water Years 1981 to 2021. The logarithmic scale is log10.

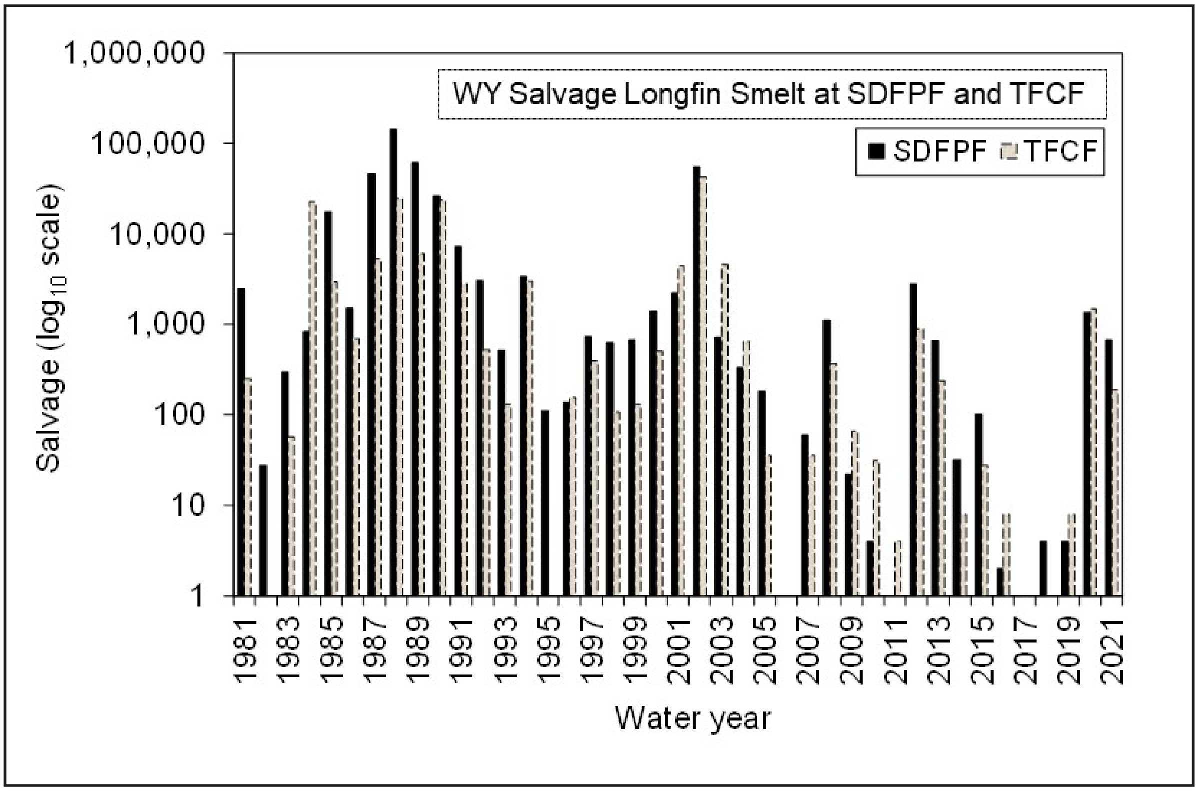

Figure 8 Annual salvage of Longfin Smelt at the State Water Project and the Central Valley Project, Water Years 1981 to 2021. The logarithmic scale is log10.

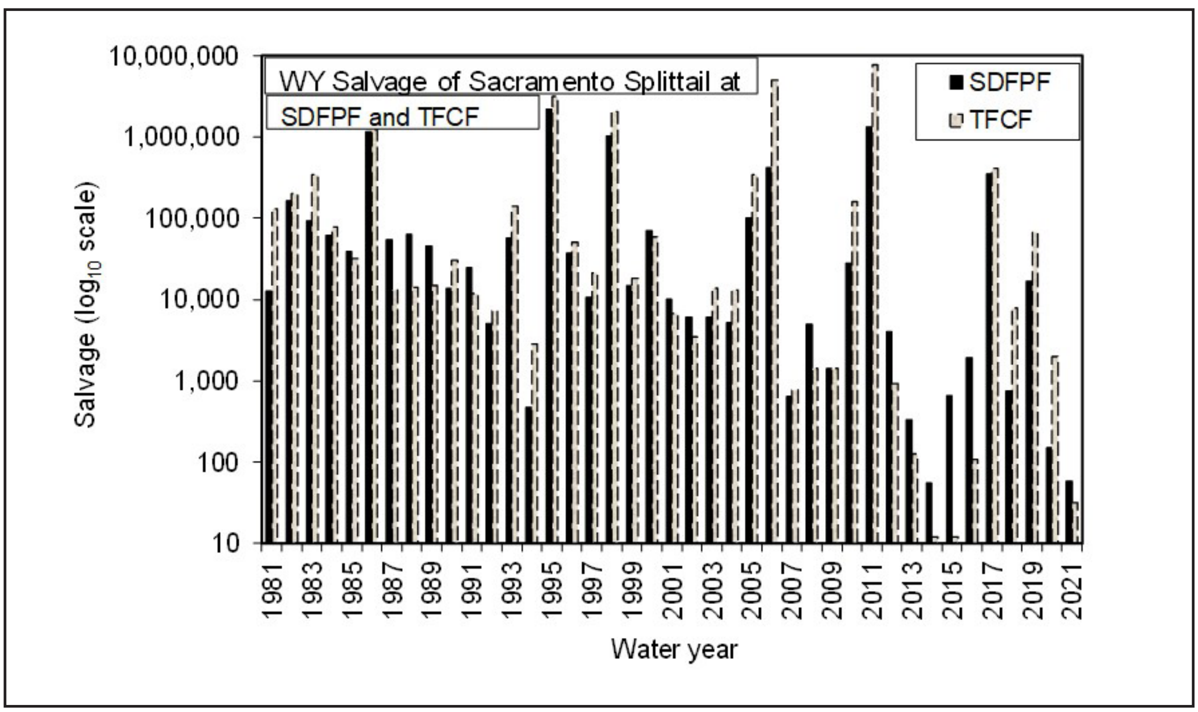

Figure 9 Annual salvage of Sacramento Splittail at the State Water Project and the Central Valley Project, Water Years 1981 to 2021. The logarithmic scale is log10.

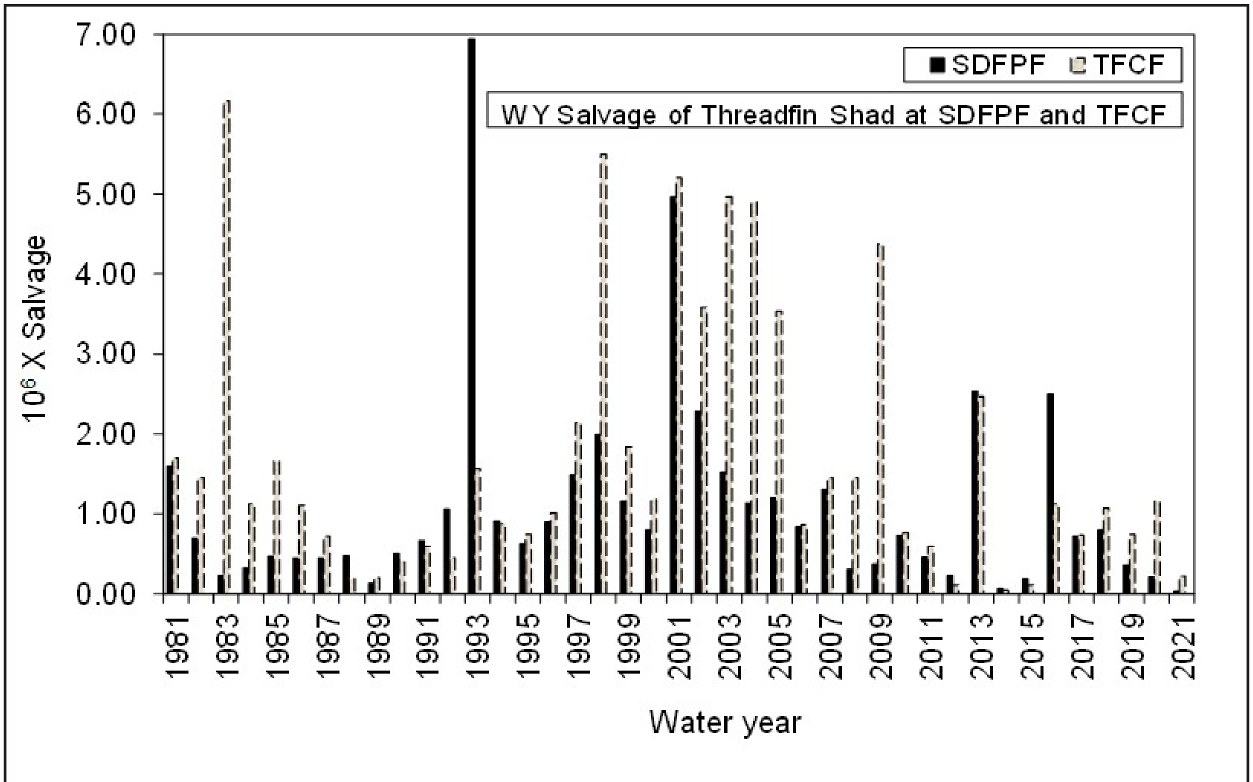

Figure 10 Annual salvage of Threadfin Shad at the State Water Project and the Central Valley Project, Water Years 1981 to 2021.

were salvaged from this facility as recently as WY 2013. This follows general population decreases as observed in recent survey data (Tempel et al. 2021).

No Delta Smelt less than 20mm FL were detected at the TFCF in WYs 2016-2019 or 2021, and only one individual was sampled in WY 2020. No Delta Smelt less than 20mm FL have been detected at the SDFPF since 2016.No Delta Smelt less than 20 mm FL was detected at the TFCF as in WY's 2016-2019, with the exception of one larva sampled in WY 2020. No Delta Smelt less than 20 mm FL were detected at the SDFPF, which has been the case throughout WY's 2016-2020.

Longfin Smelt

Salvage of Longfin Smelt at the SDFPF in WY 2021 (677) was a decrease from WY 2020 (1,360), but a large increase from WYs 2017-2019 (0-4), WY 2018 (4), and WY 2017 (0).). Longfin Smelt salvage at the TFCF in WY 2021 (188) was a large decrease from WY 2020 (1,486), but a large increase from WYs 2017-2019 (0-8) and WYs 2017-18 (0) (Figure 811). Low annual salvage of Longfin Smelt has generally been observed since 1995 and generally coincides with the declining annual populations of Longfin Smelt (Tempel et al. 2021). After 1995, the only exception occurred in WY 2002, when Longfin Smelt salvage was 43,056 at TFCF and 54,594 at SDFPF. It is uncertain why Longfin Smelt salvage continued to increase in WY 2021 but may be related to the recent increase in the population seen in the South Bay and the Delta (Ervin 2020; Tempel et al. 2021). Increases in Longfin Smelt salvage could also be an observed distributional shift as the estuary gets saltier during dry years pulling Longfin Smelt upstream and closer to the facilities.

Salvage of juvenile Longfin Smelt (20-53 mm FL) at the SDFPF occurred in March-May with peak salvage in April (351). Salvage of juvenile Longfin Smelt (20-33 mm FL) at the TFCF also occurred in March-May with peak salvage in April (128). No adult Longfin Smelt were salvaged at either facility.

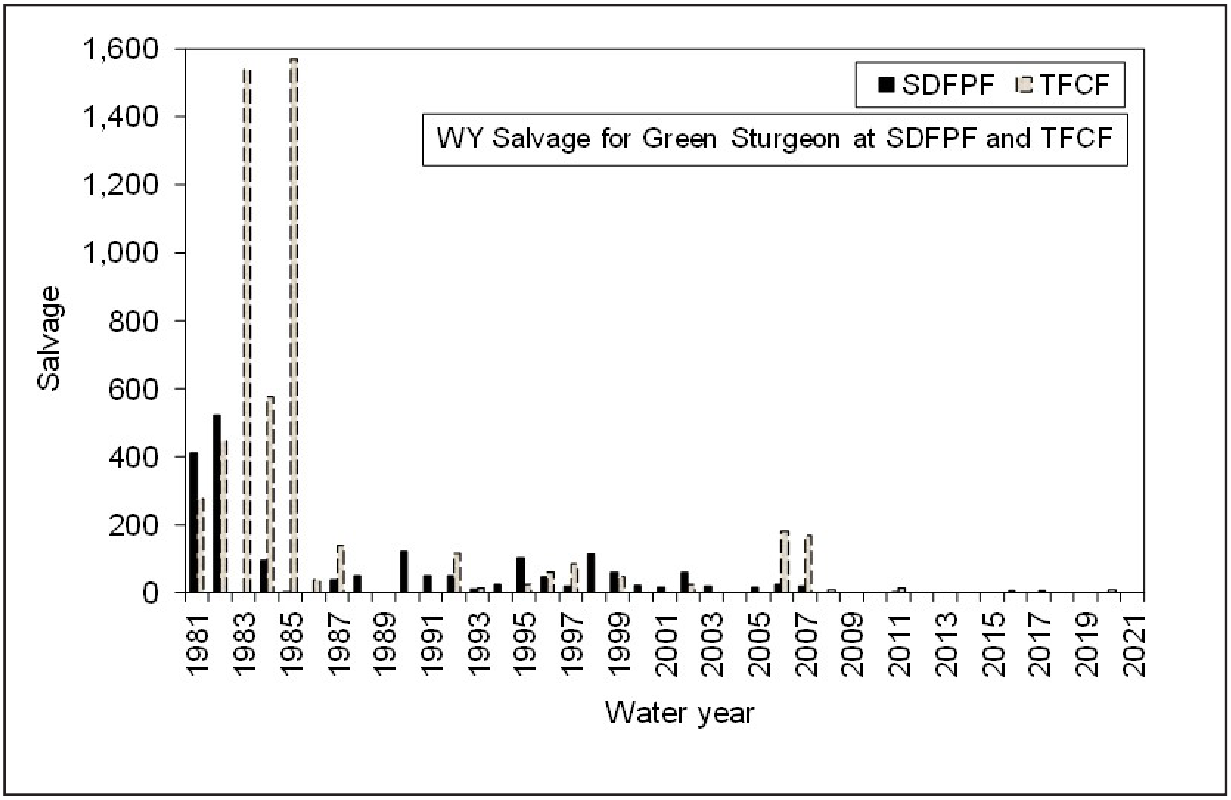

Figure 11 Annual salvage of Green Sturgeon at the State Water Project and the Central Valley Project, Water Years 1981 to 2021.

Longfin Smelt less than 20 mm FL were detected at the SDFPF during 2 dates in March-April, which was a decrease from WY 2020 (4), equal to WY 2018 (2), while none were detected in WYs 2017 and 2019. Longfin Smelt less than 20 mm FL were detected at the TFCF during 13 dates in February-May, which was a decrease from WY 2020 (18), while none were detected in WYs 2019-2017 (0).

Sacramento Splittail

Salvage of Sacramento Splittail in WY 2021 at the SDFPF (58) was a large decrease from WYs 2015-2020 (152-355,538), WY 2019 (16,927), WY 2018 (756), WY 2017 (355,538), WY 2016 (1,951), and WY 2015 (656; Figure 912). Salvage at the TFCF in WY 2021 (32) was a large decrease from WYs 2016-2020 (109-415,5171,960), WY 2019 (66,962), WY 2018 (7,788), a marked decreasefromWY 2017 (415,517)), but similarto WY 2016 (109) and theincreased from the record low in WY 2015 (12). Annual Sacramento Splittail salvage estimates have followed a boom-or-bust pattern, often varying year to year by several orders of magnitude. High Sacramento Splittail salvage is generally associated with wet years and high young-of-the-year recruitment.

Threadfin Shad

Annual salvage in WY 2021 of juvenile and adult Threadfin Shad (20-211 mm FL) was much lower at the SDFPF (35,980) than at the TFCF (228,915; Figure 103). Salvage at the TFCF in WY 2021 was substantially lower than in WYs 2017-2020 (731,760-1,161,551). , WY 2019 (739,723), WY 2018 (1,068,584), and WY2017 (731,760).Salvage at the SDFPF in WY 2021 was also substantially lower than in WYs 2017-2020 (213,244-799,776), WY 2019 (363,205), WY 2018 (799,776), and WY 2017(717,753).. Similar to Sacramento Splittail, annual salvage estimates of Threadfin Shad are highly variable between WYs.

Green Sturgeon

No Green Sturgeon wereas salvaged at the SDFPF at the SDFPF in WY 2021 as in WY's

201720-202017. The last Green Sturgeon salvage occurred in WY 2016 (4). No Green Sturgeon were salvaged at the TFCF in WY 2021, which was a decrease from WY 2020 (8), and equal to WYs 20189-20198 (0) (Figure 114). Low annual salvages (< 200 individuals) have generally been observed since 1983 at SDFPF and since 1986 at TFCF. A second distinct decline in salvage was seen since WY 2008 for both facilities.

Summary

No single parameter controls salvage, but rather there is a complex relationship between many parameters including export rate, outflow, climate, droughts, timing of winter storms, population size, biological opinions for listed species, and regulatory compliance among other factors. In general, total fish salvage has been influenced by exports in recent years (i.e. lower salvage at decreased exports). This trend was generally seen at TFCF but was not found at the SDFPF during 2017-2019 where total fish salvage was higher in WY 2016 despite lower exports. This generally corresponds to a decrease in abundance over time for many fish species, and may be one parameter which affects salvage, resulting in low salvage and detection difficulties. Salvage of species including Chinook Salmon, steelhead, Striped Bass, Delta Smelt, Sacramento Splittail, Threadfin Shad, and Green Sturgeon in WY 2021 decreased, likely attributable to reduced rainfall and drought year low water exports. But noteworthy was the WY 2021 Longfin Smelt salvage, as in WY 2020, continued to increase as compared to recent WYs.

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2021 Status and Trends Report for Pelagic Index Fishes in the San Francisco Estuary

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Abstract

This 2021 Status and Trends Report provides the relative abundance trends and distributional patterns for select pelagic fishes sampled primarily in the upper San Francisco Estuary. Specifically, this report summarizes annual abundance indices and CPUE from six of the Interagency Ecological Program's (IEP) long-term fish monitoring surveys: 1) Spring Kodiak Trawl Survey (SKT), 2) 20-mm Survey, 3) Summer Townet Survey, 4) Fall Midwater Trawl (FMWT), 5) San Francisco Bay Study (SFBS) and 6) US Fish and Wildlife Service Beach Seine Survey. Each year the California Department of Fish and Wildlife, along with the US Fish and Wildlife Service, publishes a series of survey memos reporting abundance indices and distribution of select fishes in the San Francisco Estuary. These fishes include: American Shad (Alosa sapidissima), Threadfin Shad (Dorosoma petenense), Delta Smelt (Hypomesus transpacificus), Longfin Smelt (Spirinchus thaleichthys), Splittail (Pogonichthys macrolepidotus), and Striped Bass (Morone saxatilis). The separate memos are summarized here to provide context to the 2021 fish catch from multiple surveys and gears throughout the year.

During the second year of significant drought, most of the focal species' indices declined relative to 2020, continuing the trend of declining populations for index species in the Estuary. The Longfin Smelt FMWT index notably increased, which was possibly due to high precipitation from an atmospheric river in late October, which lowered water temperature, increased turbidity, and lowered salinity in certain regions. This likely increased Longfin Smelt suitable habitat relative to the fixed FMWT stations and triggered migration into the estuary. The age-0 Striped Bass FMWT index also increased, but only marginally. The SFBS age-0 Longfin Smelt Midwater Trawl (MWT) index increased, while the Otter Trawl (OT) index decreased from 2020. The SFBS MWT age-0 Striped Bass index decreased, while the SFBS OT index increased. However, most indices in 2021 were lower than historic survey highs.

Introduction

The San Francisco Estuary (referred to as the Estuary) is a complex ecosystem that has experienced multiple ecosystem shifts; several of which have been monitored through the efforts of one or more different fish surveys in the last 61 years (Tempel et al. 2021). Individually, each survey gear provides a relative abundance index for select fish species. Collectively, these surveys provide a more holistic picture of the status of the Estuary that covers a broader spatial and temporal range than any single survey (Figure 1). Furthermore, the IEP surveys consist of multiple gear types that target different life stages of the many fish species present in the Estuary. Annual survey memos are published for each gear (except the San Francisco Bay Study) to report on the relative abundance and distribution of select species of interest.

This report provides brief summaries of each survey gear followed by the 2021 species indices and distribution patterns for American Shad (Alosa sapidissima), Threadfin Shad (Dorosoma petenense), Delta Smelt (Hypomesus transpacificus), Longfin Smelt (Spirinchus thaleichthys), Striped Bass

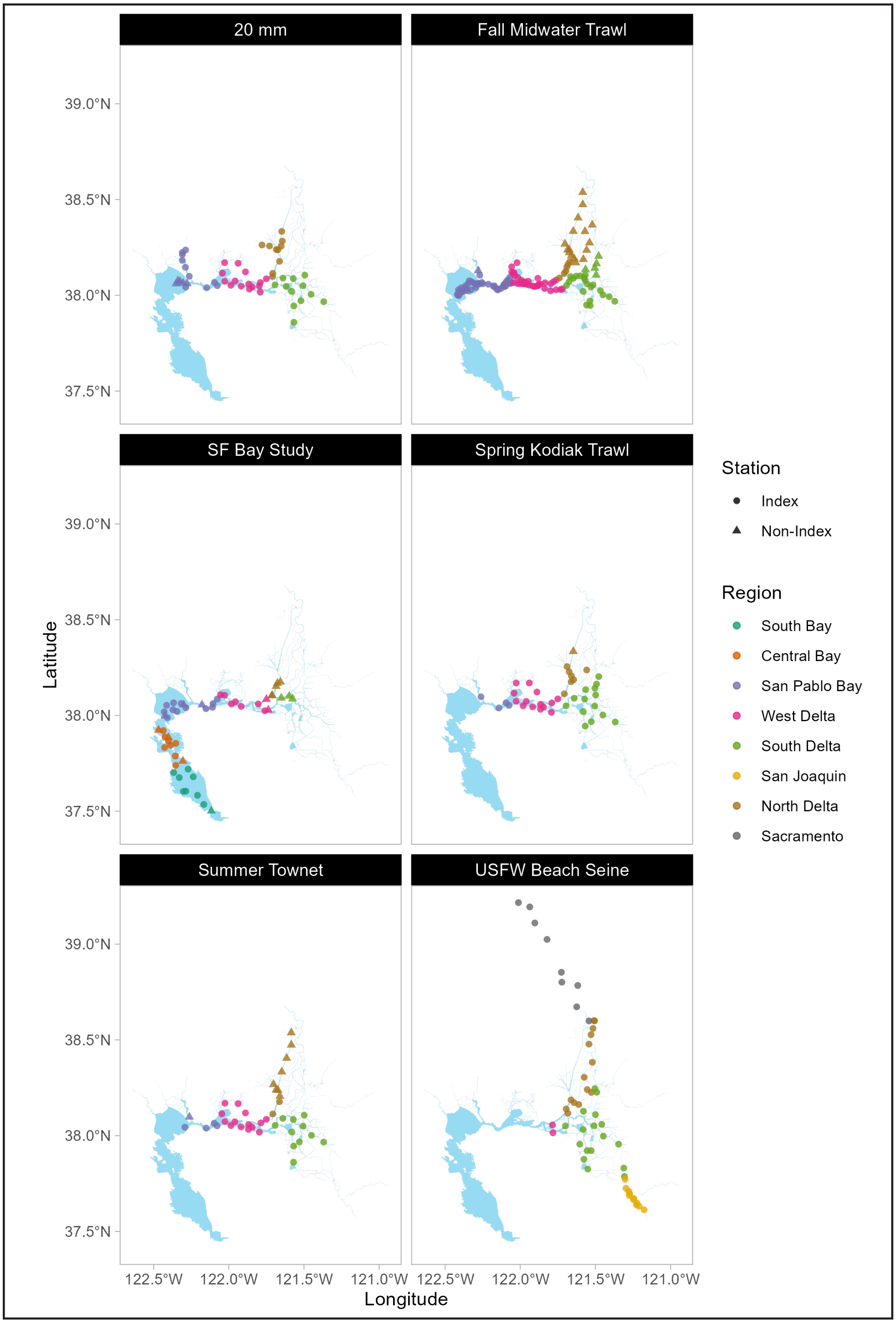

Figure 1. Station distribution for the six IEP surveys presented within this report. Starting from the top left; 20-mm (41 index stations, 11 non-index stations), Fall Midwater Trawl (100 index stations, 22 non-index stations), San Francisco Bay Study (35 index stations, 17 non-index stations), Spring Kodiak Trawl (39 index stations, 1 non-index station), Summer Townet (31 index stations, 9 non-index stations), USFWS Beach Seine (35 index stations, 5 non-index stations).

(Morone saxatilis), and Splittail (Pogonichthys macrolepidotus). We used data from the California Department of Fish and Wildlife (CDFW): 1) Spring Kodiak Trawl Survey (SKT), 2) 20-mm Survey, 3) Summer Townet Survey (STN), 4) Fall Midwater Trawl (FMWT), 5) San Francisco Bay Study (SFBS), and also the 6) US Fish and Wildlife Service (USFWS) Beach Seine Survey. This report aims to provide better context by reporting abundance indices, distribution and abundance-outflow relationships within a single document to more clearly present the changing patterns within the Estuary.

Reports of previous years may be found in the IEP Publications Library. Contrary to previous years, we removed the catch of Wakasagi smelt (Hypomesus nipponensis) from this Status and Trends report to focus on index species. A future report focusing on additional fish species, including Wakasagi smelt, and new designed-based abundance indices (Polanksy et al 2019) are expected later this year. In addition, we include flow-abundance relationships for Striped Bass, American Shad and Longfin Smelt to show impacts of the continuing drought conditions affecting the Estuary.

Methods

The 2021 Water Year, Regional Assignments and the 2021 Survey-Gear Background

Daily freshwater outflow estimates were obtained from the California Department of Water Resources (DWR) DAYFLOW website.

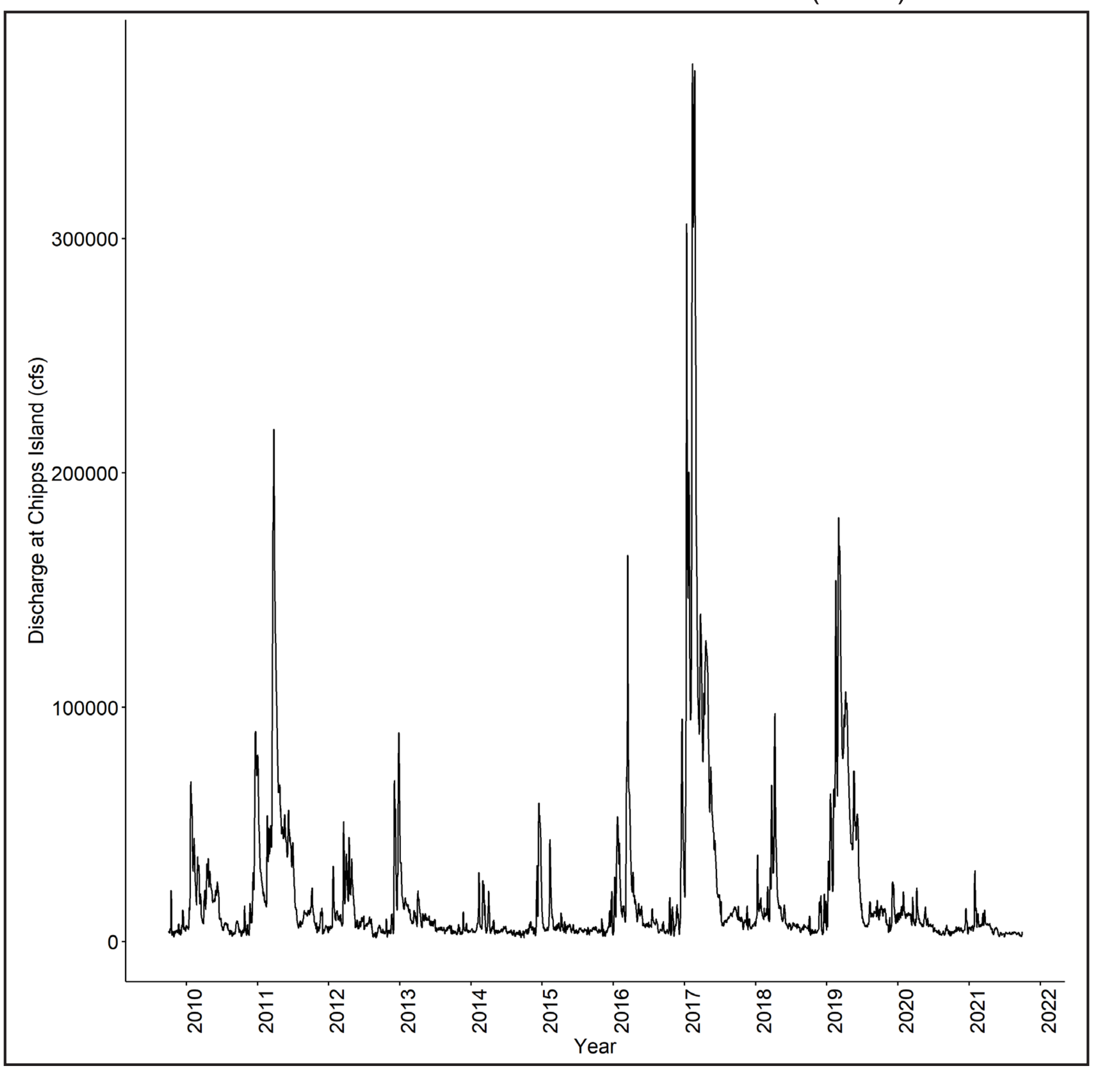

Figure 2. Mean monthly Delta Outflow (cubic feet per second, cfs) at Chipps Island from October 2009-October 2021.

Data was available through water year 2021 (October 2020-September 2021) and mean monthly outflow was plotted to present the 2021 water year relative to the highly variable conditions of the last decade (Figure 2). Water year type classifications were provided by DWR. Yearly FMWT abundance indices were plotted against mean seasonal outflow for select species. The years were classified into different eras as outlined in Tempel et al. 2021, representing regime shift periods in the San Francisco Estuary.

The results of each survey gear are reported here as relative abundance indices and regional catch per unit effort (CPUE). Relative abundance indices are unique to each survey gear and described in detail below and in Table 1. CPUE is reported as the fish catch per tow divided by the volume (m3; 20-mm, STN, FMWT, USFWS Beach Seine; SKT, SFBS MWT) or area swept (m2; SFBS OT). The CPUE from CDFW survey gears (20-mm, STN, FMWT, and SFBS) are all multiplied by 10,000 to help with interpretation. Readers should be aware that CPUE will vary across sample gears due to differences in catchability (but see Gibson-Reinemer et al. 2017 for several standardization techniques to compare CPUE across different types of sampling gear). The regional max, mean and standard error for CPUE is provided for each sample gear,species and each of the eight regions (South Bay, Central Bay, San Pablo Bay, West Delta, South Delta, San Joaquin, North Delta, Sacramento). within. Regional assignment was guided by regions used in the Delta Smelt Life Cycle Model (DSLCM), which defined regions based on CDFW abundance indices and similar environmental conditions (Polansky et al. 2019). The DSLCM does not include all the above regions; Central Bay, South Bay, the San Joaquine and Sacramento regions were added to include regions covered by the USFWS Beach Seine and the SFBS. These regions are color coded for each survey in Figure 1.

The following is a brief description of methods for the individual survey gears. Indices calculated by each survey gear are listed within their respective methods and index calculations are described in Table 1. More information is available in Honey et al. (2004) and online at CDFW Surveys and USFWS and the Juvenile Fish Monitoring Program.

Spring Kodiak Trawl Survey

The Spring Kodiak Trawl (SKT) Survey has sampled annually since its inception in 2002 and determines the relative abundance and distribution of spawning Delta Smelt (Spring Kodiak Trawl, 2021). The SKT samples 40 stations (Figure 1) monthly from January to May. All fish, shrimp, and jellyfish collected in the tow are identified and enumerated. Striped Bass are not separated by age-length and were not included in age-0 Striped Bass comparisons in this report.

In 2021, SKT began on January 4th and completed 151 sampling events by April 29th. During the 2021 season, only 5 index stations were not sampled (1 station in Survey 1 and 4 in Survey 2).

20-mm Survey

The 20-mm Survey monitors distribution and relative abundance of post-yolk sac larval and juvenile Delta Smelt throughout its historical spring range (20-mm Survey, 2021). The survey name refers to the size of Delta Smelt that the survey gear targets, which corresponds to the size at which Delta Smelt are readily identifiable and counted at the State Water Project and Central Valley Project fish salvage facilities. Although designed for Delta Smelt, 20-mm is effective at sampling the pelagic larval fish community present in the spring and early summer. Since 1995, CDFW has conducted the 20-mm Survey on alternate weeks from early March through early July, completing 9 surveys per year since 2005. Three tows are conducted at each of 47 stations (Figure 1) using a fixed-mouth, 1,600 µm mesh net (Dege and Brown 2004).

Table 1. Detailed descriptions of each index presented in this report and its corresponding survey gear including the years conducted, gear type, index calculation, index species, seasonal sampling period, and targeted life stages.

Survey	Years Active	Gear Type	Index Description	Index Species	Index time period	Sampling time period	Targeted Life Stage
Spring Kodiak Trawl	2004-present	Trawl-net, 7.6m x 1.8m mouth size with graduated changes in mesh size beginning at 5cm stretch-mesh to 0.64cm stretch Mesh at the cod-end.	To calculate the index, stations are grouped into 3 spatial regions and a mean catch per 10,000 cubic meters of water (i.e., CPUE) is calculated. The regional means are then summed to create an index for each survey, and survey indices are summed to calculate the SKT index.	Delta Smelt	4 Sampling Surveys	January-April	Adult
20 MM	1995-present	Fixed-mouth, 1,600 µm mesh net	Catch data averaged by survey (for fish <60mm FL) for all stations to determine when mean FL reaches or surpasses 20 mm. The 2 surveys before and after when this target is reached are used to calculate the annual abundance index. From this subset of surveys, DS CPUE is calculated for each of the 41 index stations. CPUE for each tow is calculated by dividing catch by the volume of water filtered during the sample and multiplied by 10000 to obtain a whole number. CPUE is then averaged across tows for each index stations. The resulting mean station CPUE values are log (log10(x+1)) transformed. These values are averaged within each survey and then the mean values are back transformed to return to original scale. One is subtracted from each survey value and these values are summed across the 4 surveys to obtain the annual abundance index.	Delta Smelt	4 sampling surveys bracketing when fish reach 20 mm fork length.	March-July	Larval-Juvenile
Summer Townet	1959-present	Fixed-mouth,	Catch per tow data from the 31 index stations are used for index calculations. For each survey, the total species catch by each station is multiplied by a water volume weighing factor. These products are then summed across all index stations within a survey, then divided by 1000 to produce the survey abundance index. The annual abundance index for age-0 Striped Bass is interpolated using index values from the two surveys that bound the date when mean FL reached 38.1 mm. For Delta Smelt, the annual index is the average of the first two survey indices of each year.	Age-0 Striped Bass, Delta Smelt	2 sampling surveys bracketing when age-0 Striped Bass reach 38.1 mm fork length; Delta Smelt index is calculated only for surveys 1 and 2.	June-August	Larval-Juvenile

Survey	Years Active	Gear Type	Index Description	Index Species	Index time period	Sampling time period	Targeted Life Stage
Survey	**Years Active**	**Gear Type**	**Index Description**	**Index Species**	**Index time period**	**Sampling time period**	**Targeted Life Stage**
Fall Midwater Trawl	1967-present	Midwater trawl using 17.7m long net tapering down to 1.2cm mesh	100 index stations are grouped into 14 regions. Monthly indices are calculated by averaging catch per tow in each region, multiplying these means by their water volume weighting factors, and summing these products. Annual abundance indices are they sum of the 4 monthly indices.	Delta Smelt, Longfin Smelt, age-0 Striped Bass, Threadfin Shad, American Shad	4 sampling surveys	September-December	Juvenile-Sub-adult
San Francisco Bay Study	1980-present	Midwater trawl using 17.7m long net tapering down to 1.2cm mesh; otter trawl with a 0.55cm mesh codend	Annual abundance indices are calculated as the average of monthly indices over the period for which the age class was most abundant. The 35 index stations are assigned to 5 regions. The region's water volume weighting factor (for the MWT) or the areal weighting factor (for the OT) is multiplied by the mean regional CPUE and these products are summed across all 5 regions for the monthly indices.	Age-0, age-1, and age-2+ Longfin Smelt, age-0 Delta Smelt, age-0 Striped Bass, age-0 American Shad, age-0 Splittail	One sampling survey per the following months, February-May (Aage-1, age-2+ Longfin Smelt); May-October (age-0 Longfin Smelt, Splittail); June-October (Delta Smelt, Striped Bass); July-October (American Shad)	Monthly year round	Juvenile-Adult
USFWS Beach Seine	1994-present	Beach seine	The catch per m3 for seine hauls conducted at each station is averaged by month, CDFW subarea, and year to calculate an annual index per subarea. The annual subarea indices are then averaged by region (Delta, Sacramento River, and San Joaquin River) and across regions to produce the overall annual age-0 Splittail index.	Age-0 Splittail	8 sampling surveys from May-June	Weekly year round	Larval-Juvenile

The 2021 20-mm Survey began on March 22nd and completed 1041 tows by July 16, 2021. The 20-mm Survey occasionally cannot sample all stations in a survey due to barriers such as aquatic vegetation, vessel mechanical challenges, staffing shortages during COVID, and weather. Two index stations were missed in Survey 4 and 3 index stations were unable to be sampled in Survey 5. In Survey 7, all stations west of the confluence could not be sampled. Finally, Survey 8 and 9 each had one index station that could not be sampled.

Summer Townet Survey

The STN survey began in 1959 to index age-0 Striped Bass abundance, which it has done for all years except 1966, 1983, 1995, and 2002. Delta Smelt indices were also calculated for the period of record, except for 1966 through 1968. Historically, STN conducted two to five surveys annually, but in 2003 CDFW standardized sampling to six surveys per year, beginning in early June and continuing every other week into August (Hieb et al. 2005). STN samples 40 stations, 9 of which are considered non-index stations. Non-index stations are not used in index calculations (Figure 1 and Table 1), but they are included in CPUE reports. More detailed descriptions of field procedures can be found at the CDFW STN web page

The 2021 STN season began on June 7th and ended on August 19th. All index stations were sampled during the 2021 season. However, station 721, a non-index station, was not sampled due to aquatic vegetation and was replaced by a new station, 722, approximately two kilometers downstream of station 721 in Cache Slough.

Fall Midwater Trawl

The FMWT survey was established in 1967 to examine the relative abundance and distribution of age-0 Striped Bass. It has been conducted in all years except 1974 and 1979 (for additional information see the CDFW FMWT web page). Over time, the FMWT survey has also been used to track other common pelagic fish species in the upper Estuary (Stevens 1977), including American Shad, Threadfin Shad, Delta Smelt, Longfin Smelt, and Splittail. The FMWT survey currently conducts a single tow at 122 stations monthly from September through December (Figure 1). The annual abundance index calculation uses catch per tow data from 100 index stations (Stevens 1977). The remaining 22 stations were added in 1990, 1991, 2009, and 2010 to improve understanding of Delta Smelt distribution and habitat use. The 100 index stations were grouped into 14 regions to calculate monthly and annual abundance indices (See Table 1). The catch from the 22 non-index stations can be substantial, as areas like the Sacramento Deep Water Shipping Channel (SDWSC) and Cache Slough appear to be refuge habitat for many pelagic species as conditions deteriorate in other areas of the Estuary. Since these new stations were added, a large portion of the total American Shad and Threadfin Shad catch has been from this area.

The 2021 FMWT sampling began on September 1st and was completed on December 16th. All stations were sampled, except for station 721. This station was not sampled due to aquatic vegetation and was replaced by station 722, approximately two kilometers downstream of station 721 in Cache Slough.

San Francisco Bay Study

The SFBS began in 1980 to determine the effects of freshwater outflow on the abundance and distribution of fishes and mobile crustaceans throughout the San Francisco Estuary (Figure 1). Each month the SFBS samples 52 stations; 35 stations are core stations (i.e., original stations; Figure 1), which have been consistently sampled since 1980 and used to calculate the annual abundance indices (see Table 1, Orsi 1999). Every station is sampled with an otter trawl (OT) to sample the demersal fishes, shrimp, and crabs, and a midwater trawl (MWT) to sample pelagic fishes and gelatinous zooplankton (see the CDFW SFBS web page for additional information).

Most SFBS surveys and stations were completed in 2021, except the entire January survey was cancelled due to COVID restrictions. An otter trawl at station 317 was not sampled in February due to fouling of mud and amphipod tubes. Additional information about study methods, including index calculation, can be found in IEP Technical Report 63 (Orsi 1999). See Hieb et al. (2019) for fish abundance and distribution trend information for other species through 2016.

USFWS Beach Seine

The USFWS has conducted the Beach Seine Survey since 1976 and has held its current design since 1994.The USFWS conducts weekly beach seine sampling year-round at approximately 40 stations in the Delta and in the lower Sacramento and San Joaquin rivers (Figure 1; Brandes and McLain 2001). Data collected from 35 stations in May and June are used to calculate the annual age-0 Splittail abundance index (see Table 1). Age-0 Splittail are determined using a fork length minimum cutoff of 25 mm and maximum fork length cutoffs of 85 mm in May and 105 mm in June. Fish below the minimum cut off are too small to be sampled effectively by the net and fish above the maximum cutoff are considered age-1.

In May and June of 2021, the USFWS beach seine survey was minimally impacted by COVID mitigation measures with only four of the seine sites cancelled on one occasion due to COVID mitigation measures. For the other times that scheduled sampling was not able to occur the reasons varied, but mostly was due to vegetation growing in the site or an excess of mud that made sampling impossible. In total, 155 out of 243 scheduled beach seine hauls were completed (~64%) and a total of 769 age-0 Splittail were captured.

At the time of writing, the complete 2021 catch report was not available, therefore only Splittail CPUE is reported from the Beach Seine Survey.

Results and Discussion; Flow-Catch Relationships

Flow and FMWT Catch Relationships

The 2021 water year was the second contiguous year of drought in the Estuary (See discharge Figure 2; CA Dept of Water Resources, 2021). Similar drought conditions occurred in California in 2014 (CA Dept of Water Resources, 2021), however 2021 had higher air temperatures including record setting monthly average temperatures in October (2020), June and July (2021). During severely dry years, water flow in the Sacramento River, the major source of water for the Estuary, is dominated by reservoir releases. Lake Oroville and San Luis Reservoir reached record or near record low conditions by the end of the 2021 water year. In response to the drought, the State constructed a temporary emergency salinity control barrier in the West False River in the Sacramento-San Joaquin Delta to help preserve reservoir water storage by reducing need for reservoir releases and prevent further salinity intrusion into the central and south Delta (CA Dept of Water Resources, 2021). Barriers could alter fish connectivity within the Delta and impact the catch reported by surveys conducted in the Estuary.

Decreased water flow into the Estuary can have complex impacts on fishes. In general, decreased flow can result in poor habitat conditions (I.e., increased temperatures, increase in harmful algal blooms, decreased size, a more upstream location of the low salinity zone, lower primary and secondary productivity, etc.), which can negatively impact production and survival of young fish. American Shad and Striped Bass abundance from the FMWT maintained a positive relationship to freshwater outflow (Figures 3 and 4, respectively). A linear regression comparing FMWT abundance indices to outflow showed a statistically significant positive relationship since 2013 for American Shad ($F(1,7) = 14.6$, p = 0.007; Figure 3) and Striped Bass (F(1,7) = 17.1, p = 0.004; Figure 4).

However, native age-0 Longfin Smelt (Figure 5) had higher than expected abundances relative to Delta Outflow which rendered the linear regression for 2013 to 2021 statistically insignificant (F(1,7) = 0.264, p = 0.6). Because 2021 FMWT Longfin Smelt catch was mostly age-0 size class, this pattern likely reflects a change in habitat location, relative to the fixed FMWT stations, wherein greater salinity intrusion could have brought more Longfin Smelt into the geographic range of the FMWT survey. Alternatively, prior to the 2021 November survey an atmospheric river temporarily increased freshwater flow into the delta, possibly initiating Longfin Smelt migration into the Estuary and temporarily

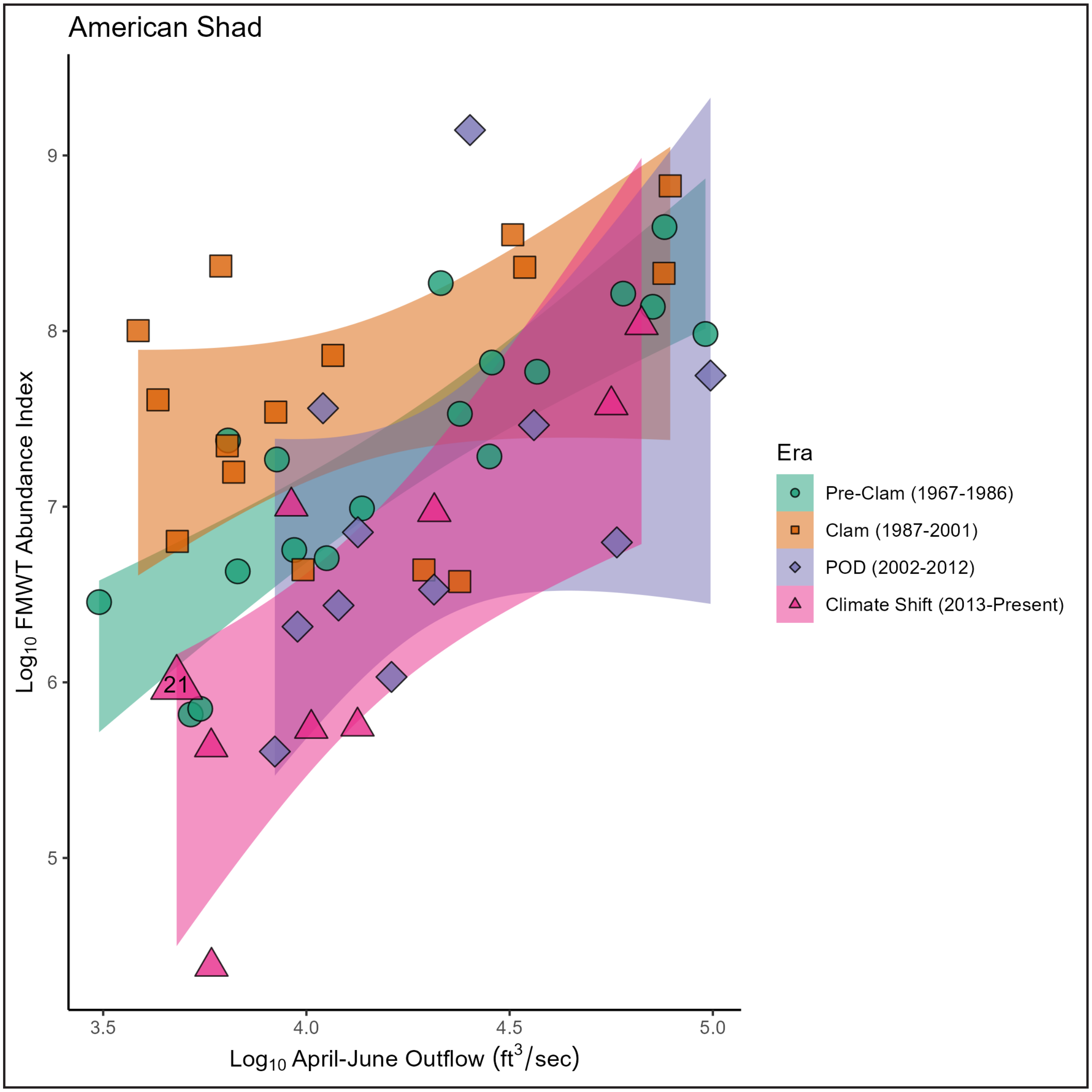

Figure 3. April – June Outflow (log cfs) relationships with the Fall Midwater Trawl American Shad indices (log scale, all fork length sizes, 1967-2021). Temporal ranges are from Tempel et al 2021 and correspond to regime shift periods in the San Francisco Estuary. Linear regressions were statistically significant for the Pre-Clam (1967-1986; F(1,16) = 43.3, p < 0.001) and Climate Shift (2013-2021; F(1,7) = 14.6, p = 0.007) Eras. The regression was not significant for the Clam (1987-2001; F(1,13) = 2.83, p = 0.116) or POD (2002-2012; F(1,9) = 2.64, p = 0.138) Eras.

Table 2. The 2021 American Shad regional CPUE (catch per 10,000 m3 for 20-mm, STN, FMWT and SFBS MWT; catch per 10,000 m2 for SFBS OT).

Region	Gear	Stations (n)	max CPUE	mean CPUE	se
South Bay	SFBS MWT	9	5.19	1.15	0.55
Central Bay	SFBS MWT	8	3.3	1.62	0.37
San Pablo Bay	20MM	50	0	0	0
San Pablo Bay	FMWT	164	16.13	0.93	0.18
San Pablo Bay	SFBS MWT	40	18.03	2.83	0.52
San Pablo Bay	SFBS OT	1	33.81	33.81	NA
San Pablo Bay	SKT	19	1.03	0.05	0.05
San Pablo Bay	STN	15	0	0	0
West Delta	20MM	75	0	0	0
West Delta	FMWT	136	22.78	1.41	0.29
West Delta	SFBS MWT	51	37.23	5.71	1.08
West Delta	SFBS OT	3	35.06	16.07	10.23
West Delta	SKT	70	34.33	3.84	0.81
West Delta	STN	42	0.02	0	0
North Delta	20MM	49	1.45	0.08	0.04
North Delta	FMWT	88	79.41	2.74	1.04
North Delta	SFBS MWT	22	593.08	48.09	26.6
North Delta	SFBS OT	1	10.52	10.52	NA
North Delta	SKT	40	11.87	1.02	0.43
North Delta	STN	30	1.76	0.12	0.07
South Delta	20MM	58	0.12	0.01	0
South Delta	FMWT	99	8.65	0.3	0.13
South Delta	SFBS MWT	11	23.77	9.3	2.37
South Delta	SFBS OT	1	24.27	24.27	NA
South Delta	SKT	66	2.79	0.1	0.05
South Delta	STN	33	0	0	0

increasing Longfin Smelt catch. The long-term impacts to the Longfin Smelt population due to decreased freshwater outflow and subsequent changes to the spatial salinity gradients will need to be observed carefully going in the future.

Results and Discussion; Fish Catch

American Shad Summary

American Shad are native to the Atlantic Coast of North America and were introduced to the Estuary in the 1800's (Dill and Cardone 1997). American Shad are anadromous, and adults return from the ocean to fresh water in the upper Estuary in the spring to spawn. Juveniles are usually detected by surveys in late-spring and summer as they migrate to the ocean. The FMWT and SFBS MWT American Shad indices represented mainly out-migrating juveniles. Annual indices from both surveys decreased in 2021 (Figure 6). The FMWT reported an index of 398, a 64% decrease from the previous year. SFBS also reported a lower index at 2,960, a 85% decrease from 2020. Decreasing indices likely reflect the continuing dry conditions experienced in and upstream of the upper Estuary, closing in on other historical dry periods. In 2021, 31% of the total American Shad catch was from non-index stations and 91% of these was from the SDWSC. Non-index station catch showed a similar decline to index station catch, decreasing 65% from the previous year.

Adult American Shad were first observed by SKT in January, moving into freshwater regions to spawn (Kimmerer et al. 2009), peaking in March (West Delta 3.8 CPUE). These regions included the North and South regions of the Delta. Larval American Shad were first observed by 20-mm in March and CPUE peaked within the North and South Delta regions in June. STN also saw peak

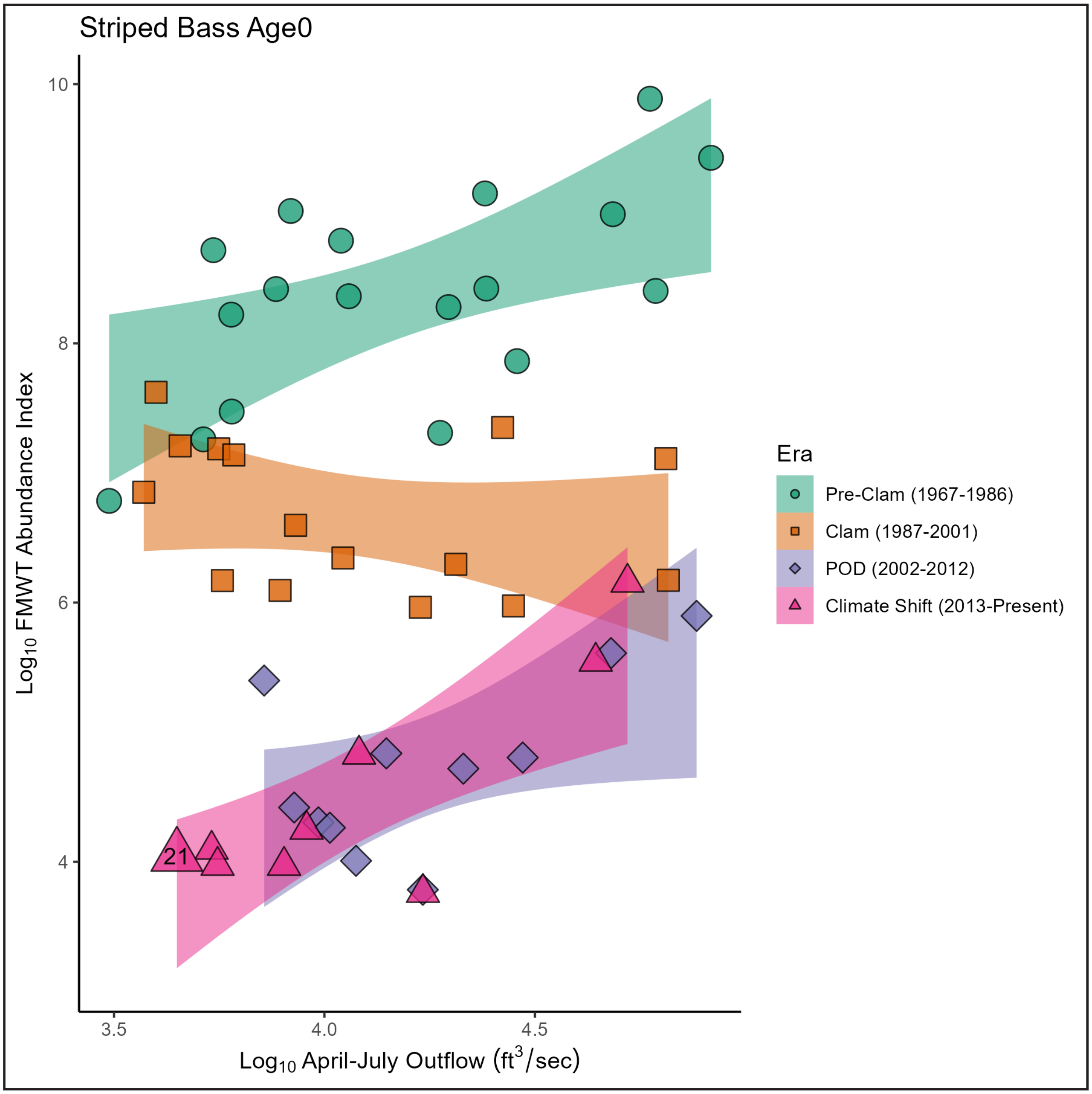

Figure 4. April – July Outflow (log cfs) relationships with the Fall Midwater Trawl age-0 Striped Bass indices (log scale, 1967-2021). Temporal ranges are from Tempel et al 2021 and correspond to regime shift periods in the San Francisco Estuary. Linear regressions were statistically significant for the Pre-Clam (1967-1986; $F(1,16) = 9.38$, $p = 0.007$), POD (2002-2012; $F(1,9) = 5.16$, $p = 0.049$), and Climate Shift (2013-2021; $F(1,7) = 17.1$, $p = 0.004$) Eras. The regression was not significant for the Clam (1987-2001; $F(1,13) = 1.49$, $p = 0.243$) Era.

numbers of larval to juvenile American Shad in June, but only in the North Delta stations. In fall (FMWT catch), peak American Shad numbers were observed in the West and North Delta in October (79.4), and peak numbers in the South Delta were seen in November. These fish began to migrate towards the ocean (Moyle 2002) in November, with peak numbers of American shad observed in San Pablo Bay in the month of December. The SFBS first collected age-0 American Shad in July in the North, South, and West Delta regions. SFBS MWT CPUE peaked in September in the North Delta region (593; Table 2). Through summer and fall, SFBS MWT CPUE increased in the San Pablo Bay, Central Bay, and South Bay regions reflecting American Shad migration downstream (Figure 2).

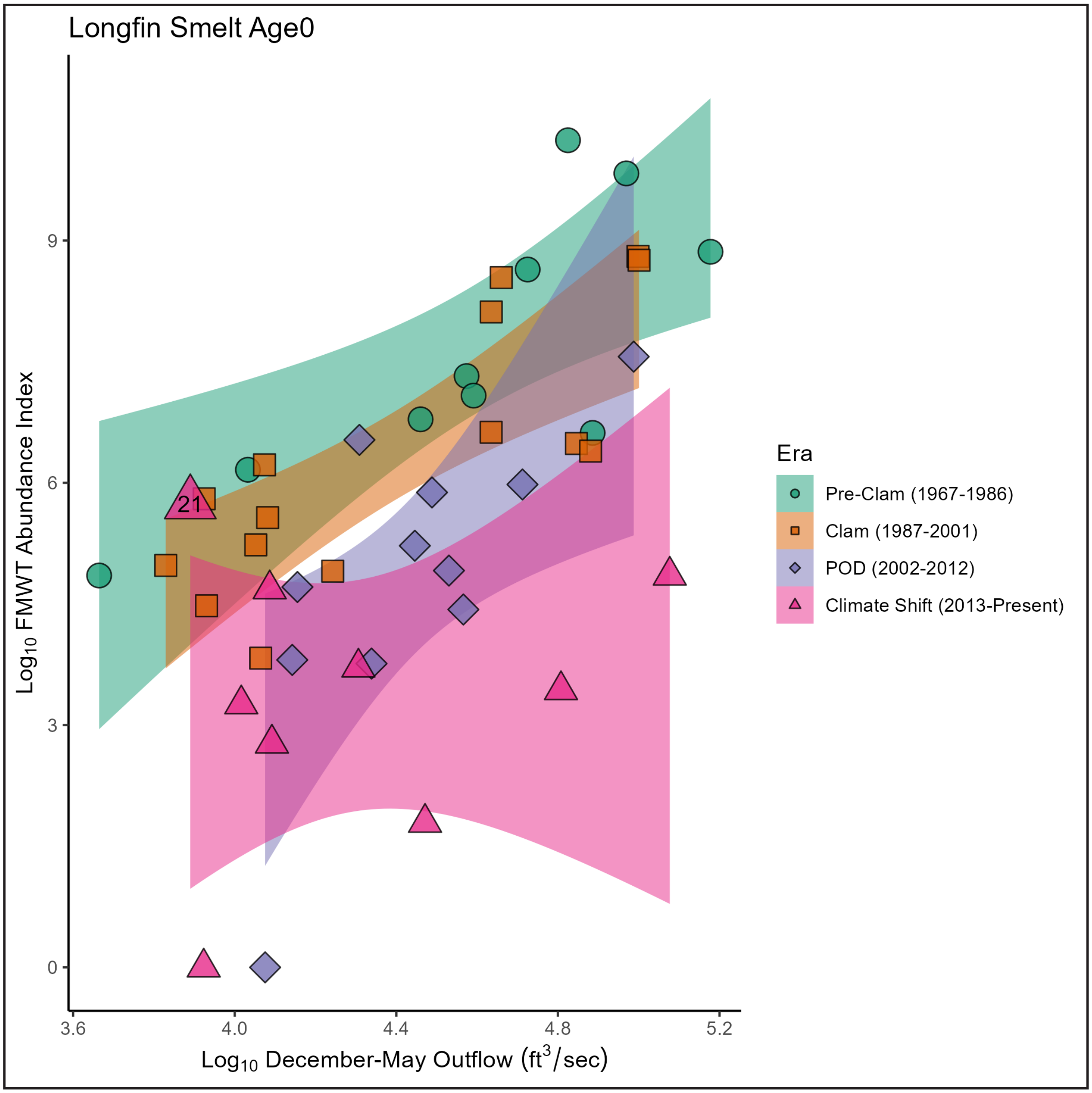

Figure 5. December – May Outflow (log cfs) relationships with the Fall Midwater Trawl age-0 Longfin Smelt indices (log scale, 1975-2021). Temporal ranges are from Tempel et al 2021 and correspond to regime shift periods in the San Francisco Estuary. Linear regressions were statistically significant for the Pre-Clam (1967-1986; $F(1,8) = 13.7$, $p = 0.006$), Clam (1987-2001; $F(1,13) = 23.9$, $p < 0.001$) and POD (2002-2012; $F(1,9) = 9.47$, $p = 0.013$) Eras. The regression was not significant for the Climate Shift (2013-2021; $F(1,7) = 0.264$, $p = 0.6$) Era.

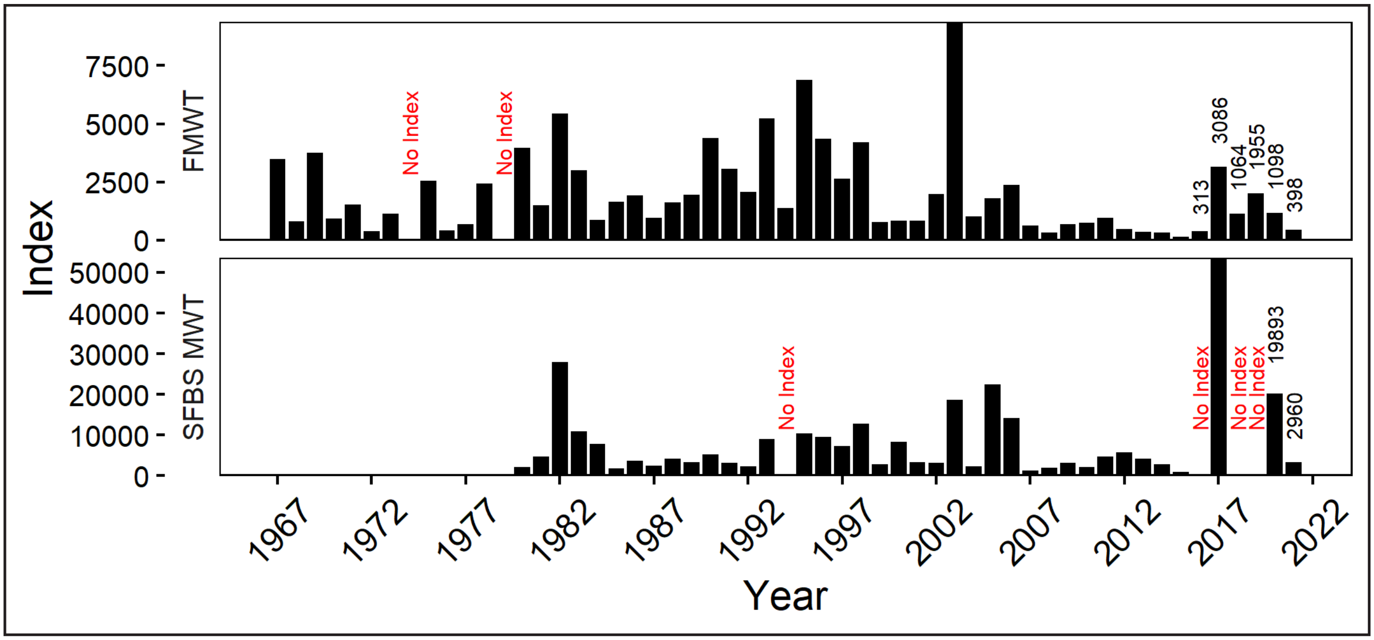

Figure 6. American Shad annual abundance indices from (top): Fall Midwater Trawl Survey (all sizes, 1967-2021), A) San Francisco Bay Study Midwater Trawl (age-0, 1980-2021).

Threadfin Shad
Summary

Threadfin Shad are native to the Gulf Coast of North America and were introduced to California in the 1950's as food supply for other pelagic species (Dill and Cordone 1997). They spawn in freshwater (Delta regions) during late-spring and summer. The 2021 FMWT Threadfin Shad index was 221, a 65% decrease from the previous year (Figure 7). Catch from non-index stations accounted for 76% of the total catch, of which 99% was from the SDWSC. There was a 52% decline in the total catch for all 122 stations from 2020. The Threadfin Shad index remained below historical ranges, similar to other pelagic fishes in the upper Estuary.

Catch Observations (for full details see Table 3)Over 2021, SKT Threadfin Shad CPUE was the highest in the freshwater North Delta in January (max 1699 and mean 783) and tidally-mixed West Delta region. Catch declined in these regions after January, however small increases in Threadfin Shad were observed by SKT in the South Delta in February and in San Pablo Bay in April. The 20-mm survey collected the first larval Threadfin Shad in March in all regions except San Pablo Bay. The 20-mm catch peaked in June within the West & North Delta and later in July for the South Delta. This cohort was observed by STN with the first Threadfin Shad reported in low numbers in June, followed by peak Threadfin Shad CPUE in July in the West and North Delta regions. In the North and South Delta, FMWT saw below average Threadfin Shad catch in September and October, and increased catch in November and December (maximum CPUE 449, mean 13.75). However, the South Delta had below average catch except for November when CPUE peaked in the FMWT.

SFBS collected Threadfin Shad in the North Delta, South Delta, West Delta, San Pablo Bay, and South Bay regions with higher catch in the MWT compared to the OT. Like other surveys, SFBS reported the highest CPUE in the North Delta region with catch increasing in

September (Table 3). Later, in November and December, Threadfin Shad catch increased further seaward in the West and San Pablo Bay regions.

Delta Smelt
Summary

The State and Federally listed (Fish and Wildlife Service, 1993; Tempel et al. 2021) Delta Smelt was only collected by the 20-mm survey in 2021 among the CDFW surveys. This survey collected only a single juvenile located in the Sacramento Deep Water Shipping Channel (SDWSC). For the first time since its inception, the SKT collected no Delta Smelt. The US Fish and Wildlife Service, Enhanced Delta Smelt Monitoring Survey (EDSM) Kodiak trawl only observed two adult Delta Smelt. Later, using a larval fish net, the EDSM program observed additional larval and juvenile smelt (n=14). These were primarily in the North Delta (EDSM Monitoring Reports). The STN, FMWT and SFBS also caught no Delta Smelt in 2021.

This continues a trend of severe population decline that has been observed among several monitoring programs particularly within the last 40 years (Figure 8). Delta Smelt are considered environmentally sensitive due to an annual life cycle, dependence on a spatially-limited oligohaline to freshwater habitat, and low fecundity (1,200 to 2,600 eggs per female on average; Moyle et al 1991). Low freshwater outflow and high water temperatures (>22°C; Swanson et al. 2000) in 2021 were recognized as stressfull conditions for the population. The year 2020 also had low outflow and high water temperatures, which could have limited the spawning stock available for 2021. Thus, low abundance in 2021 may be compounded by

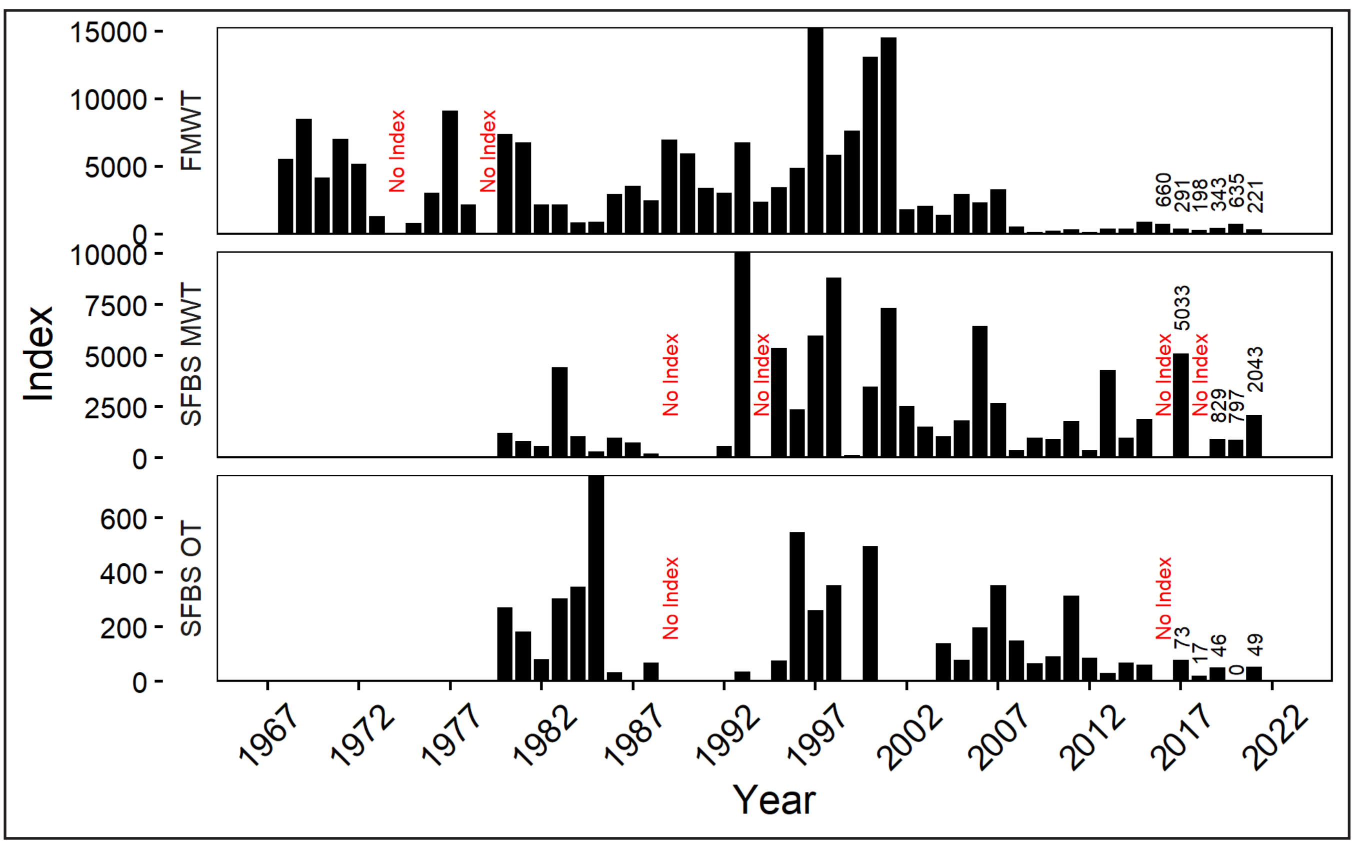

Figure 7. Threadfin Shad annual abundance indices from the Fall Midwater Trawl Survey (all sizes, 1967-2021).

Table 3. The 2021 Threadfin Shad regional CPUE (catch per 10,000 m3 for 20-mm, STN, FMWT and SFBS MWT; catch per 10,000 m2 for SFBS OT).

Region	Gear	Stations (n)	max CPUE	mean CPUE	se
South Bay	SFBS MWT	2	1.29	1.23	0.06
San Pablo Bay	20MM	50	0	0	0
San Pablo Bay	FMWT	164	0	0	0
San Pablo Bay	SFBS MWT	4	15.26	4.76	3.5
San Pablo Bay	SKT	19	2.36	0.12	0.12
San Pablo Bay	STN	15	0	0	0
West Delta	20MM	75	0.1	0	0
West Delta	FMWT	136	23.38	0.87	0.28
West Delta	SFBS MWT	20	63.23	8.6	3.08
West Delta	SFBS OT	1	26.3	26.3	NA
West Delta	SKT	70	405.32	11.87	7.16
West Delta	STN	42	0.06	0	0
North Delta	20MM	49	19.86	1.51	0.59
North Delta	FMWT	88	449.09	13.75	6.44
North Delta	SFBS MWT	14	170.59	17.11	11.87
North Delta	SKT	40	1699.25	77.36	50.11
North Delta	STN	30	3.89	0.62	0.2
South Delta	20MM	58	8.74	0.31	0.15
South Delta	FMWT	99	63.98	0.91	0.66
South Delta	SFBS MWT	6	4.14	2.23	0.48
South Delta	SKT	66	387.44	17.44	9.07
South Delta	STN	33	0.09	0.01	0

repeated stresses of drought conditions and low spawning stock.

FMWT and SFBS completed their last stations on 12/16/2021 and 12/15/2021, respectively. Following this the first year of an experimental release study of hatchery-raised Delta Smelt was conducted; these fish were not available to CDFW surveys for detection in 2021. The experimental release of Delta Smelt was conducted by a multi-agency effort with fish produced in culture by UC Davis Fish Conservation and Culture Laboratory. Beginning December 14, 2021, >55,000 cultured Delta Smelt were released into the North Delta Arc of the upper San Francisco Estuary over a period of three months (December 2021-Febrary 2022). All released fish were marked with an adipose fin clip or a visible implant elastomer tag, so they could be identified upon capture. These fish were observed by EDSM, and may be available to CDFW gear in the 2022 season.

Longfin Smelt

Summary

Pelagic catch of age-0 Longfin Smelt (i.e. FMWT and SFBS MWT) was generally low compared to demersal sampling by SFBS OT. However, in 2021 the FMWT Longfin Smelt index increased from the previous 5 years (Figure 9). The 2021 FMWT Longfin Smelt index was 310, over 10 times higher than the 2020 index. Similarly, the 2021 SFBS MWT age-0 Longfin Smelt index was 3435, which was over 3 times the 2020 index. Although this was the highest SFBS MWT age-0 Longfin

Smelt index since 2000, it is still much lower than historic highs from the 1980s and early 1990s. The SFBS MWT age-1 (Figure 10) index was the highest since 2012 at 802. The SFBS MWT age-2+ index was 48 (Figure 11), which was the 4th lowest index in survey history and continued a trend of low indices. We cannot compare the age-1 and age-2+ MWT indices to multiple recent years, as no MWT index was calculated in four of the previous five years (due to boat issues and the pandemic) but can look to the SFBS OT that was sampled with more consistency (Figure 9). SFBS OT raw age-0 catch continued to be higher than SFBS MWT catch; however, the SFBS OT age-0 index decreased from 2020 by 25% to 8,969. The OT age-1 index was 1993, a 93% increase from the last calculated index in 2019 and the highest since 2011. The OT age-2+ index was 38, which was a 74% decrease in the last calculated index in 2019 and the 3rd lowest index in survey history. SFBS OT age-0 indices in 2019 and 2020 were higher than the few preceding years, so we expect to see increases in the 2021 age-1 and age-2+ indices, though this was only true for the age-1 indices. Overall, SFBS Longfin Smelt indices continued to be lower than historic survey highs (Figures 9 to 11).

Longfin Smelt were observed by SKT in January in the San Pablo Bay, North Delta and West Delta. SKT catch peaked in April within all three regions with the maximum CPUE of 270 in the West Delta and the highest

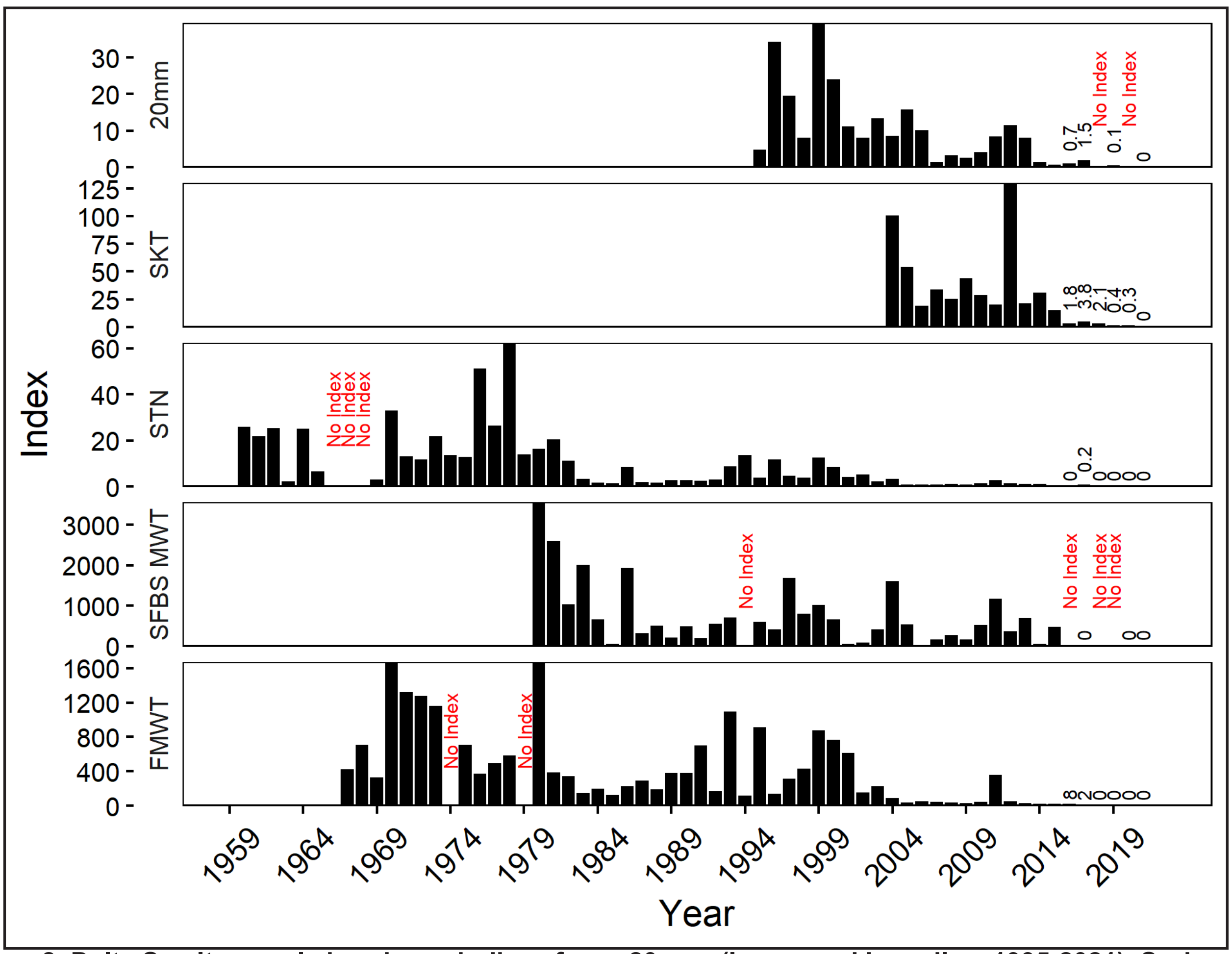

Figure 8. Delta Smelt annual abundance indices from: 20-mm (larvae and juveniles, 1995-2021), Spring Kodiak Trawl (adults, 2002-2021), Summer Townet Survey (all sizes, 1959-2021), and Fall Midwater Trawl (age-0, 1967-2021). No Delta Smelt were caught in index stations in 2021 by CDFW long term monitoring studies. Only 1 larval Delta Smelt was observed by the 20-mm survey at a non-index station in the North Delta.

mean CPUE of 9.8. Although observed in low numbers, 20mm was the only survey to report Longfin CPUE in the South Delta. The highest larval Longfin Smelt CPUE observed by 20mm was in the North Delta region (maximum 43.2, April-May), however Longfin Smelt were more consistently caught in the West Delta (mean CPUE 2.1, March-July). The STN observed this pattern with their max CPUE in the West Delta in June (1.0). Finally, FMWT only observed Longfin Smelt in the West Delta and San Pablo Bay regions. Catch was below average in September and October, but began to increase till peaking in November (San Pablo Bay; 0.93 CPUE) and December (West Delta; 0.49 CPUE). SFBS first collected age-0 Longfin Smelt with the OT in May in the West Delta, San Pablo Bay, and Central Bay regions. The SFBS MWT first collected age-0 Longfin Smelt in May in the West Delta region. Age-0 CPUE peaked in San Pablo Bay in September and Central and South bays in October (Figure 16 and Table 4). SFBS OT age-1 CPUE peaked in February in the West Delta (near Chipps Island), Central Bay (just south of the Bay Bridge), and South Bay (at

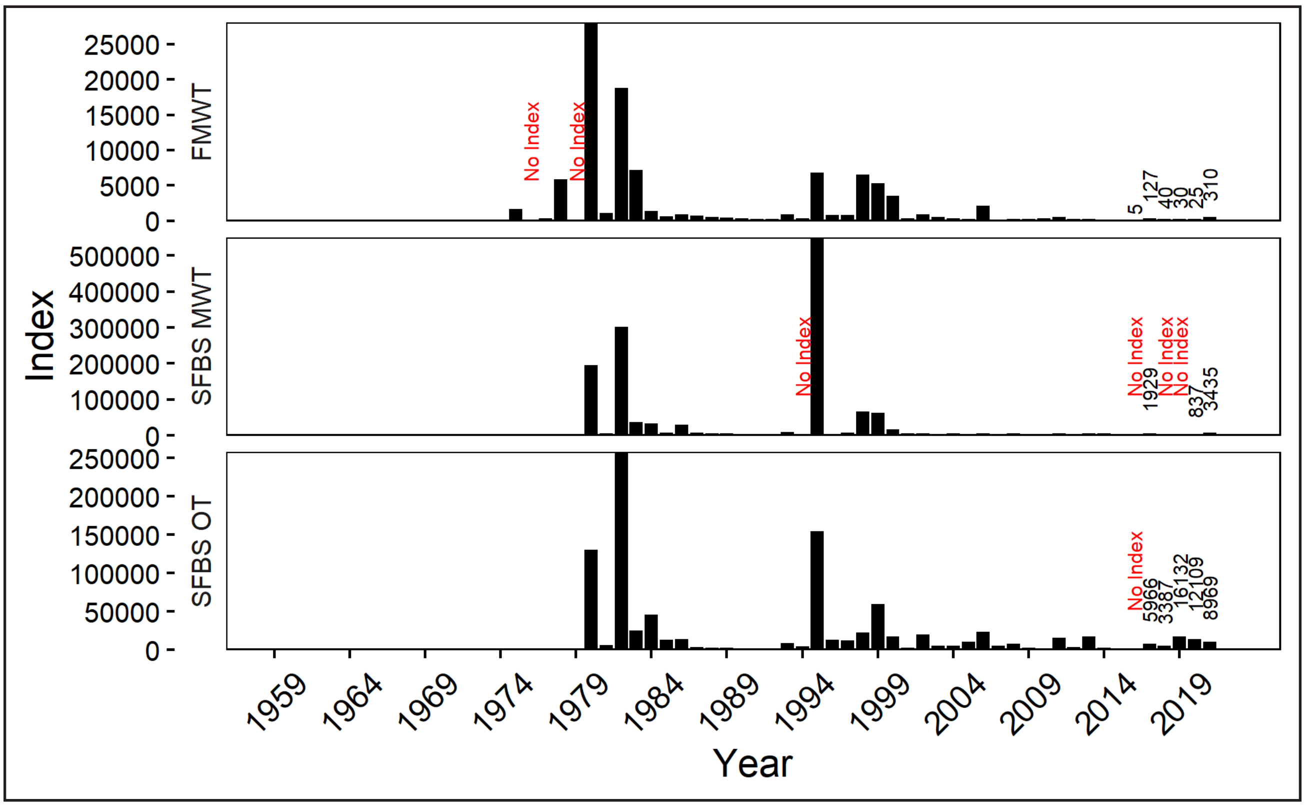

Figure 9. Age-0 Longfin Smelt annual abundance indices from (Top to Bottom): Fall Midwater Trawl (age-0, 1975-2021), San Francisco Bay Study (SFBS) midwater trawl (age-0, 1980-2021), and the SFBS otter trawl (age-0, 1980-2021). Note differences in the y-axes scales for each graph.

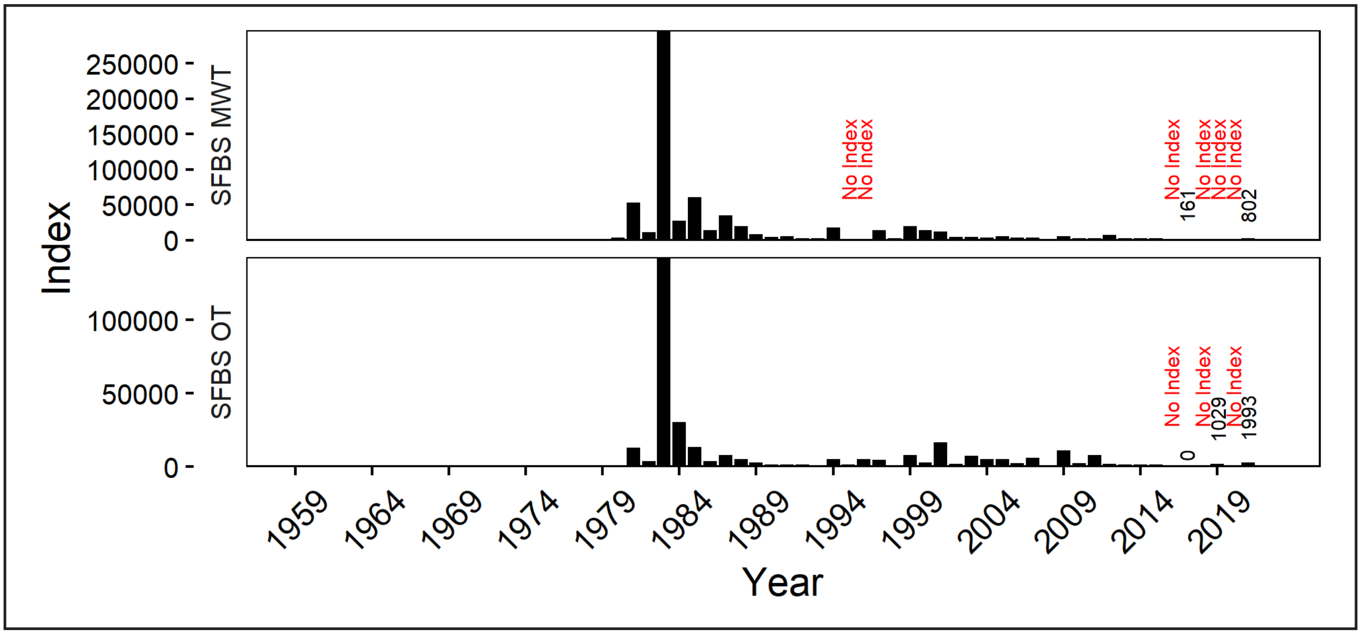

Figure 10. Age-1 Longfin Smelt annual abundance indices from (Top to Bottom): San Francisco Bay Study (SFBS) midwater trawl (age-0, 1980-2021), and the SFBS otter trawl (age-0, 1980-2021). Note differences in the y-axes scales for each graph.

SFBS' southernmost station). SFBS MWT age-1 CPUE peaked in the eastern San Pablo Bay region (Suisun Bay) and the West Delta region in April and May. Age-2+ Longfin Smelt were only collected in San Pablo Bay in May by the SFBS OT and West Delta in April and May by the SFBS MWT.

Longfin Smelt are anadromous and typically rear in habitats with greater salinity such as Central and San Pablo bays (But see Lewis et al. 2019 for residence in San Francisco South Bay tidal wetlands). Low freshwater flow into the Estuary in 2021 may have encouraged Longfin Smelt residence further inland into the Estuary, increasing catchability (and therefore increased Longfin Smelt indices and CPUE) at CDFW sampling stations.

Splittail

Summary

Splittail is a large cyprinid endemic to central California that typically forages in shallower regions of the Estuary, such as inundated floodplains and river margins (Sommer et al. 1997; Moyle et al. 2004)endemic to the Central Valley of California, declined by 62% over a 13-year period. Splittails are now found mostly in the estuary, a fraction of their former range. In a gill-net survey in August 1994, 50% of the splittails taken in the estuary were from the Suisun Bay area, and 50% were just upstream in shallow, well-vegetated areas. Splittails migrate into freshwater to spawn, and river outflow carries juveniles into productive, shallow, low-salinity areas downstream. The high correlation of abundance of young with river outflow (average r-2, 0.60. As such, Splittail is commonly collected by the USFWS Beach Seine Survey. It is also caught by pelagic and demersal surveys (FMWT and SFBS), usually when the Splittail population is particularly high.

The 2021 SFBS MWT and OT age-0 Splittail abundance indices were both 0 with zero catch at all stations (Figure 12). An annual total of 4 Splittail were caught in the SDWSC non-

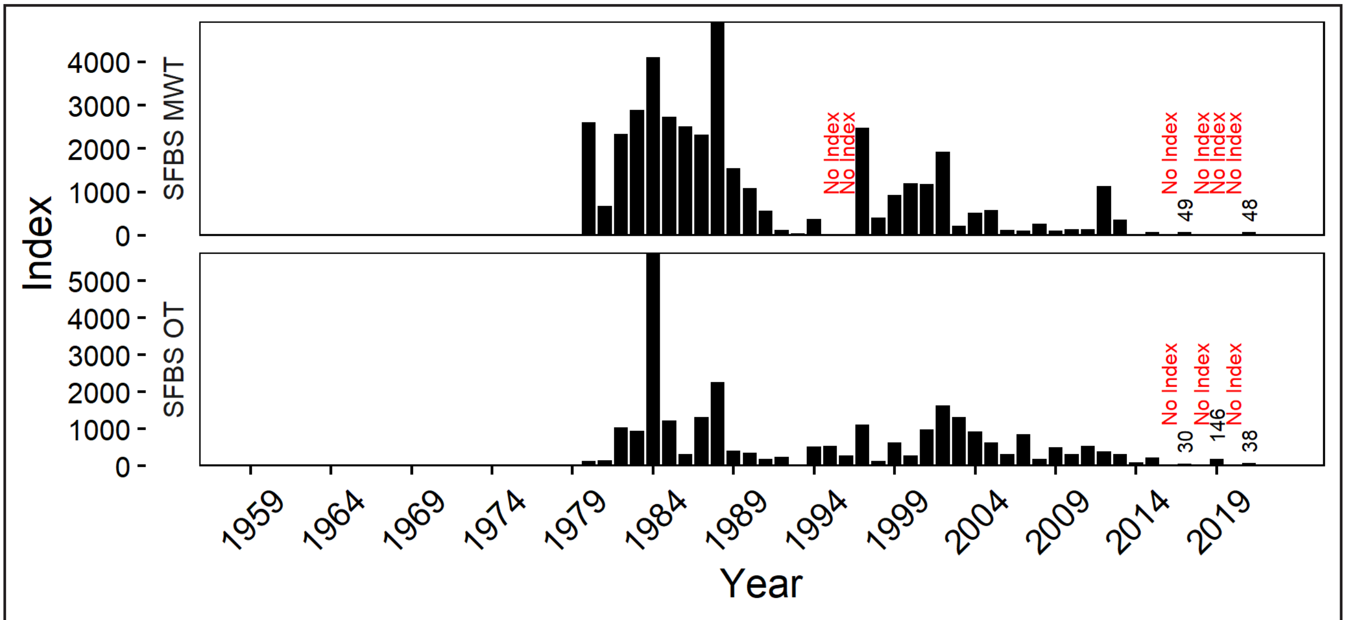

Figure 11. Age-1 Longfin Smelt annual abundance indices from (Top to Bottom): San Francisco Bay Study (SFBS) midwater trawl (age-0, 1980-2021), and the SFBS otter trawl (age-0, 1980-2021). Note differences in the y-axes scales for each graph.

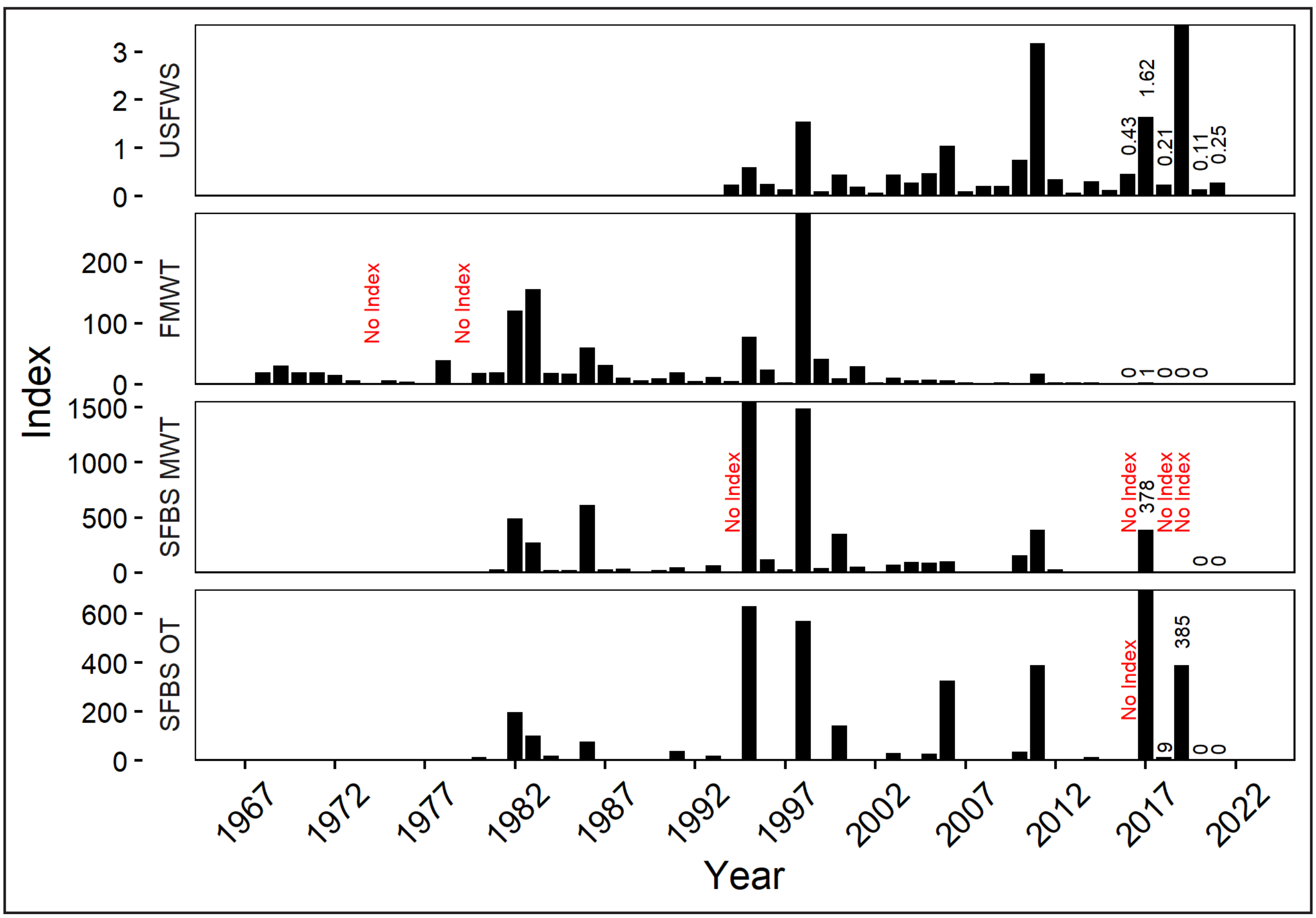

Figure 12. The annual abundance indices for Sacramento Splittail from (Top to Bottom): USFWS Beach Seine Survey (juveniles ≥ 25mm; 1994-2021), Fall Midwater Trawl Survey (all sizes; 1967-2021), San Francisco Bay Study (SFBS) midwater trawl (age-0, 1980-2021), and the SFBS otter trawl (age-0, 1980-2021). Note differences in the y-axis scales for each graph.

Table 4. The 2021 Longfin Smelt regional CPUE (catch per 10,000 m3 for 20-mm, STN, FMWT and SFBS MWT; catch per 10,000 m2 for SFBS OT).

Region	Gear	Stations (n)	max CPUE	mean CPUE	se
South Bay	SFBS MWT	8	24.19	5.25	2.98
South Bay	SFBS OT	14	59.17	17.97	5.75
Central Bay	SFBS MWT	8	21.59	6.99	2.64
Central Bay	SFBS OT	44	399.09	57.05	12.52
San Pablo Bay	20MM	50	0.12	0	0
San Pablo Bay	FMWT	164	33.88	0.93	0.25
San Pablo Bay	SFBS MWT	29	78.76	4.74	2.68
San Pablo Bay	SFBS OT	33	334.3	40.19	10.23
San Pablo Bay	SKT	19	33.01	2.34	1.79
San Pablo Bay	STN	15	0.12	0.01	0.01
West Delta	20MM	75	27.85	2.14	0.64
West Delta	FMWT	136	13.19	0.49	0.13
West Delta	SFBS MWT	11	4.31	1.54	0.51
West Delta	SFBS OT	11	31.56	10.09	3.2
West Delta	SKT	70	270.36	9.71	5.02
West Delta	STN	42	1.01	0.04	0.03
North Delta	20MM	49	43.21	1.38	0.96
North Delta	FMWT	88	0	0	0
North Delta	SFBS OT	2	0	0	0
North Delta	SKT	40	54.6	1.53	1.37
North Delta	STN	30	0	0	0
South Delta	20MM	58	1.74	0.07	0.04
South Delta	FMWT	99	0	0	0
South Delta	SKT	66	0	0	0
South Delta	STN	33	0	0	0

index stations of FMWT, but no Splittail were observed at index stations, leading to a FMWT index of 0.

The 2021 USFWS Beach Seine index for age-0 Splittail was 0.25 fish per m³, which was lower than the running survey average from 1994–2020 (0.61 fish per m³, Figure 12). Regional abundance was highest in the Sacramento River region (0.64 fish per m³), followed by the Delta (0.10 fish per m³) and lowest in the San Joaquin River (0 fish per m³).

Zero catch observed among pelagic and demersal trawls is unsurprising, since Splittail often spawn in the Sacramento, San Joaquin, Cosumnes, Napa, and Petaluma rivers floodplains, as well as in Butte Creek and other small tributaries (Moyle et al. 2004; Feyrer et al. 2015) from March through May. The resulting larvae and small juveniles disperse downstream in late spring and summer. The outmigration of Splittail coincides with reduced river flows that decrease available backwater and edge-water habitats. These patterns were observed in the USFWS Juvenile Fish Monitoring program, which frequently catches Splittail in the beach seine. Further, this survey samples much further north than the range of CDFW survey gears.

In addition, most of the CDFW gears operate in water >2 m deep, whereas Splittail,

Table 5. The 2021 Splittail regional CPUE (catch per 10,000 m3 for 20-mm, USFW Beach Seine, STN, FMWT and SFBS MWT; catch per 10,000 m2 for SFBS OT).

Region	Gear	Stations (n)	max CPUE	mean CPUE	se
San Pablo Bay	20MM	50	0	0	0
San Pablo Bay	FMWT	164	0	0	0
San Pablo Bay	SKT	19	0	0	0
San Pablo Bay	STN	15	0	0	0
West Delta	20MM	75	0	0	0
West Delta	FMWT	136	0	0	0
West Delta	SFBS OT	3	0	0	0
West Delta	SKT	70	2.98	0.06	0.05
West Delta	STN	42	0	0	0
West Delta	USFWS Beach Seine	4	213.68	53.42	53.42
North Delta	20MM	49	0	0	0
North Delta	FMWT	88	2.61	0.07	0.04
North Delta	SKT	40	0	0	0
North Delta	STN	30	0.07	0.01	0
North Delta	USFWS Beach Seine	18	49950.84	3859.77	2770.63
Sacramento	USFWS Beach Seine	11	39540.23	3922.17	3576.69
San Joaquin	USFWS Beach Seine	4	0	0	0
South Delta	20MM	58	0	0	0
South Delta	FMWT	99	0	0	0
South Delta	SKT	66	0	0	0
South Delta	STN	33	0	0	0
South Delta	USFWS Beach Seine	16	8571.43	549.23	534.98

particularly age-0 fish, appear to primarily inhabit water <2 m deep. FMWT and SFBS generally detect strong year classes, such as in 1998 and 2011, related to high outflow and long periods of floodplain inundation (Moyle et al. 2004).

SKT collected Splittail from January to April, with the highest mean CPUE in the West Delta, peaking in March. The Beach Seine survey also reported Splittail in the West Delta in May with increasing CPUE into June. A similar pattern was observed in the South Delta and Sacramento River regions. Opposite of this, Beach Seine CPUE was highest in the North Delta in May and decreased in June. As the beach seine saw decreased CPUE, STN observed its highest CPUE in the North Delta in June, with decreased CPUE in July and August. Finally, FMWT reported Splittail present in the North Delta each month, with increasing CPUE reported each month in the North Delta (September-December, max 2.61 CPUE, mean 0.07 CPUE).

Age-0 Striped Bass

Summary

The STN, FMWT, and SFBS (MWT and OT) 2021 age-0 Striped Bass indices continued a declining trend since the 1970s (Figure 13). In 2021, the STN recorded its lowest age-0 Striped Bass index (index = 0.1) in its 63-year history. Striped Bass reached an average FL of 38.1 mm on July 5th. In contrast to the lower STN index, the FMWT index marginally increased, from 2020, with an index of 56). FMWT non-index catch was relatively minor, with 4% of the total catch coming from non-index stations in the Napa River and SDWSC. The SFBS MWT index decreased by 88% from

2020 to 42. The SFBS OT age-0 striped bass index increased by 46% from 2020 to 1822, however this is still below the survey mean of 8,474 (Figure 13).

The majority of age-0 Striped Bass were observed in the North and West Delta regions (Table 6). Age-0 Striped Bass were first reported by the 20-mm survey in March. Striped Bass 20mm CPUE was below the seasonal average in the North, South, West and San Pablo regions. CPUE increased in 20-mm and peaked in May for all regions, the highest in North region (9.29 maximum, 0.49 mean). As catch decreased for 20mm, it increased in the STN survey, peaking in June and decreasing in July and August. Similar to the 20mm survey, the highest CPUE was observed in the North Delta (maximum 1.35, mean 0.14). FMWT had below average age-0 Striped Bass seasonal CPUE in September. In the North Delta, CPUE peaked in October (mean 0.17), then in November Striped Bass catch increased in the West (mean 0.44) and South Delta (mean 0.15) regions. Finally, Striped Bass catch increased in San Pablo Bay in December (mean 0.01 CPUE). This follows typical patterns for the movement of larval and juvenile Striped Bass into fresh and brackish water (Moyle 2002). CPUE of age-0 fish collected by SFBS MWT and OT from February to May, hatched in 2020, peaked in the South Delta in April (maximum 508 in SFBS OT;

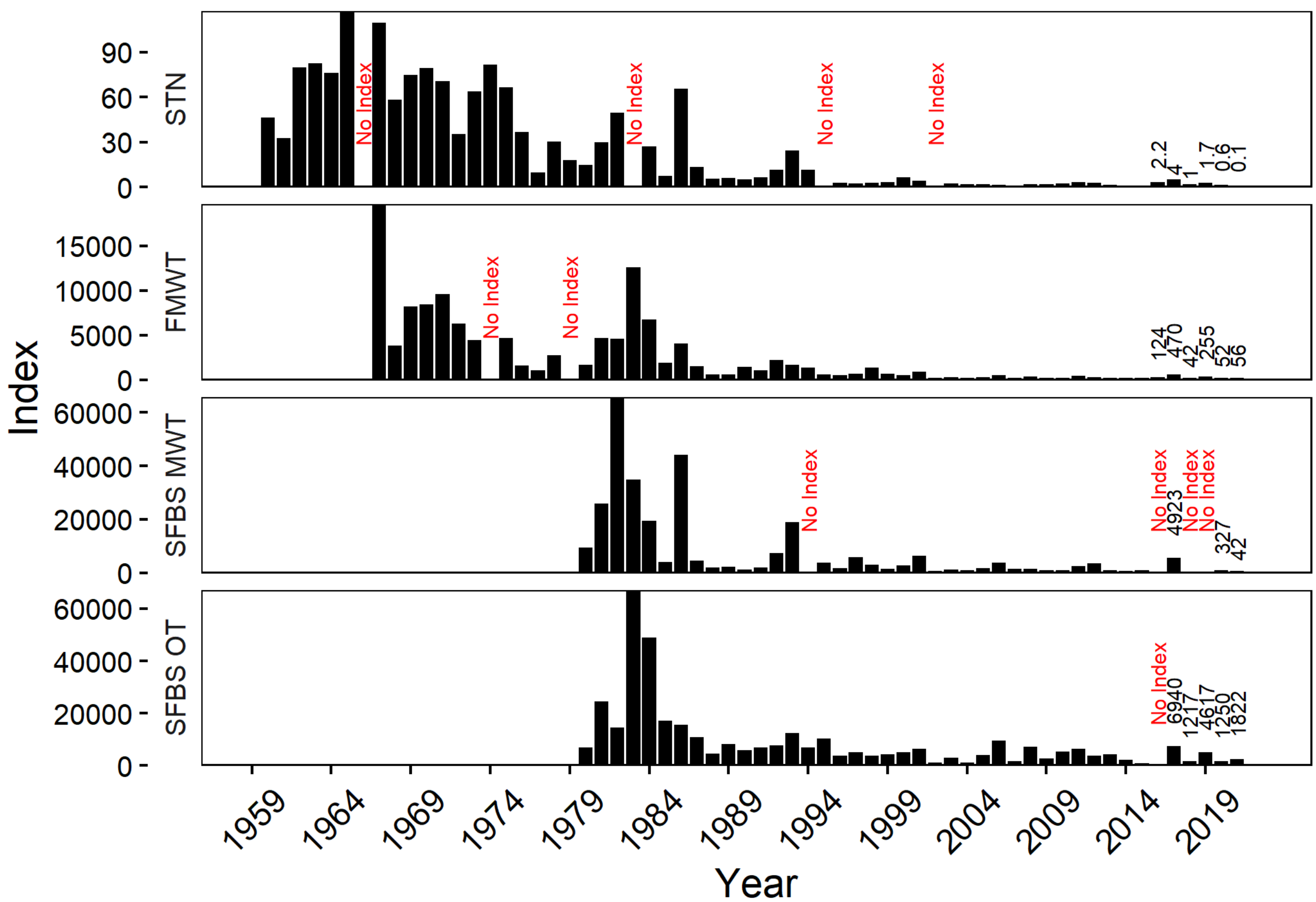

Figure 13. The annual abundance indices of age-0 Striped Bass from (Top to Bottom): Summer Townet (all sizes; 1959-2021), Fall Midwater Trawl Survey (all sizes; 1967-2021), San Francisco Bay Study (SFBS) midwater trawl (age-0, 1980-2021), and the SFBS otter trawl (age-0, 1980-2021). Note differences in the y-axis scales for each graph.

Table 6. The 2021 age-0 Striped Bass regional CPUE (catch per 10,000 m3 for 20-mm, STN, FMWT and SFBS MWT; catch per 10,000 m2 for SFBS OT).

Region	Gear	Stations (n)	max CPUE	mean CPUE	se
South Bay	SFBS MWT	1	0	0	NA
San Pablo Bay	20MM	50	0.35	0.01	0.01
San Pablo Bay	FMWT	164	1.3	0.01	0.01
San Pablo Bay	SFBS MWT	21	11.77	1.52	0.75
San Pablo Bay	SFBS OT	12	72.82	13.95	6.19
San Pablo Bay	STN	15	0.02	0	0
West Delta	20MM	75	0.25	0.02	0.01
West Delta	FMWT	136	9.5	0.44	0.11
West Delta	SFBS MWT	26	3.63	1.03	0.22
West Delta	SFBS OT	42	383.18	33.95	10
West Delta	STN	42	0.13	0.02	0.01
North Delta	20MM	49	9.28	0.49	0.23
North Delta	FMWT	88	12.13	0.17	0.14
North Delta	SFBS MWT	12	16.64	3.99	1.58
North Delta	SFBS OT	24	55.69	14.56	2.71
North Delta	STN	30	1.35	0.14	0.07
South Delta	20MM	58	3.44	0.22	0.07
South Delta	FMWT	99	6.92	0.15	0.09
South Delta	SFBS MWT	5	1.62	0.89	0.37
South Delta	SFBS OT	24	508.05	69.09	21.79
South Delta	STN	33	0.06	0.01	0

Table 6). The SFBS first detected 2021 age-0 Striped Bass in June in the West, South, and North Delta regions. Like FMWT, age-0 Striped Bass were collected in the San Pablo Bay region (more specifically western Suisun Bay) in November and December. However, highest CPUE remained in the West, South, and North Delta regions through the end of the year.

Stevens et al. (1985) hypothesized that four factors may be responsible for the decreasing abundance of Striped Bass: 1) the adult population was too small to maintain adequate egg production; 2) planktonic food production has decreased to a point that is too low to sustain historic population levels; 3) loss to entrainment in water diversions; and 4) pollution in the form of pesticides, petrochemicals, and other toxic substances. More recently, Sommer et al. (2011) argued that age-0 Striped Bass distribution had shifted to shoal and shoreline areas from channels due to food availability, based on long term FMWT and SFBS catch comparisons between shoal and channel stations. This distributional trend is still supported by more recent data. However, Sommer et al. (2011) cautioned against attributing low values in Striped Bass abundance solely to a change in habitat use.

Conclusions

2021 was the second year of the current drought. Decreased freshwater outflow can have a plethora of impacts on native and non-native fishes in the Estuary including timing and location of spawning, larval growth and survival, and juvenile residence. In addition, decreased outflow can lead to greater salinity intrusion, shifting the habitats of fishes relative to fixed stations in the Delta. Warmer temperatures and decreased outflow, impacts of climate change in the Estuary, likely contributed to decreased American Shad, Threadfin Shad, Splittail, and age-0 Striped Bass abundance and the continued absence of Delta Smelt. While Longfin Smelt indices decreased for several surveys (20mm, SKT, STN, SFBS MWT age-2+, and SFBS OT age-0 and age-2+) it increased for the FMWT, SFBS MWT (age-0 and age-1), and SFBS OT (age-1) surveys. This may not reflect a change in the population, but a shift in the available habitat (for age-0 size class) or triggering of migration due to a short period of high flows in the fall in the Estuary (for adult size classes), particularly the Suisun Bay.

For more information on CDFW surveys, including indices, catch values, length frequency and access to the various datasets discussed above visit: CDFW Bay-Delta Surveys. In addition, you may contact Timothy.Malinich@wildlife.ca.gov for more information.

For more information on the USFW beach seine surveys visit: Delta Juvenile Fish Monitoring Program.

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Interagency Ecological Program for the San Francisco Estuary

IEP

The Interagency Ecological Program for the San Francisco Estuary is a cooperative effort of the following agencies:

California Department of Water Resources

State Water Resources Control Board

U.S. Bureau of Reclamation

U.S. Army Corps of Engineers

California Department of Fish and Wildlife

U.S. Fish and Wildlife Service

U.S. Geological Survey

U.S. Environmental Protection Agency

National Marine Fisheries Service

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