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Interagency Ecological Program for the San Francisco Estuary

IEP Newsletter

Interagency Ecological Program
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In this Issue:

IEP Newsletter

Interagency Ecological Program for the San Francisco Estuary

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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 Articles in the IEP newsletter are intended for rapid communication and are not peer reviewed.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: Sunset following a day on the water performing CDFW's Smelt Larval Survey. Photo provided by Vanessa Mora (CDFW).

Cover: Surveying the bank for an acoustic receiver cable hidden in a levee in the lower Mokelumne River/east Delta. Photo provided by Jeremy Notch (NOAA).

Of Interest to Managers

This issue of the newsletter features the following science articles:

From Spawning Grounds to the Sea: Development of a California Central Valley Fish Tracking System

The acoustic telemetry array throughout California's Central Valley (CCV) provides critical information on the movement and survival rates of state and federally-listed salmonid species by allowing individual fish to be tracked using micro transmitters placed inside the fish and detections recorded by underwater receivers. This technology has been improving since its inception in the CCV almost 20 years ago; receivers now transmit data in real-time and the number of fish being tagged and released by researchers is increasing each year. Today there is widespread use of this fish monitoring technology by state and federal agency researchers allowing for more informed water management decisions. For example, real-time information about the location and timing of fish arriving at critical locations, such as the pumping facilities in the southern Delta, may inform water conveyance schedules at daily temporal scales. This technology continues to improve as tags becoming smaller and lighter. The technological advancements ill allow the tracking of smaller size classes of salmonids which have been understudied in the past. In this review article, **Jeremy Notch (NOAA) and co-authors** utilize an extensive 15 year dataset to present two case studies that investigate salmonid movement and survival in the CCV. The data are currently available on the CalFishTrack website (https://oceanview.pfeg.noaa.gov/CalFishTrack/)

2022 Spring Kodiak Trawl Summary

The California Department of Fish and Wildlife (CDFW) conducts the Spring Kodiak Trawl Survey (SKT) annually from January through May to determine the distribution and relative abundance of adult Delta Smelt in the upper San Francisco Estuary. **Vanessa Mora (CDFW)** presents a data report for the 2022 SKT season. Additionally, the SKT provides information about the gonadal maturation of Delta Smelt, which indicates when and where spawning is likely to be occurring. Eighteen Delta Smelt were caught by the SKT this season. This is increase from last year's catch of zero. All Delta Smelt captured were marked which indicates that they were among the 55,733 hatchery-origin fish released into the system from December 2021 to February 2022.

2022 20-mm Survey Summary

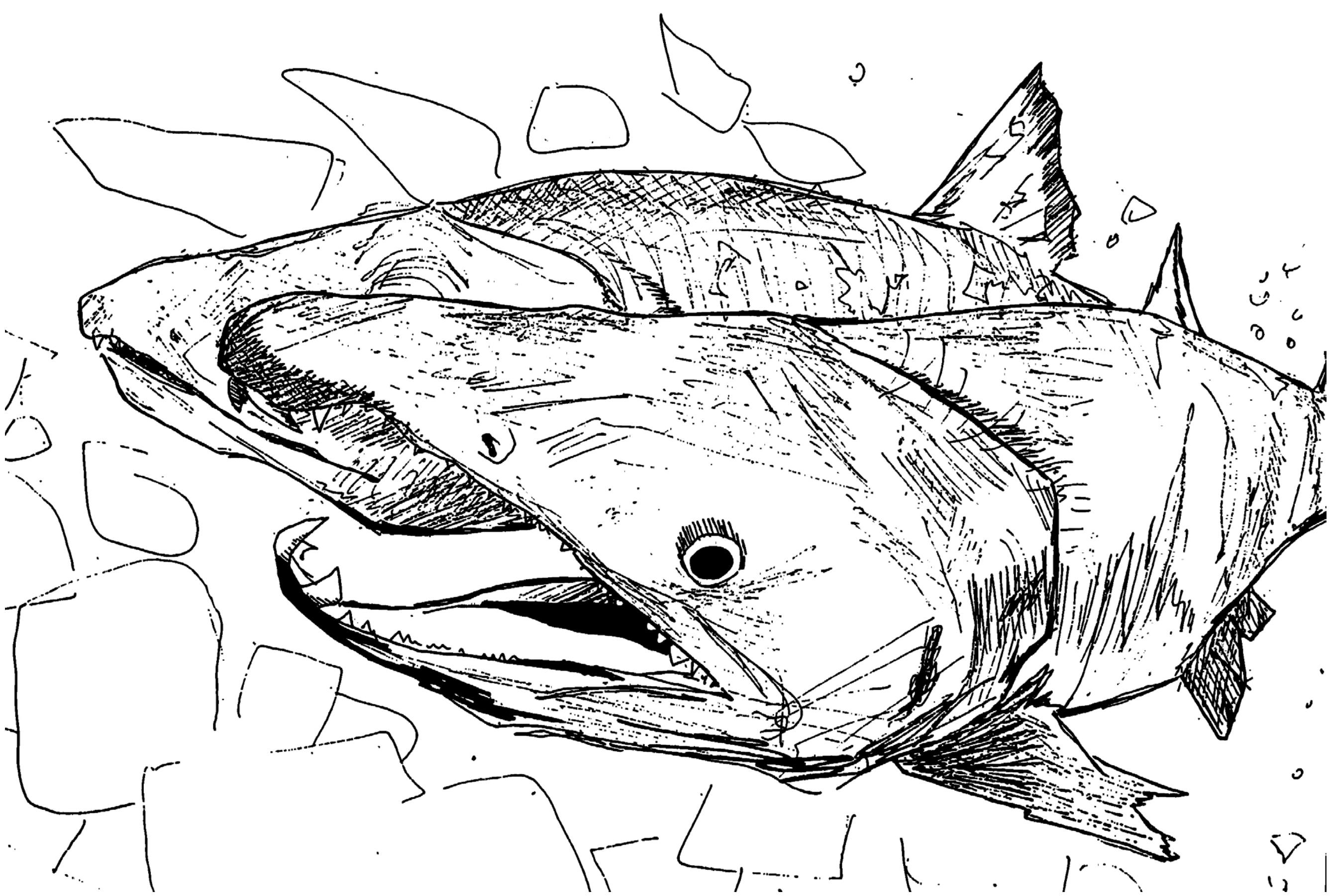
The 2022 20-mm Survey is summarized by **Jessica A. Jimenez (CDFW)**. The 20-mm Survey is conducted annually to monitor the distribution and relative abundance of larval and juvenile Delta Smelt (Hypomesus transpacificus) and Longfin Smelt (Spirinchus thaleichthys) in the upper San Francisco Estuary (SFE). Nine larval Delta Smelt measuring between 8 mm and 13 mm were caught in late March and early April. It is likely these larvae were the offspring of the adult hatchery-origin Delta Smelt that were experimentally released between December 2021 and February 2022. Due to the low catch and abundance, this year's index is NA (Damon 2022).

A total of 13,172 Longfin Smelt were caught in the 2022 20-mm Survey. The average monthly length increased from 13 mm in March to 31 mm in June. These fish moved eastward out of freshwater as the average temperature and electrical conductivity increased between March and June.

2022 Smelt Larva Survey Summary

The 2022 Smelt Larva Survey (SLS) is summarized by **Jessica A. Jimenez (CDFW)**. The SLS is conducted annually in four regions (8 surveys total) from December to March to monitor the distribution and relative abundance of native larval Osmerids in the upper San Francisco Estuary (SFE). In 2022, Longfin Smelt with yolk sacs were observed in every survey and present throughout the SFE, but the highest catch occurred in the Confluence of the Sacramento and San Joaquin Rivers and downstream. Despite their presence throughout the SFE, the annual catch is still relatively low compared to previous years. Despite the release of 55,733 hatchery origin Delta Smelt from December 2021 to February 2022, only a single 10 mm Delta Smelt was caught in late March. The parents likely spawned in late February.

Below: Pre-spawning Chinook salmon by sisters Yoko (age 17) and Toko (age 14) Nakajima, who reside in Duluth, MN. They began making art at a young age as part of their daily activities. They were influenced by their parents, Ryuta Nakajima and Aya Kawaguchi, who are both internationally exhibiting artists. Not surprising, the sisters are interested biology and conservation of aquatic species, often following their father on research expeditions and summers abroad. Their works have been displayed at the Aquamarine aquarium in Fukushima, Japan and the Cephalopod International Advisory Council Conference. Their artwork is featured throughout this newsletter.



Research

From Spawning Grounds to the Sea: Development of a California Central Valley Fish Tracking System

Jeremy Notch (UC Santa Cruz, NOAA), Alex McHuron (UC Santa Cruz, NOAA), Rebecca Robinson (UC Santa Cruz, NOAA), Tom Pham (UC Santa Cruz, NOAA), Brendan Lehman (UC Santa Cruz, NOAA), Renae Logston (UC Santa Cruz, NOAA), Jessica Frey (UC Santa Cruz, NOAA), Cyril Michel (UC Santa Cruz, NOAA), Arnold Ammann (NOAA)*

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Abstract

Acoustic telemetry has become a popular and widespread tool in California's Central Valley (CCV) to study the movement and survival of many fish species. Since its initial conception in the early 2000's, acoustic tags have become smaller and acoustic receivers are now capable of transmitting detections in real-time. NOAA's Southwest Fisheries Science Center, in partnership with the University of California at Santa Cruz, has utilized this technology since 2007 to track out-migrating juveniles from all four populations of Chinook Salmon in the CCV. Here we present an overview of the acoustic telemetry program, the general research findings from two recent case studies, and examples of emerging opportunities and partnerships to study anadromous fish using this technology.

Introduction

In In California's Central Valley (CCV) rivers, low survival rates of outmigrating juvenile salmon have been identified as a bottleneck impeding population recovery (Healey 1991; Michel et al. 2015; Cordoleani et al. 2018; Notch et al. 2020). Developing management solutions for reducing mortality requires high-quality, reliable data on fish movement rates and location-specific mortality (Johnson et al. 2017). Currently, tracking fish movements using acoustic telemetry technology is the best method for estimating survival of salmon cohorts moving through large watersheds, such as the Sacramento and San Joaquin Rivers (McMichael et al. 2010).

Since 2007, NOAA's Southwest Fisheries Science Center (SWFSC), in collaboration with the University of California, Santa Cruz, has deployed, tested, maintained, and continuously worked to improve the acoustic tracking technology in the CCV. Today there exists a large receiver array to track fish within the CCV's anadromous waters. The SWFSC started tracking fish in 2007 with a pilot study to track hatchery-reared late-fall Chinook salmon (*Oncorhynchus tshawytscha*) and steelhead trout (*O. mykiss*). Since this initial tracking study, there has been a steadily growing interest in the use of acoustic telemetry by resource agencies, universities, and fisheries biologists interested in refining and enlarging a reliable watershed-wide tag detection system.

This paper provides a brief overview of acoustic tag technology and the current state of tracking infrastructure in the CCV. We share two case studies highlighting how acoustic telemetry has been used in the CCV to answer focused research questions. We then discuss the planned and potential future research opportunities that exist to develop management tools using fish tracking data.

Accoustic Technology and Methods

Tag and receiver technology

Acoustic telemetry requires the use of battery-powered tags that are attached to fish and the receivers that detect them. Depending on the application, tags are attached to fish either externally or internally (the latter requiring surgical implantation). Tags emit a high-frequency sonic ping, in the range of 69 to 416 kHz, depending on the manufacturer and tag technology employed. Transmissions occur at user-defined intervals, typically ranging from 3 to 180 seconds, and each transmission provides a unique identification code that is recorded by underwater receivers.

Prior to acoustic telemetry, coded wire tagging (CWT) of juvenile hatchery-reared salmon smolts was the primary method of tracking fish, which provides an estimate of smolt to adult survival rates. These data are not available until several years after the cohort has been released into the wild because tags must be extracted from dead adult fish, limiting CWT's use for timely fisheries management actions. Furthermore, there is no reliable method to decouple survival rates between freshwater migration and ocean residency. Acoustic telemetry overcomes these challenges by allowing for nearly real-time survival estimates, and has become an important monitoring tool to inform hatcheries of survival rates in relation to environmental conditions, which can ultimately help strategize optimum release timing. Furthermore, when acoustic tags are paired with CWTs, freshwater and ocean survival can be decoupled (Michel, 2020).

The most common acoustic tag technologies currently used in the CCV are designed and manufactured by Vemco (69kHz) and the Juvenile Salmon Acoustic Telemetry System (JSATS, 416kHz). At this time, Vemco technology is primarily used for larger migratory fish, due to the larger battery which prohibit their effective use in very small (e.g. <120 mm FL) fishes where survival estimates may be influenced by tag burden. However, Vemco tags with larger batteries make it possible to track fish for up to 10 years in some cases (Lindley et al. 2008). JSATS technology is currently the favored technology to track small (>80mm FL) young-of-year juvenile salmon outmigrating to the ocean. These tags are manufactured in an injectable (0.2g) and standard (0.3 g) style, depending on the battery type used. Tags can last from 30 to 120 days, depending on the ping rate, and work well in both fresh and saltwater environments. (Advanced Telemetry Systems, Inc. 2015; McMichael and Kagley 2015).

Acoustic receivers listen for passing tags and record each event with a time stamp. Receivers for both tag technologies are deployed underwater, typically either tethered directly to the shoreline, a piling or other underwater structure, or attached to weights in deep water without a connection to shore. In the latter case, acoustic release devices are typically used to allow recovery of the receiver. The receivers are traditionally autonomous units powered by batteries and left unattended for months, requiring periodic data downloads and maintenance. However, due to the time and cost of recovery and maintenance, as well as a desire for near-instantaneous tag detection data, a growing interest in real-time tracking has led to the development of shore-based recording units with underwater hydrophones connected to cell phones or satellite modems that upload data remotely on demand. Data from these units can be uploaded to websites every hour and survival rates and routing probabilities can be estimated and relayed back to resource managers, allowing for real-time decision-making for water operations.

The Receiver detection range depends on the tag configuration as well as local geography and ambient underwater noise. Tags can theoretically be detected at distances up to 500 m in open, still water, but factors such as river sinuosity, bottom topography, and water velocity typically reduce the range to 100−200 m (Lu et al. 2016). Orientation of the tag inside the fish in relation to the receiver can further influence the detection range (Ammann, 2020). Compared with passive integrated transponder (PIT) technology, which requires tags to pass within approximately one meter of an antenna, acoustic telemetry allows the detection of fish passage through wide and deep river channels such as the lower Sacramento, a waterway large enough to accommodate cargo vessels and tankers. Because of their large detection range, we are currently able to track fish moving under the Golden Gate Bridge with a linear array of just ten receivers.

Development of real-time array and website

Autonomous receivers are usually deployed for two to three months at a time between data downloads. Traveling to receiver sites and servicing units can be time-consuming, and expensive and the data are not available until the receiver is retrieved. Furthermore, receiver malfunction cannot be assessed until the data are viewed, resulting in the potential for critical data gaps. In 2018, the SWFSC, along with the U.S. Geological Survey (USGS), installed and continues to maintain a real-time array of acoustic receivers throughout the Sacramento River watershed and the Sacramento−San Joaquin Delta (Figure 1). In most locations, real-time receivers are fixed to bridge abutments and powered by solar panels. Data are uploaded hourly via the cellular network and are available immediately. The array required extensive initial investment in developing hardware and software for acquiring data remotely; however, since then this technology has been a tremendous resource for resource managers interested in the location of tagged individuals in real-time. The real-time receivers are programmed to alert operators about technical problems (e.g., receiver not downloading, no power, missing data, etc.), allowing researchers to conduct a site visit to correct the problem and mitigate data loss. Importantly, the SWFSC maintains a website (https://oceanview.pfeg.noaa.gov/CalFishTrack/pageRealtime_download.html) where all users can access survival, routing, and movement data, as well as detection histories from the growing number of different tagging and tracking studies that rely on the acoustic receiver array.

Data management and access

Preliminary real-time data can be accessed immediately via ERDDAP (https://oceanview.pfeg.noaa.gov/erddap/tabledap/FEDcalFishTrack.html). These data can be useful for resource managers who need customized information that is not readily available via the real-time data visualizations on the real-time website.

For analyses that do not require real-time information, the final quality-controlled detection data can also be downloaded remotely. Once recovered from the field, autonomous receivers are brought back and downloaded at SWFSC. To account for false detections created by riverine "noise", we filter the raw autonomous and real-time receiver files so that only detections of the same tag ID recorded multiple times within a short time period are included (Ammann, 2020). Once receiver files are processed and pass quality control standards, they are made available to other agencies and the public through the ERDDAP website (https://oceanview.pfeg.noaa.gov/erddap/tabledap/FED_JSATS_detects.html), usually within 4 to 6 months of retrieval. Detailed instructions on downloading both the preliminary real-time data, as well as the final, quality-controlled, real-time, and autonomous data can also be found on the SFWSC real-time website (https://oceanview.pfeg.noaa.gov/CalFishTrack/pageRealtime_download.html). This includes instructions for reading detection data straight into R statistical programming software.

To update, track, and view the locations of active receiver deployments throughout the CCV, a sharable spreadsheet is hosted online which allows researchers to input start and end times for receivers at any location, new or ongoing. These data populate a map of all locations where JSATS receivers are actively deployed (https://oceanview.pfeg.noaa.gov/CalFishTrack/pageDEPLOY.html). Additionally, we update an interagency database that provides all users with information on the CCV array of receivers deployed throughout the year. This provides a spatial and temporal record of data coverage, gaps in the array, and receiver ownership.

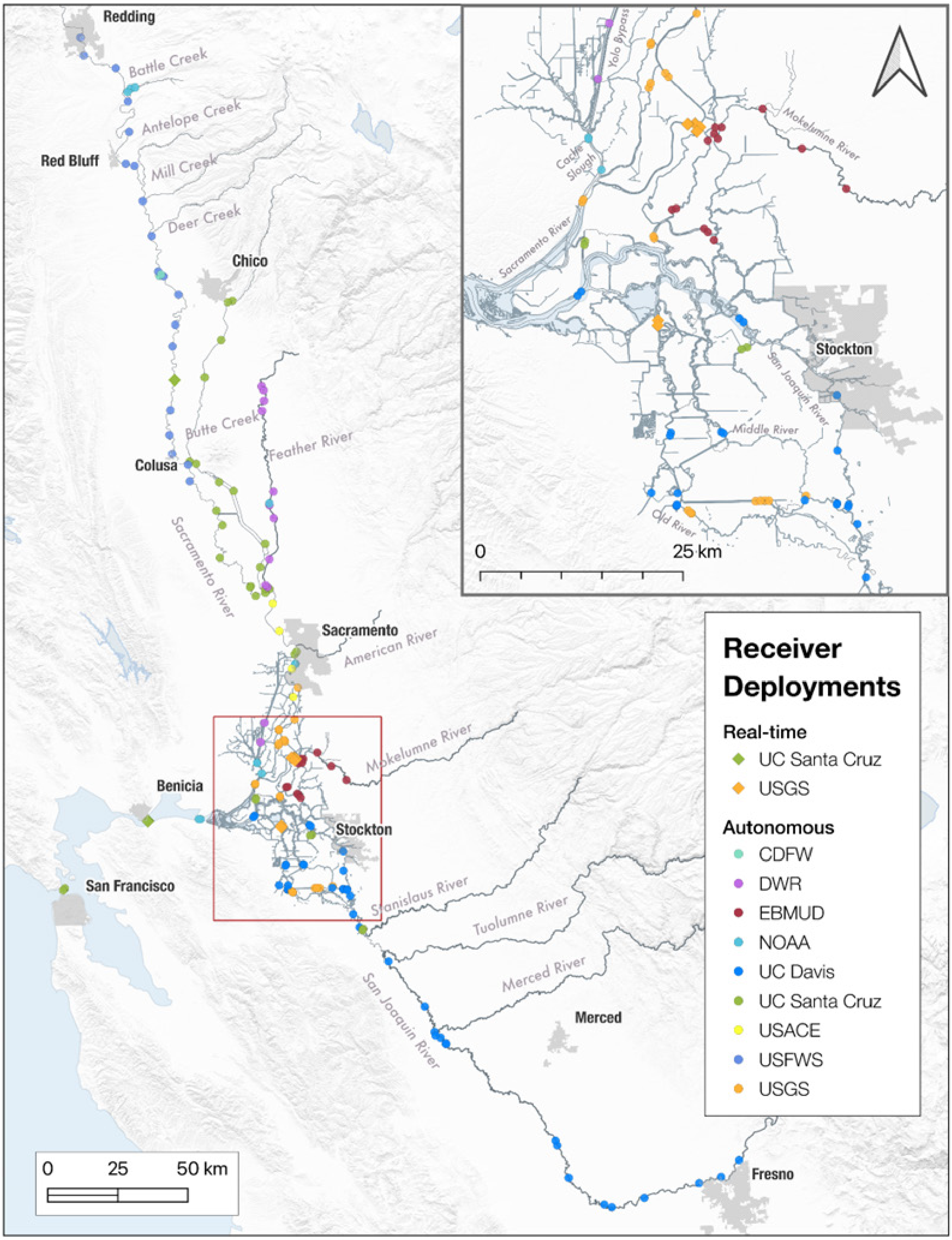

Figure 1 A map displaying the deployment locations of autonomous and real-time receivers. The receiver deployment sites shown are sites that were commonly used between 2012 and 2021, and the different agencies that deploy specific locations. Alternative text: This map shows the river systems in California's Central Valley which have receiver coverage for tagged fish migrating downstream towards the ocean. Individual receiver locations are labeled by the agencies who maintain them, and are also separated by autonomous and real-time receiver types.

Key study design and data analysis concepts

Traditional animal survival estimates are made using mark-recapture data collected through time (e.g., repeated seasonal sampling). However, for Chinook Salmon survival analysis purposes, we can employ a Cormack-Jolly-Seber model for live recaptures (Cormack 1964; Jolly 1965; Seber 1982), where fish detections along a river can serve as recapture events. This is possible because juvenile Chinook Salmon express obligate anadromy so it is likely that fish has died if it is not detected again downstream of its last known location. Consequently, survival can be estimated for individual reaches throughout the riverine and estuary environment between receiver locations (Michel et al. 2015). The unique detection histories of each fish are combined to develop a model that can predict reach-specific survival rates as well as the detection probability of each receiver at that location (Burnham, 1987. When fish are tagged and released at different times (i.e., throughout a season or over several years), it is possible to model the influence of varying environmental conditions on fish survival (Henderson et al. 2019).

The Delta is a complex and highly modified environment with a maze of interconnected waterways. By placing receivers at key channel intersections, it is possible to determine routing and survival probabilities within each route using multistate mark-recapture models. For example, receivers placed at key locations within Georgiana Slough as well as in the Sacramento River allowed Perry et al. (2018) to determine that 27% to 43% of juvenile salmon passing this junction will enter the interior Delta via Georgiana Slough. As a result, fish entering the interior Delta are about half as likely to survive to the Bay as those remaining in the mainstem Sacramento River.

Results and Discussion

Summary of tagging years and receiver locations used over the past decade

From 2007 to 2020, Vemco and JSATS receivers have been deployed throughout the Sacramento River, Delta and San Francisco Bay to track migrating fish (Table 1). While there is some variation in receiver deployment sites between years, there is a core group of receiver locations repeatedly used over the years (Figure 1). Initially these receivers were solely managed by the SWFSC. More recently the U.S. Fish and Wildlife Service (USFWS), USGS, University of California Davis (UCD), University of California Santa Cruz, East Bay Municipal Utilities District, California Department of Water Resources, and U.S. Army Corps of Engineers have joined the SWFSC in collaboration to ensure the array is consistently deployed and maintained throughout the CCV.

Water Year	Receiver Deployments	Unique General Locations
2007	300	21
2008	300	21
2009	300	21
2010	300	21
2011	300	21
2012	63	20
2013	241	58
2014	262	53
2015	208	65
2016	306	81
2017	361	96
2018	558	110
2019	423	98
2020	134	24
2021	148	27

Table 1 The number of times individual receivers deployed (and re-deployed) within each water year from 2012 to 2019. The number of unique general locations represents sites that were covered during that water year.

Acoustic tagging summary

Since 2007, over 15,000 fish have been tagged using Vemco and JSATS technology. These fish are primarily Chinook Salmon from four different runs (populations): fall, late-fall, winter, and spring (Figure 2). Though the tagging efforts have primarily focused on juvenile Chinook Salmon, steelhead smolts and multiple predatory fish species that are known or presumed to eat juvenile salmon have also been tagged (Table 2).

Case study 1: Hatchery tagging efforts

We share two case studies highlighting how acoustic telemetry has been used in the CCV to answer focused research questions. In the first (Michel et al. 2015), we examined the habitat features and environmental conditions that drive patterns in survival and migration, with the goal of leveraging this information for prioritizing management actions or habitat restorations. Using the existing dataset of tagged hatchery fish, patterns in survival were identified across years and among regions within the Sacramento River and Delta where reaches of low survival were consistently observed and the need to identify critical rearing habitat is paramount to resource managers.

The largest tagging studies conducted by the SWFSC thus far have been to estimate survival for cohorts of hatchery smolts from several state and federally-managed hatcheries in the CCV. Between 2007 and 2011, late-fall Chinook salmon smolts were tagged (n = 1350) at Coleman National Fish Hatchery and released into Battle Creek (Michel et al. 2015). The first four years of the study were drought years, resulting in low flows in the Sacramento River, and fish cohorts experienced between 2.2% and 5.9% survival from the release sites to Benicia Bridge (Figure 2). Year 2011 was a high-flow year, and survival increased fivefold (15.9%) compared to low water years. The study also identified reaches of the Sacramento River that had consistently high mortality among years. Although the Delta was previously believed to be the primary source of mortality (Michel et al. 2015), the acoustic tagging study documented that the upper Sacramento River and the San Francisco Bay had lower survival than other regions of the migration corridor (Michel et al. 2015). This same dataset was reanalyzed in the following years to examine survival in relation to habitat features and predation-related covariates (Henderson et al. 2019). This subsequent analysis found that flow volume was the best-supported covariate in describing the annual changes in survival through the Sacramento River.

Migration rates of acoustically tagged salmon smolts including late-fall (Michel et al. 2013), spring-run (Notch et al. 2020), and fall-run (Zeug et al. 2020) indicate that, once these fish begin their downstream migration, they move quickly without seemingly stopping in the Sacramento River or Delta. However, during the winter and early spring, there appear to be reaches where juvenile winter-run salmon consistently slow their movement speeds to spend additional time during their outmigration to sea (Figure 3). As described by Hassrick et al. (2022), winter-run migrating through the middle Sacramento River took many more days to transit compared to other reaches and presumably exhibited a stopover strategy within this section of the Sacramento River that is more sinuous and contains more large woody debris than other reaches. This finding has management implications as the middle Sacramento River region could be critical rearing habitat for winter-run Chinook Salmon and worthy of future habitat restoration projects. Furthermore, their holding period may coincide spatially and temporally with the spawning migration of striped bass (*Morone saxatilis*), a known predator of juvenile salmon (Turner, 1976).

Winter-run Chinook Salmon have the longest freshwater migration distance of any hatchery-reared fish in the CCV. When these smolts are released near Redding, CA during the late winter, water exports for agricultural purposes

Run	Fish Origin	Years Tagged	Total Tagged	Release RKM	Fork Length Range (mm)	Weight Range (g)
Fall	Hatchery	2012 (169) 2013 (300) 2015 (65) 2016 (597) 2017 (1161) 2018 (561) 2019 (500) 2020 (723) 2021 (961)	5037	40 - 517	75 - 105	5.9 - 15.1
Fall	Natural	2017 (44) 2018 (307)	351	461	80 - 120	6 - 20.4
Late Fall	Hatchery	2007 (200) 2008 (304) 2009 (300) 2010 (306) 2011 (240) 2018(584) 2019 (440) 2020 (603)	2977	363-517	97 - 215	10 - 120.5
Predatory Fish	Natural	2013 (55)	55	153 - 260	220 - 550	100 - 2020
Spring	Hatchery	2013 (452) 2014 (502) 2015 (698) 2019 (600)	2252	139 - 287	78 - 107	5.8 - 13.8
Spring	Natural	2018 (59)	59	340	80 - 104	5.7 - 12.9
Spring/Fall	Natural	2013 (59) 2014 (113) 2015 (326) 2016 (249) 2017 (229) 2018 (671) 2019 (205) 2021 (113)	1938	249 - 517	73 - 136	4.7 - 32
Steelhead	Natural	2015 (19) 2016 (33) 2018 (3)	55	441 - 462	128 - 380	43.8 - 500
Steelhead	Hatchery	2021 (1498)	1498	183 - 135	124 - 299	20 - 327
Winter	Hatchery	2013 (148) 2014 (358) 2015 (567) 2016 (570) 2017 (569) 2018 (598) 2019 (650) 2020 (502)	3962	540 - 551	80 - 141	5.2 - 32.9
Winter	Natural	2018 (14)	14	461	85 - 120	6.4 - 18.6

Table 2 A summary of the tagging efforts of Chinook salmon and other fish species by the acoustic telemetry team between 2012 and 2019.

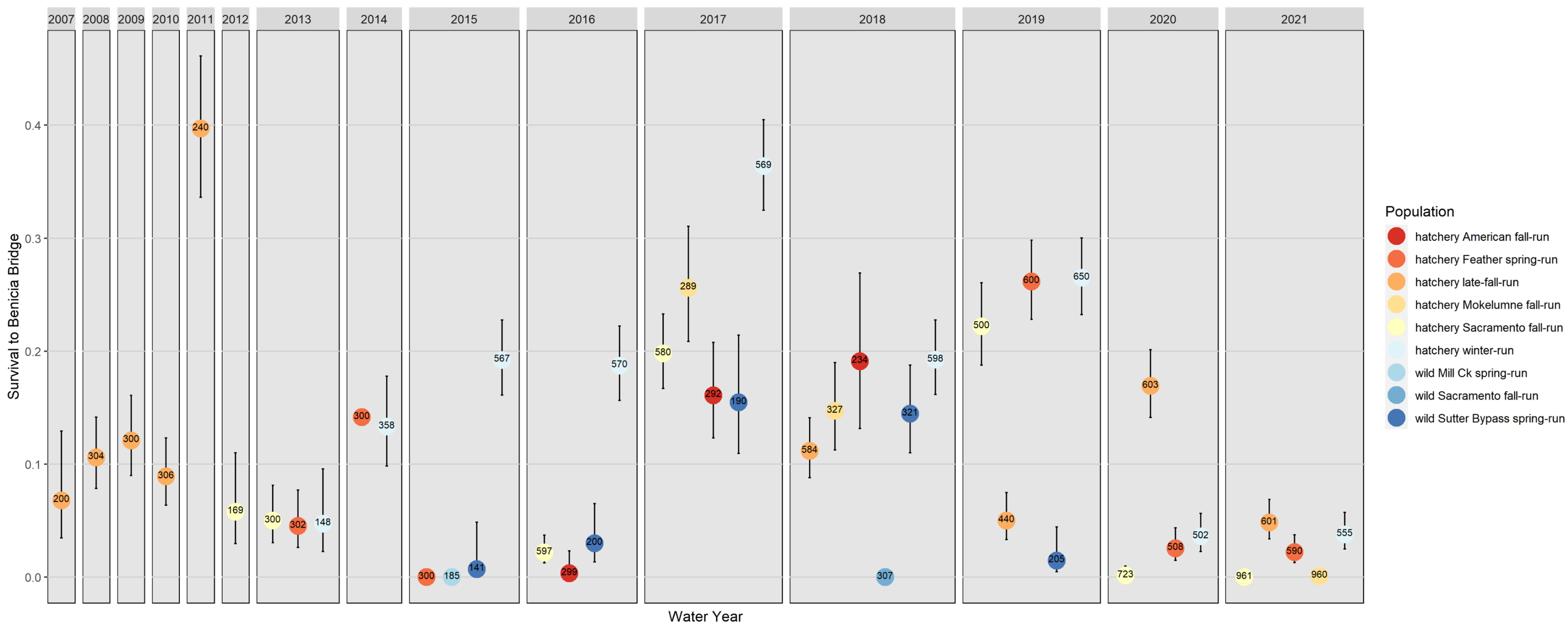

Figure 2 The survivorship of hatchery and wild tagged Chinook salmon from their release location to Benicia Bridge from 2007 to 2021. Alternative text: This figure displays the estimated survival for all groups of fish tagged from 2007 to 2021 from release location to Benicia Bridge.

are minimal and flows in the Sacramento River downstream of Keswick Dam can be as low as ~3000 cubic feet per second (cfs) to conserve storage in the Shasta Reservoir. Due to these low winter flows, hatchery managers are increasingly scheduling fish releases to coincide with natural high-flow events resulting from storms during the winter and early spring. Since 2013, the SWFSC has tagged winter-run Chinook Salmon (n = 3962) from the Livingston Stone National Fish Hatchery (LSNFH) and released them into the upper Sacramento River. During this time, release groups experienced a wide range of environmental conditions which allows for the examination of survival in relation to various environmental and physical parameters. As this dataset continues to grow, it may eventually be possible to estimate optimal river discharge thresholds, above which survival increases or below which it may be best to delay release and wait for a larger flow event.

Promoting conditions that improve survival rates, such as increasing stream flow during the critical outmigration period, as well as protecting and restoring habitat in reaches where fish are known to rear, would potentially enhance restoration of threatened and endangered populations of CCV Chinook salmon. By utilizing the fine-scale resolution of the acoustic telemetry dataset, resource managers can prioritize management actions or pinpoint the most promising locations for habitat restoration projects based on the cumulative results of many tagging studies conducted across years, seasons, locations, and populations.

Case study 2: Wild fish tagging

Populations of wild Chinook Salmon in the CCV do not benefit from regular supplementation from hatcheries and, as a result, their numbers fluctuate more widely among years. The factors driving these fluctuations remain unclear. In the CCV, where many wild populations are imperiled, understanding the mechanisms affecting juvenile outmigration survival is critical for future recovery efforts. Life cycle models have recently been developed to examine the stressors that threatened populations may experience, but data are lacking for many life stages (Cordoleani et al. 2020). This study provided essential estimates of outmigration survival for wild smolts.

Populations of wild Chinook Salmon in the CCV have been in decline over the past decade. Wild populations of salmon now persist in just a few tributaries to the Sacramento River as a result of human activities and infrastructure projects that reduced spawning and rearing habitat, altered natural flow regimes, and introduced non-native predator fishes (Yoshiyama et al. 2001). It has been hypothesized that wild juvenile Chinook Salmon have increased fitness relative to their hatchery counterparts and, as a result, should experience higher survival rates while migrating to the ocean (Araki et al. 2008). With the advent of miniature acoustic transmitters, we are now able to test this hypothesis by tagging and tracking wild populations throughout the CCV.

The second case study, by Notch et al. (2020), was designed to evaluate juvenile migratory survival and inform life-cycle models for one of the few remaining wild Chinook populations in the CCV. This study was partially funded by the Anadromous Fish Restoration Project (AFRP) and focused on Mill Creek, one of the last remaining tributaries to the upper Sacramento River harboring populations of wild CCV spring-run Chinook Salmon (NMFS 2014). As part of the California Department of Fish and Wildlife's ongoing life-cycle monitoring efforts, rotary screw traps were used to capture juvenile wild salmon in lower Mill Creek. These fish were implanted with JSATS tags and released on-site. Only fish >80 mm fork length were used in this study, following established size guidelines (Brown et al. 2010). While smolts make up a relatively small proportion of the overall juvenile outmigrants from Mill Creek compared to fry and parr, they are an essential

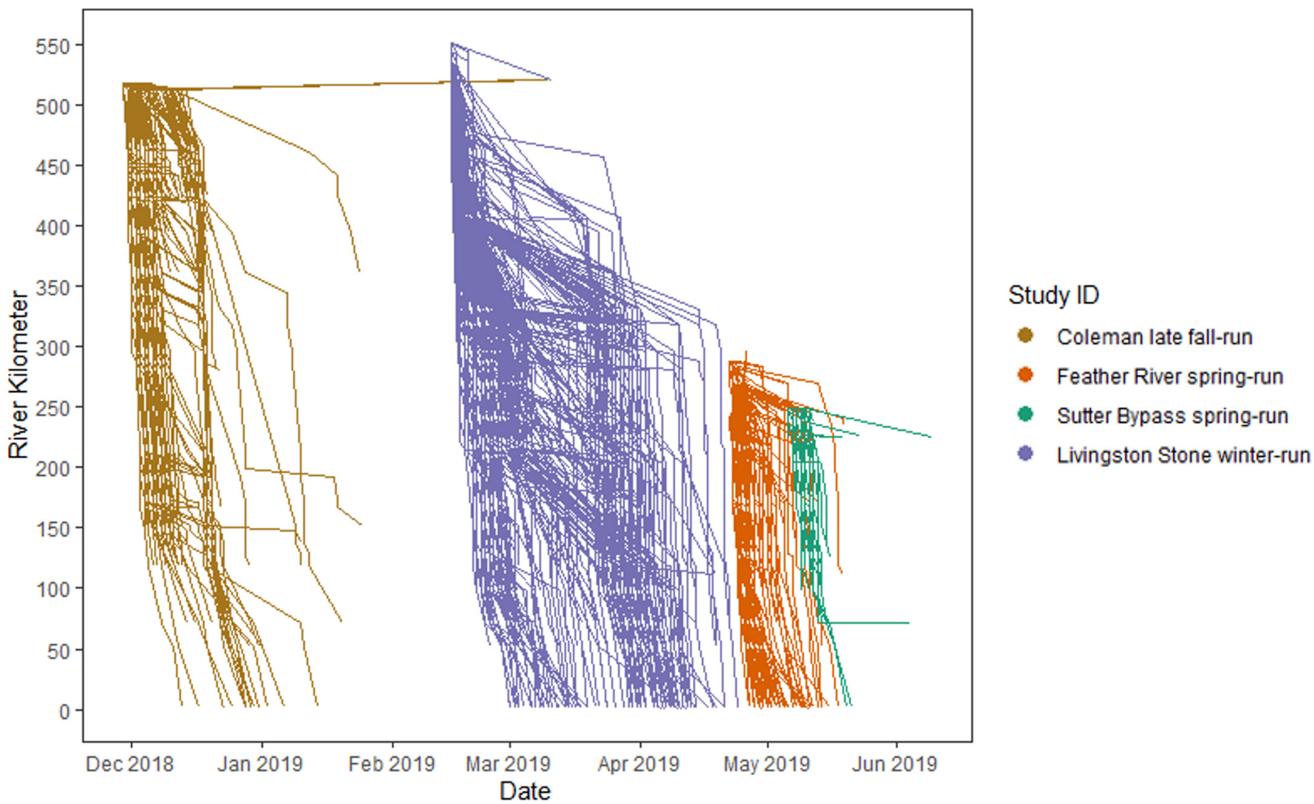

Figure 3 The movement of individual acoustic tagged fish in 2019 as they outmigrate from their release location to receiver locations downstream, ending at the Golden Gate (RKM 1). Alternative text: This figure displays individual fish movement patterns from release location in the Sacramento River to each receiver location downstream to the Golden Gate. There are four runs of fish (late fall, wild spring, hatchery spring, winter run) displayed here which were tagged and released during the winter and spring of 2019.

component of the spring-run life history, exhibiting prolonged tributary rearing before rapid outmigration to the ocean (Cordoleani et al. 2021).

Over 140 acoustic receivers were deployed throughout the Sacramento River, Delta, and San Francisco Bay to track outmigrating smolts for this case study. This extensive network of receivers, maintained by various state and federal agencies, provided the first glimpse of wild smolt movement and survival rates throughout the CCV. Across five consecutive years, 334 wild origin smolts were acoustically tagged and released in Mill Creek near the confluence with the Sacramento River. The results suggested there was relatively low survival within lower Mill Creek and much of the Sacramento River, especially during extreme drought conditions (2015). During a year of above-average precipitation (2017), smolt survival dramatically improved, likely due to increased flow and lower water temperatures (Notch et al. 2020). These findings suggest that smolt survival in natal tributaries and through the mainstem Sacramento River are strongly associated with streamflow, with survival through the Sacramento River increasing to 42% compared to previous years of below 15% survival.

Other wild populations have been tagged in subsequent years, including those from Butte Creek, Deer Creek, Antelope Creek, and the mainstem Sacramento River. These data have helped inform resource management by providing information on the movement and survival dynamics of wild juvenile salmon in the CCV and their presence throughout the system. With the advent of real-time acoustic receivers, monitoring tagged fish at specific regions of interest such as channel junctions can help water managers make better informed decisions while conserving threatened and endangered populations (Johnson et al. 2017). As population abundances of wild salmon in the CCV remain precariously low, the use of acoustic telemetry will help to establish annual survival rates from spawning grounds to the ocean and allow for the development of more focused studies in regions of low survival (Cordoleani et al. 2018, 2019; Notch et al. 2020).

Future Opportunities

Development of management tools

Sufficient telemetry data have been collected over the last decade to understand the nuances in the relationship between major environmental drivers and fish survival. One promising future direction is to look for potential ecological nonlinearities, or thresholds, which might give resource managers the information they need to optimize the use of limited resources to benefit both fish and human needs (Munsch et al. 2020). Several studies confirm that streamflow is a primary driver of Chinook salmon smolt survival in the Sacramento River (Henderson et al. 2019; Michel et al. 2015; Notch et al. 2020). More recently, a study utilizing the acoustic telemetry dataset found a survival threshold relative to flow, with flows above approximately 10,700 cfs resulting in significantly higher survival rates than flows below this value (Michel et al. 2021). This information is currently being used to design spring pulse flows in the Sacramento River to benefit juvenile spring-run Chinook salmon as part of the new 2019 NMFS Biological Opinion on the Long-term Operations of the Central Valley Project (CVP) and State Water Project (SWP).

There is a well-documented need for improved detection and modeling of salmon migration and survival in the CCV (Johnson et al. 2017; Cordoleani et al. 2020; Ammann 2020). Additional real-time stations can help achieve this need by (1) providing timely information on migrating salmon smolt locations and travel speeds, (2) expanding existing acoustic arrays to increase coverage and detection efficiencies, and (3) providing real-time data for critical management-relevant questions, such as entrainment estimates at critical junctions and water diversions.

To this end, researchers have recently increased the size and resolution of the existing real-time acoustic array. In the past year, USGS and UCD have increased the number of real-time receivers at sites in the South Delta to examine movement through the Old and Middle Rivers and potentially at CVP and SWP pumping locations. Additional stations in the Delta and the Sacramento River would help further achieve the three objectives listed above. Areas of consideration for more stations in the Sacramento River include near Red Bluff, Butte City, Tisdale weir, and Fremont weir. Real-time stations at Red Bluff would inform winter-run movement out of the upper river. In Butte City, an additional real-time station would allow instantaneous estimation of survival by creating a dual line of receivers and stations at the Tisdale and Fremont Weirs would provide timely information to managers about the proportion of fish utilizing the Sutter and Yolo Bypasses when high flows in the Sacramento River overtop the weirs and inundate the bypasses.

Visibility and Outreach

As a publicly funded science agency, an important goal of the SWFSC is to share data and research findings from projects being conducted in the CCV. The primary forms of information available about salmonid telemetry studies are peer-reviewed journal articles and NOAA, USGS, USFWS, and U.S. Bureau of Reclamation (BOR) technical reports. Now, in conjunction with the development of a real-time array, data are also freely and publicly available via the CalFishTtrack website (https://oceanview.pfeg.noaa.gov/CalFishTrack/).

Furthermore, complete datasets (autonomous and real-time detections) are available on the ERDDAP website (https://oceanview.pfeg.noaa.gov/erddap/tabledap/FEDcalFishTrack.html), giving scientists the opportunity to engage a wider audience with more timely and easily understood information. In addition, agency researchers have the opportunity to interact with the public both while collecting data in the field, maintaining receiver arrays, and when tagging fish at state and federal fish hatcheries. For this reason, we have developed an infographic explaining the process of salmon acoustic tagging that can be shared with the public (Figure 4).

Acknowledgements

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References

ATS Advanced Telemetry Systems. 2015. Acoustic Transmitters Model SS300: ATS, Inc; [accessed 2023 Jan 10].atstrack.com/tracking-products/transmitters/SS300-acoustic-tag-.aspx

Ammann AJ, Michel CJ, MacFarlane RB. 2013. The effects of surgically implanted acoustic transmitters on laboratory growth, survival and tag retention in hatchery yearling Chinook. Environmental Biology of Fishes. 96:135-143.

Ammann AJ. 2020. Factors affecting detection probability and range of transmitters and receivers designed for the juvenile salmon acoustic telemetry system. Environmental Biology of Fishes. 103:625-634.

Araki H, Berejikian BA, Ford MJ, Blouin MS. 2008. Fitness of hatchery reared salmonids in the wild. Evolutionary Applications. 1(2):342-355.

Brown RS, Harnish RA, Carter KM, Boyd JW, Deters KA, Eppard MB. 2010. An evaluation of the maximum tag burden for implantation of acoustic transmitters in juvenile Chinook salmon. North American Journal of Fisheries Management. 30(2):499-505.

Burnham KP. 1987. Design and analysis methods for fish survival experiments based on release-recapture. American Fisheries Society monograph. 5:437

Cordoleani F, Notch J, McHuron AS, Ammann AJ, Michel CJ. 2018. Movement and survival of wild Chinook salmon smolts from Butte Creek during their out-migration to the ocean: Comparison of a dry year versus a wet year. Transactions of the American Fisheries Society. 147(1):171-184.

Cordoleani F, Notch J, McHuron AS, Michel CJ, Ammann AJ. 2019. Movement and survival rates of Butte Creek spring-run Chinook salmon smolts from the Sutter Bypass to the Golden Gate Bridge in 2015, 2016, and 2017. NOAA technical memorandum NMFS-SWFSC (618). [accessed 2023 Jan 10]. doi:https://doi.org/10.25923/cwry-bx03

Cordoleani F, Satterthwaite WH, Daniels ME, Johnson MR. 2020. Using Life-Cycle Models to Identify Monitoring Gaps for Central Valley Spring-Run Chinook Salmon. San Francisco Estuary and Watershed Science. 18(4).

Cordoleani F, Phillis CC, Sturrock AM, FitzGerald AM, Malkassian A, Whitman GE, Weber PK, Johnson RC. 2021. Threatened salmon rely on a rare life history strategy in a warming landscape. Nature Climate Change. 11(11):982-988.

Cormack RM. 1964. Estimates of Survival from the Sighting of Marked Animals. Biometrika. 51(3/4):429-438.

Hassrick J. Instream dynamics and reach-specific movement and survival of Sacramento River winter-run Chinook Salmon. 2019 River Restoration Northwest Symposium.(pdf)

Healey MC. 1991. Life history of Chinook salmon. Pacific salmon life histories. University of British Columbia Press

Henderson MJ, Iglesias IS, Michel CJ, Ammann AJ, Huff DD. 2019. Estimating spatial–temporal differences in Chinook salmon outmigration survival with habitat- and predation-related covariates. Canadian Journal of Fisheries and Aquatic Sciences. 76(9):1549-1561.

Johnson RC, Windell S, Brandes PL, Conrad JL, Ferguson J, Goertler PA, Harvey BN, Heublein J, Isreal JA, Kratville DW, et al. 2017. Science advancements key to increasing management value of life stage monitoring networks for endangered Sacramento River winter-run Chinook salmon in California. San Francisco Estuary and Watershed Science. 15(3):1-41.

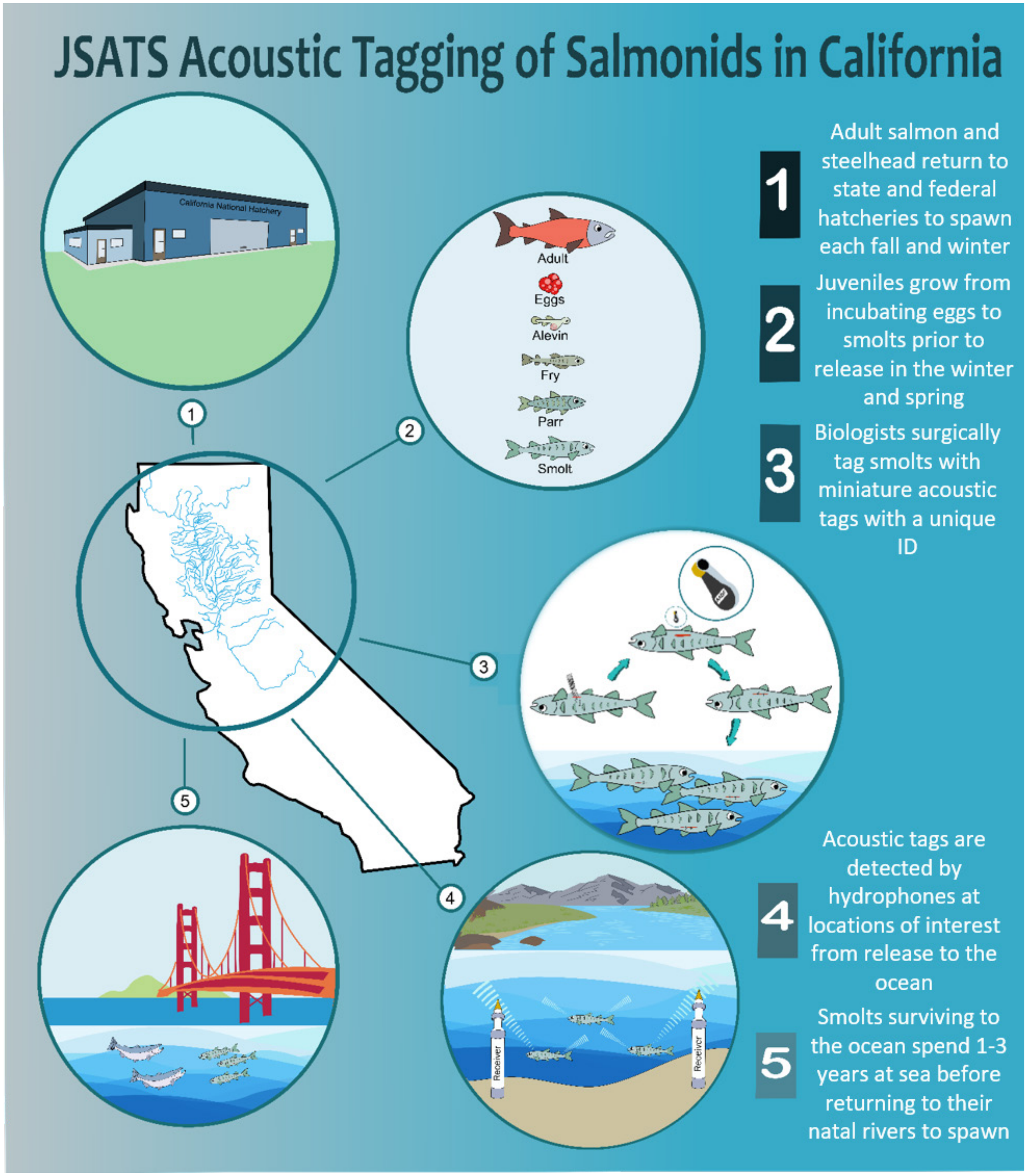

Figure 4 An overview of the JSATS acoustic tagging process including the lifecycle of a Pacific salmon. Alternative text: This image describes the lifecycle of a Pacific salmon, and the acoustic tagging process of surgically implanting micro transmitters inside juvenile salmon at state and federal fish hatcheries.

Jolly GM. 1965. Explicit Estimates from Capture-Recapture Data with Both Death and Immigration-Stochastic Model. Biometrika. 52 (1/2):225-247.

Klimley A, MacFarlane RB, Sandstrom PT, Lindley ST. 2013. A summary of the use of electronic tagging to provide insights into salmon migration and survival. Environmental Biology of Fishes. 96(2):419-428.

Lindley ST, Moser ML, Erickson DL, Belchik M, Welch DW, Rechisky EL, Kelly JT, Heublein J, Klimley AP. 2008. Marine Migration of North American Green Sturgeon. Transactions of the American Fisheries Society. 137(1):182-194.

Lu J, Deng ZD, Li H, Myjak MJ, Martinez JJ, Xiao J, Brown RS, Cartmell SS. 2016. A small long-life acoustic transmitter for studying the behavior of aquatic animals. Review of Scientific Instruments. 87(11):114902.

McMichael GA, Eppard MB, Carlson TJ, Carter TJ, Ebberts BD, Brown RS, Weiland M, Ploskey GR, Harnish RA, Deng ZD. 2010. The Juvenile Salmon Acoustic Telemetry System: A New Tool. Fisheries. 35(1):9-22.

McMichael GA, Kagley A. 2015. Field tests two acoustic telemetry systems to examine range and detection efficiency. Conference: American Fisheries Society Annual Meeting 2015. At: Portland, Or.

Michel CJ, Ammann AJ, Chapman ED, Sandstrom PT, Fish HE, Thomas MJ, Singer GP, Lindley ST, Klimley AP, MacFarland RB. 2013. The effect of environmental factors on the migratory movement patterns of Sacramento River yearling late-fall-run Chinook salmon (*Oncorhynchus tshawytscha*). Environmental Biology of Fishes. 96(2):257-271.

Michel CJ, Ammann AJ, Lindley ST, Sandstrom PT, Chapman ED, Thomas MJ, Singer GP, Klimley AP, MacFarlane RB. 2015. Chinook salmon outmigration survival in wet and dry years in California's Sacramento River. Canadian Journal of Fisheries and Aquatic Sciences. 72(11):1749-1759.

Michel CJ. 2019. Decoupling outmigration from marine survival indicates outsized influence of streamflow on cohort success for California's Chinook salmon populations. Canadian Journal of Fisheries and Aquatic Sciences. 76(8):1398-1410.

Michel CJ, Notch JJ, Cordoleani F, Ammann AJ, Danner EM. 2021. Nonlinear survival of imperiled fish informs managed flows in a highly modified river. Ecosphere. 12(5):e03498.

National Marine Fisheries Service (NMFS). 2014. Recovery plan for the evolutionarily significant units of Sacramento River winter-run Chinook salmon and Central Valley spring-run Chinook salmon and the distinct population segment of California Central Valley Steelhead.[accessed 2023 Jan 10]. https://www.fisheries.noaa.gov/resource/document/recovery-plan-evolutionarily-significant-units-sacramento-river-winter-run

Notch JJ, McHuron AS, Michel CJ, Cordoleani F, Johnson M, Henderson MJ, Ammann AJ. 2020. Outmigration survival of wild Chinook salmon smolts through the Sacramento River during historic drought and high water conditions. Environmental Biology of Fishes. 103(5):561-576.

Perry RW, Pope AC, Romie JG, Brandes PL, Burau JR, Blake AR, Ammann AJ, Michel CJ. 2018. Flow-mediated effects on travel time, routing, and survival of juvenile Chinook salmon in a spatially complex, tidally forced river delta. Canadian Journal of Fisheries and Aquatic Sciences. 75(11):1886-1901.

Seber GA. 1982. The estimation of animal abundance and related parameters. 2nd edition. Chapman, London and Macmillan.

Turner JL. 1976. Striped bass spawning in the Sacramento and San Joaquin Rivers in Central California from 1963 to 1972. California Fish and Game. 62: 106–118.

Yoshiyama RM, Gerstung ER, Fisher FW, Moyle PB. 2001. Historical and present distribution of Chinook salmon in the Central Valley drainage of California. Fish Bulletin. 179(1):71-176

Zeug SC, Null R, Brodsky A. 2020. Effect of release timing on apparent survival of juvenile fall run Chinook Salmon from Coleman National Fish Hatchery. Environ Biol Fish 103, 411–423.

Data Reports

2022 Spring Kodiak Trawl Summary

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Introduction

Since 2002, the California Department of Fish and Wildlife (CDFW) has conducted the Spring Kodiak Trawl (SKT) survey annually to determine the distribution and relative abundance of adult Delta Smelt (*Hypomesus transpacificus*), which are endemic to the San Francisco Estuary (SFE) and are listed as endangered and threatened under the California and United States Endangered Species Acts, respectively. The SKT survey also provides data about the gonadal maturation of Delta Smelt, which indicates when and where spawning is likely to be occurring.

The SKT conducts one survey each month from January to May. The survey consists of sampling 39 index stations and 1 non-index station throughout the upper SFE (Figure 1). Catch data at index stations are used to calculate an index of relative abundance. Station 719 was added in 2005 in the Sacramento Deep Water Shipping Channel as a non-index station. Each station is sampled for 10 minutes using a Kodiak Trawl net that is towed between two boats at the water's surface. Water quality parameters are recorded at each station and fishes are identified, enumerated, and measured for length. Unidentified fishes are brought back to the laboratory for later identification.

A total of 196 sampling tows were conducted during the 2022 SKT season which ran from January 18th through May 12th. COVID-19 safety precautions prevented sampling at stations 610, 609, 606, and 602 during survey 1. All stations were sampled in surveys 2-5. A total of 4,079 fish from 24 taxa were sampled in 2022 (Table 1). Pacific Herring (*Clupea pallasi*), Northern Anchovy (*Engraulis mordax*), Threadfin Shad (*Dorosoma petenense*), and Longfin Smelt (*Spirinchus thaleichthys*) were the most abundant species, comprising 82% of the total catch (Table 1).

Eighteen Delta Smelt were collected in the 2022 SKT season (Figure 2). Although detection rates continue to be low, this is an increase in catch from last year's catch of zero. All 18 fish were marked, indicating they originated from the experimental release of 55,733 marked hatchery-origin Delta Smelt released into the system between December 2021 and February 2022 (USFWS 2022). Fourteen Delta Smelt were collected in Montezuma Slough (stations 606 and 609), 3 in the Sacramento Deepwater Shipping Channel (station 719), and 1 in the lower Sacramento River (station 704) between February and April. Sixteen fish were determined to be in a pre-spawn condition. Two gravid females were caught in March in Montezuma Slough, indicating that some experimentally released Delta Smelt likely began spawning around that time. Larval Delta Smelt were first detected in late March in both CDFW's Smelt Larva Survey and 20-mm Survey (n=10) which provides additional evidence that spawning began in late February or early March (Jimenez 2022, Mager 2004).

Longfin Smelt, which is listed as a threatened species under the California Endangered Species Act, was the fourth most abundant species with 321 individuals collected this year (Table 1). This is the fourth highest annual catch of Longfin Smelt in the program's history (Figure 3). Only one adult Longfin Smelt (87 mm FL) was collected in March and it was captured in Grizzly Bay. Four larval Longfin Smelt (17-19 mm FL) were collected in April and May and all were sampled in Montezuma Slough. The majority (n=316) of Longfin Smelt caught were juveniles with fork lengths ranging from 20 mm to 84 mm. Juvenile Longfin

Smelt were collected in lower portions of the Sacramento River and downstream of the Sacramento-San Joaquin River Confluence between March and May.

Pacific Herring was the most abundant species encountered in the 2022 SKT survey with 2,304 caught making up 56% of the total catch (Table 1). This is the third highest annual Pacific Herring catch in the program's history (Figure 4). The SKT's annual Pacific Herring catch varies widely and is loosely associated with low flow/dry water years. Given that 2021 was a critically dry water year (DWR 2022), inland waters were more saline than in wet years, contributing to higher Pacific Herring catch within the Estuary.

Chinook Salmon (*Oncorhynchus tshawytscha*) were observed throughout the sampling area and was the sixth most abundant species (n=173; Table 1). The 2022 combined catch of all races of Chinook Salmon increased slightly from last year, though catch continues to be low (Figure 5). Most of the Chinook Salmon were caught in the Sacramento River system between April and May (Figure 6).

Data from the SKT is reported in near real-time to the Smelt Monitoring Team and the Salmon Monitoring Team to help inform adaptive management decisions. The SKT web page (https://wildlife.ca.gov/Conservation/Delta/Spring-Kodiak-Trawl) provides catch distribution maps for all species collected, along with information on Delta Smelt sex and reproductive maturity and Chinook Salmon adipose fin status and race information based on length-at-date and coded wire tag (CWT) results.

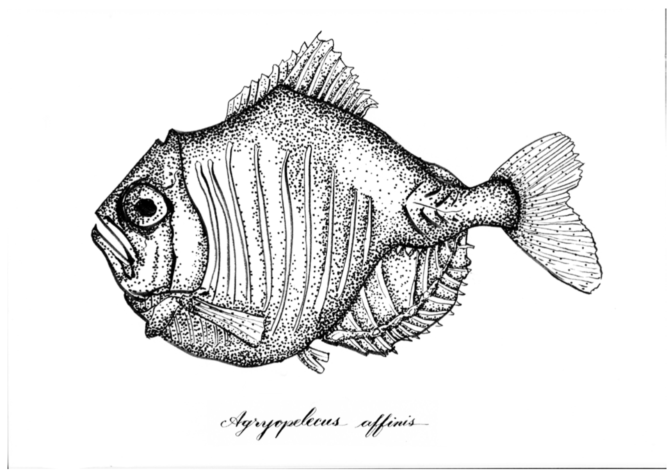
The 2023 Spring Kodiak Trawl is scheduled to begin in January 2023 and run through May 2023. Data and metadata are available on the CDFW file library (https://filelib.wildlife.ca.gov/Public/Delta%20Smelt/).

Literature Cited

Department of Water Resources (DWR). 2022. Chronological Reconstructed Sacramento and San Joaquin Valley Water Year Hydrologic Classification Indices. Retrieved from https://cdec.water.ca.gov/reportapp/javareports?name=WSIHIST

Jimenez J. 2022 Smelt Larva Survey Summary. Interagency Ecological Program Newsletter. 41(3): 37-44.

Mager RC. 2004. Early Life Stages of Delta Smelt. American Fisheries Society Symposium 39: 169-180United States Fish and Wildlife Service (USFWS). 2022. BY2021 ERTT Summary of Activities. Technical Report. p. 1-55 plus appendices.



Common Name	Scientific Name		Percent of Total
Pacific Herring	*Clupea pallasi*		56.48%
Northern Anchovy	*Engraulis mordax*		10.20%
Threadfin Shad	*Dorosoma petenense*		8.43%
Longfin Smelt	*Spirinchus thaleichthys*		7.87%
Threespine Stickleback	*Gasterosteus aculeatus*		4.46%
Chinook Salmon	*Oncorhynchus tshawytscha*		4.24%
Inland Silverside	*Menidia beryllina*		3.85%
American Shad	*Alosa sapidissima*	62	1.52%
Topsmelt	*Atherinops affinis*	36	0.88%
Delta Smelt	*Hypomesus transpacificus*	18	0.44%
Steelhead	*Oncorhynchus mykiss*	13	0.32%
Jacksmelt	*Atherinopsis californiensis*	12	0.29%
Hitch	*Lavinia exilicauda*	8	0.20%
Splittail	*Pogonichthys macrolepidotus*	7	0.17%
Wakasagi	*Hypomesus nipponensis*	6	0.15%
Prickly Sculpin	*Cottus asper*	5	0.12%
Golden Shiner	*Notemigonus crysoleucas*	3	0.07%
Bluegill	*Lepomis macrochirus*	3	0.07%
Tule Perch	*Hysterocarpus traski*	2	0.05%
Striped Bass	*Morone saxatilis*	2	0.05%
Starry Flounder	*Platichthys stellatus*	2	0.05%
Bluefin Killifish	*Lucania goodei*	1	0.02%
Shimofuri Goby	*Tridentiger bifasciatus*	1	0.02%
Bigscale Logperch	*Percina macrolepida*	1	0.02%

Table 1 Total organism catch for the 2022 California Department of Fish and Wildlife's Spring Kodiak Trawl. Alternative text: The species are listed from most abundant to least abundant in this order: Pacific Herring, Northern Anchovy, Threadfin Shad, Longfin Smelt, Threespine Stickleback, Chinook Salmon, Inland Silverside, American Shad, Topsmelt, Delta Smelt, Steelhead, Jacksmelt, Hitch, Splittail, Wakasagi, Prickly Sculpin, Golden Shiner, Bluegill, Tule Perch, Striped Bass, Starry Flounder, Bluefin Killifish, Shimofuri Goby, and Bigscale Logperch.

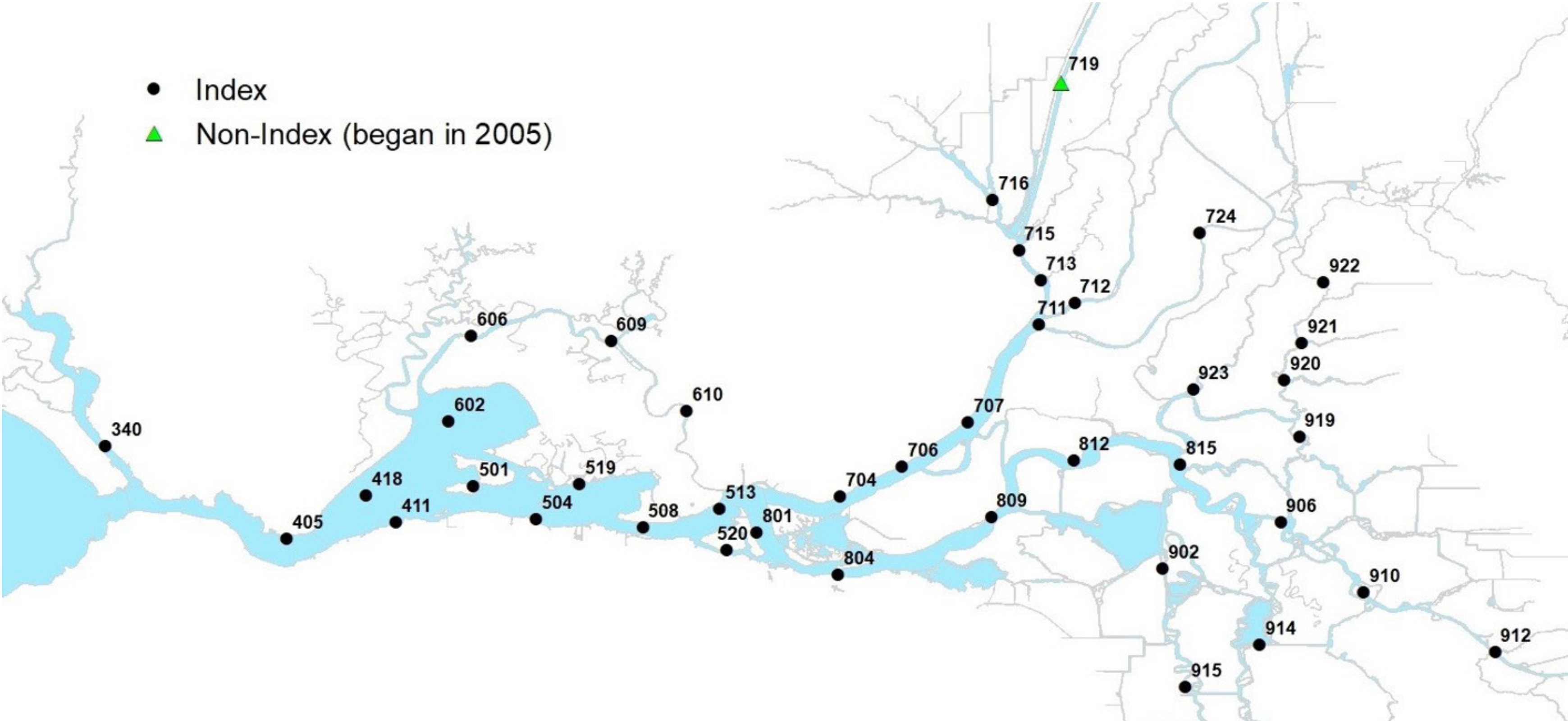


Figure 1 Station locations for the 2022 CDFW Spring Kodiak Trawl in the upper San Francisco Estuary. Stations marked with a black dot are index stations and stations marked with a green triangle are non-index stations. Alternative text: 40 stations cover a large geographic area from the base of the Sacramento Deep Water Shipping Channel to Stockton and west through the Carquinez Strait and the mouth of the Napa River.

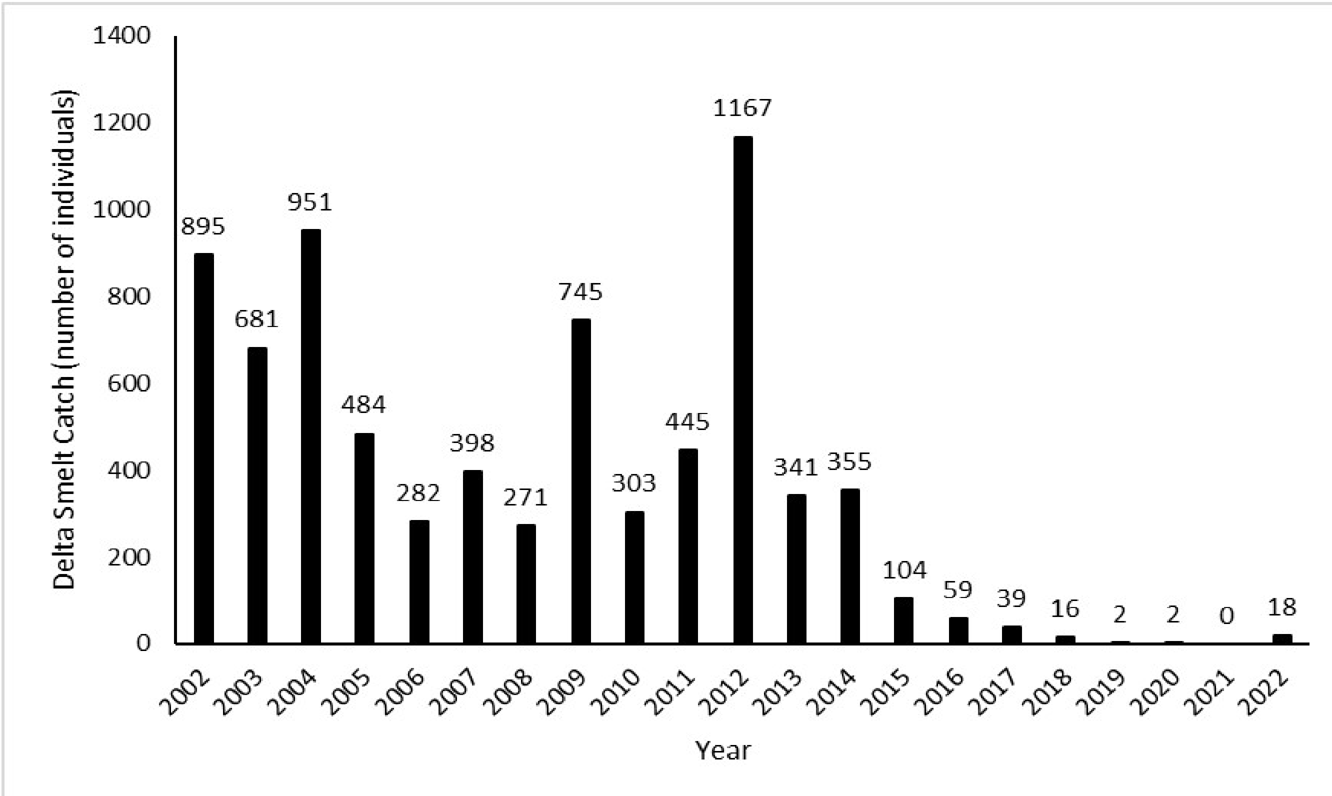


Figure 2 Total annual Delta Smelt catch from the California Department of Fish and Wildlife's Spring Kodiak Trawl excluding December supplemental sampling. Sampling in 2020 was limited to surveys 1-3 due to the COVID pandemic. Alternative text: Delta Smelt catch has been steadily declining since 2014.

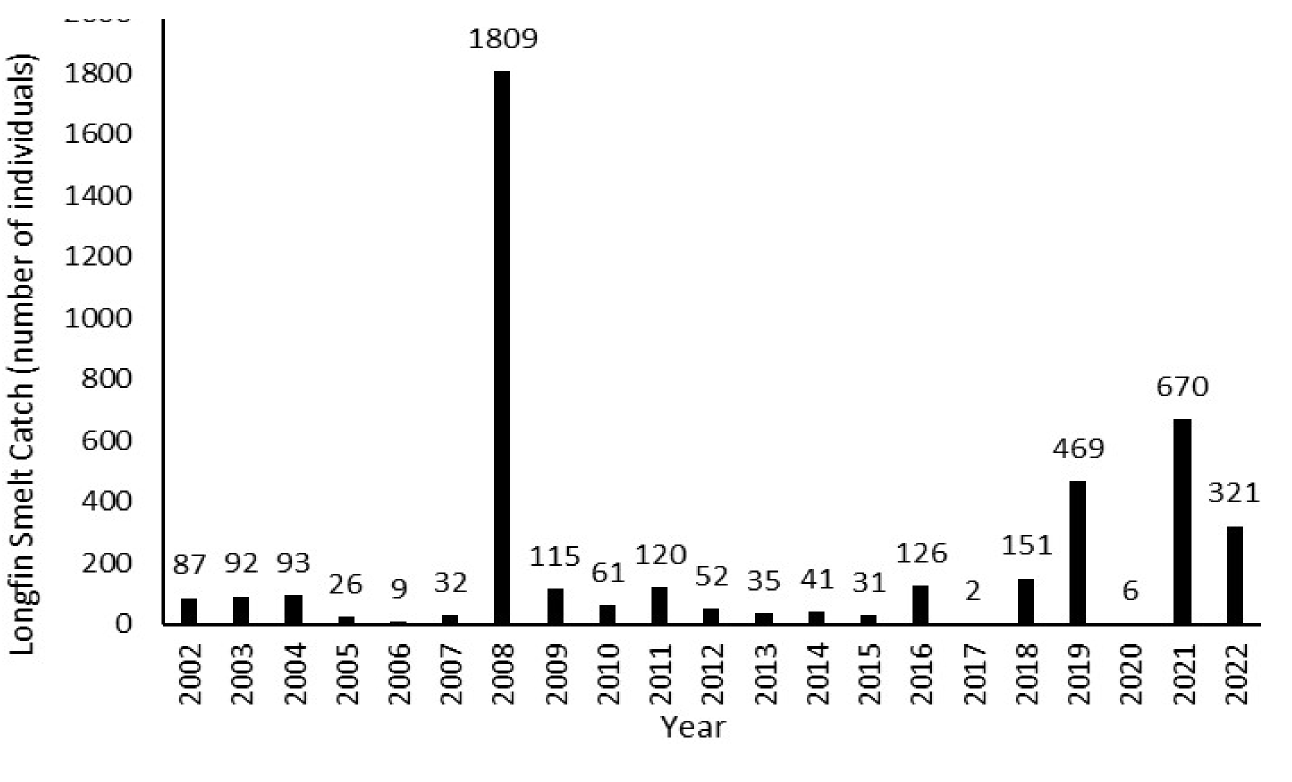


Figure 3 Total annual Longfin Smelt catch from the California Department of Fish and Wildlife's Spring Kodiak Trawl excluding December supplemental sampling. Sampling in 2020 was limited to surveys 1-3 due to the COVID pandemic. Alternative text: Year 2008 represented the greatest catch of Longfin Smelt by over a thousand fish compared to other years.

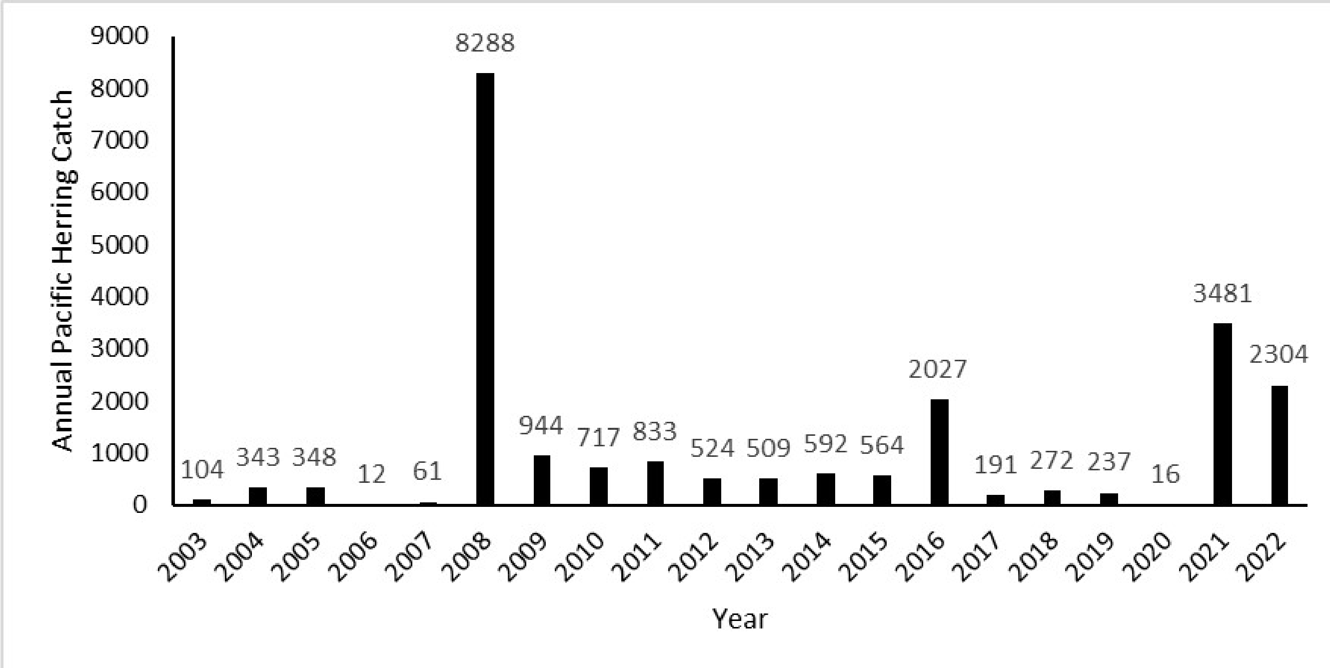


Figure 4 Total annual Pacific Herring catch from the California Department of Fish and Wildlife's Spring Kodiak Trawl excluding December supplemental sampling. Sampling in 2020 was limited to surveys 1-3 due to the COVID pandemic. Alternative text: Year 2008 represented the greatest catch of Pacific herring by far with 2003-2007, 2009-2015, and 2017-2020 all having less than a thousand individuals captured annually.

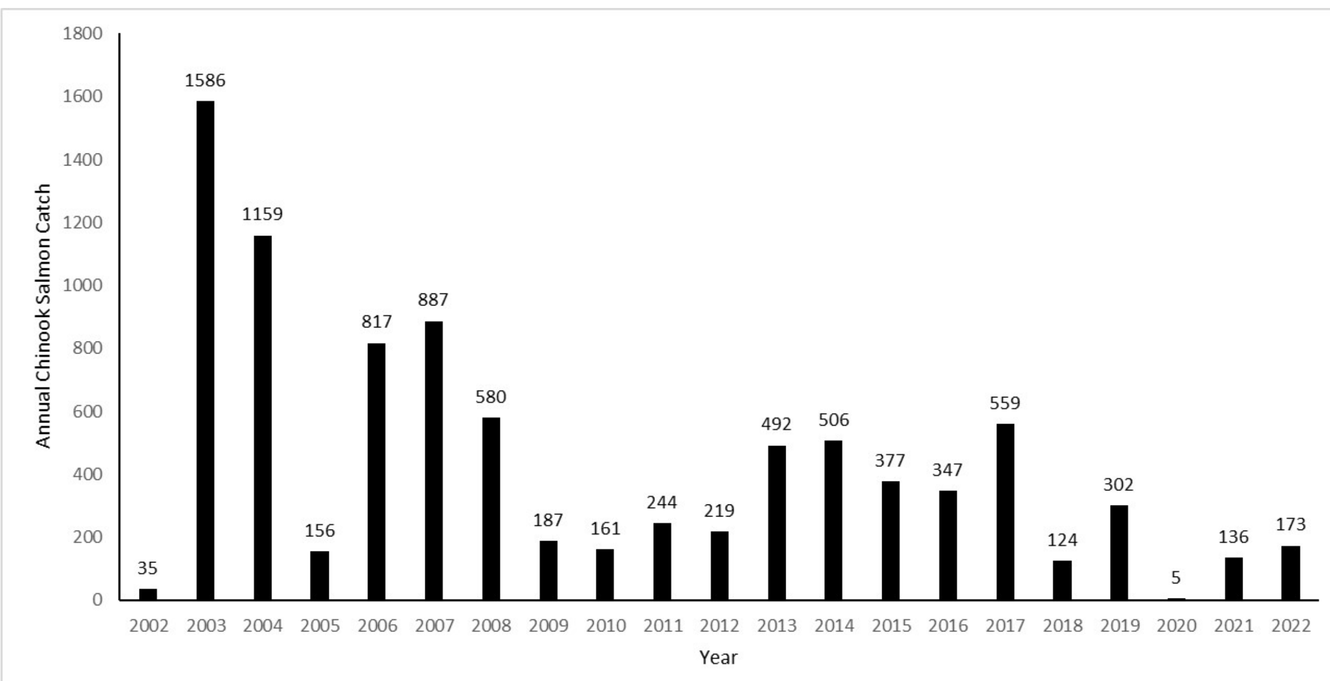


Figure 5 Annual Chinook Salmon catch from the California Department of Fish and Wildlife's Spring Kodiak Trawl excluding December supplemental sampling. Sampling in 2020 was limited to surveys 1-3 due to the COVID pandemic. Alternative text: Chinook Salmon has been on the decline since 2003 with various peaks and valleys, 2003 being the highest catch.

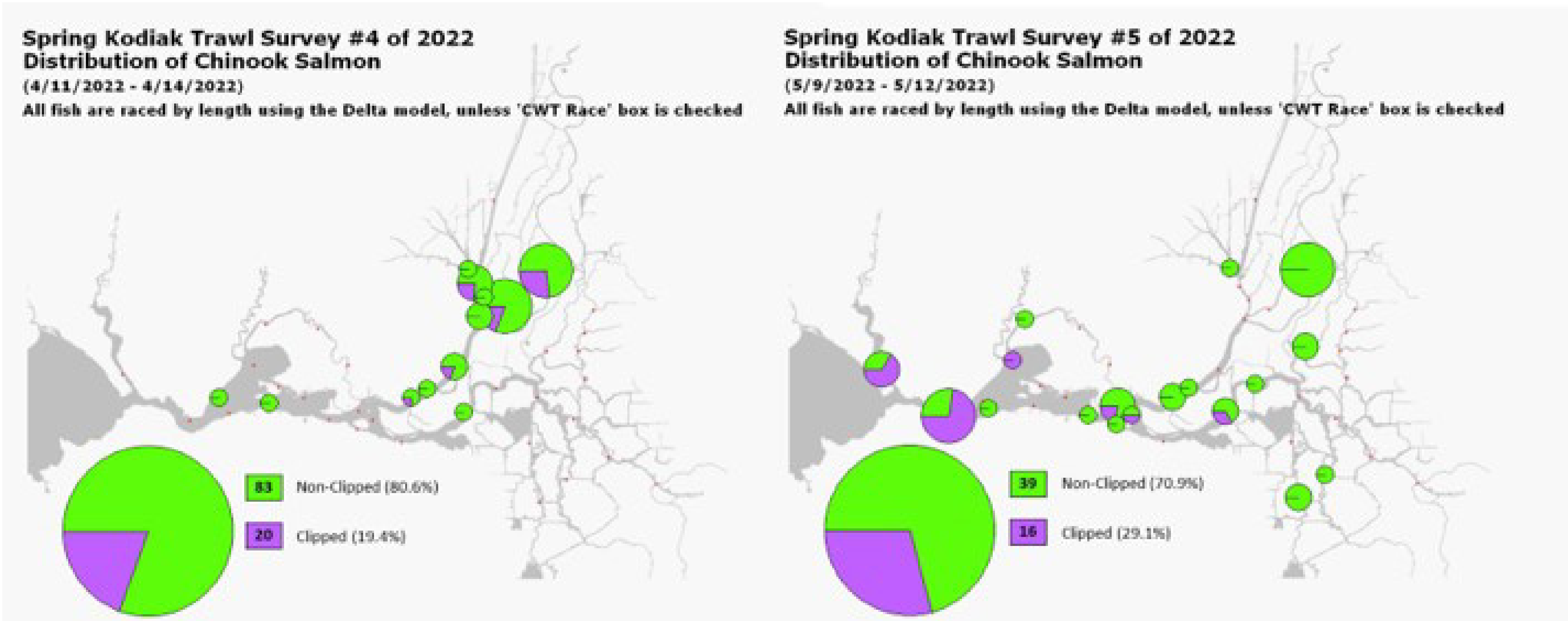


Figure 6 Geographic bubble plot of Chinook Salmon catch and adipose fin status from April and May of the 2022 California Department of Fish and Wildlife's Spring Kodiak Trawl. Bubble size is proportional to total catch. Alternative text: In April, 80.6% of all fish caught had adipose fins intact and were caught in the Sacramento River system. In May, 70.9% of all fish caught had adipose fins intact and catches were more widespread geographically.

2022 20-mm Survey Summary

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The California Department of Fish and Wildlife (CDFW) conducts the 20-mm Survey annually to monitor the distribution and relative abundance of larval and juvenile Delta Smelt (*Hypomesus transpacificus*) and Longfin Smelt (*Spirinchus thaleichthys*) in the upper San Francisco Estuary (SFE). The survey began in 1995 and provides near real-time catch data to water and fisheries managers for the purpose of assessing the risk of entrainment of these species at water export facilities.

The 20-mm Survey uses a conical net with 1600-micron nylon mesh to collect young-of-year fish. The net is 5.1 m long with a mouth area of 1.51 m2 and is attached to a rigid steel D-ring frame mounted on skis. Nine surveys were conducted at 47 fixed sites, or stations, every other week from March through July (Figure 1). Pending requests by the Smelt Monitoring Team during periods of high flow, five additional high outflow stations are sampled in San Pablo Bay to better characterize potential Osmerid distribution. At each station, the entire water column up to a maximum depth of approximately 32 ft is concurrently sampled with three stepped-oblique tows and a single zooplankton tow. All samples are preserved in 10% buffered formalin and dyed with rose bengal for subsequent identification and enumeration in the laboratory. Fish are measured to the nearest millimeter by fork length if the caudal fin is forked or total length if the caudal fin is not forked.

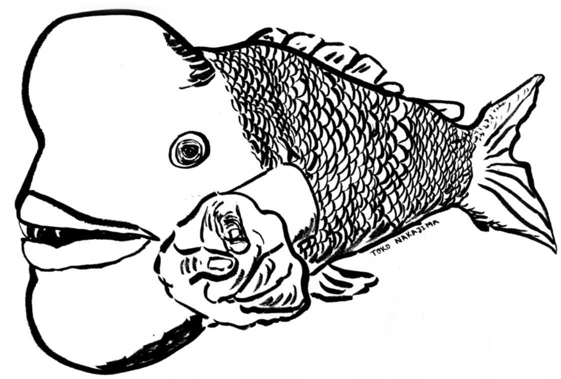
A total of 1,095 sampling events over the course of eight surveys between March 21, 2022 and June 30, 2022 were conducted. High outflow stations were not sampled during the 2022 sampling season. Survey 9 was not conducted due to vessel breakdowns. Occasionally, we were unable to sample a station due to excessive debris or by-catch; in 2022, we did not sample three stations in the Napa River (Surveys 2 and 3) and two stations in the lower Sacramento River (Survey 7) due to an excessively high catch of jellyfish and vegetation (Table 1).

A total of 76,820 fish representing 44 taxa were collected. *Tridentiger* spp. (gobies), Longfin Smelt, and the Yellowfin Goby (*Acanthogobius flavimanus*) were the three most abundant taxa caught in 2022; individuals comprised about 82% of the total catch (Table 2). These species, in addition to Striped Bass (*Morone saxatilis*), Pacific Herring (*Clupea pallasii*), and Threadfin Shad (*Dorosoma petenense*), have consistently comprised most of the total catch since the survey began in 1995 (Figure 2).

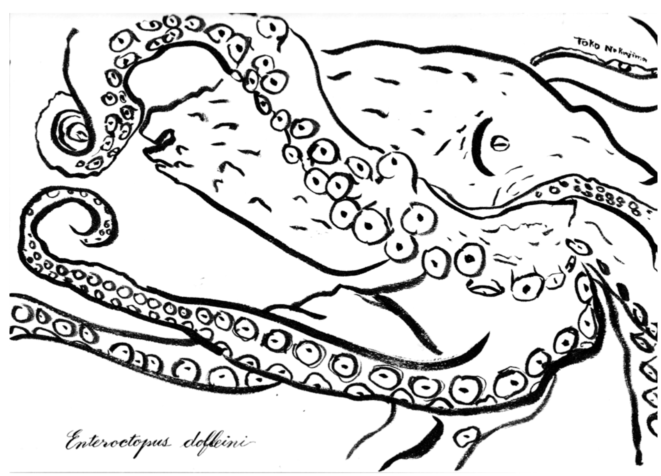
The 2022 20-mm Survey yielded nine larval Delta Smelt (Figure 3). Seven larvae (8 mm-13 mm) were found in late March and two larvae (8 mm-12 mm) were found in early April. Eight larval Delta Smelt were caught in the Sacramento River Complex, and one was caught in Old River at station 902 (Figure 4). Given that 55,733 marked adult hatchery-origin Delta Smelt were experimentally released into the Bay-Delta between December 2021 and February 2022, (USFWS 2022), it is likely that most or all of the larvae caught in the 20-mm Survey were offspring of those fish. Two ripe female Delta Smelt were sampled by the 2022 Spring Kodiak Trawl in March, indicating spawning may have occurred at this time (Mora 2022). It is likely they also successfully spawned once in late February since one larva (10 mm) was captured by the Smelt Larva Survey on March 21, 2022 (Jimenez 2022). No adults or larvae were captured later in the spawning season.

As Delta Smelt continue the trend of record low abundances and rare detections, we were unable to calculate the 20-mm Delta Smelt index (Damon 2022) this year due to lack of catch. Consequently, this year’s index is not available.

A total of 13,172 Longfin Smelt were caught in the 2022 20-mm Survey (Figure 5). The average juvenile Longfin Smelt length was 13 mm in March and 31 mm in June (Figure 6). A total of 643 Longfin Smelt were caught in the South Delta and Sacramento River in March and no individuals were caught in these areas in June (Figure 7A and 7D). Their distribution shifted from east to west within the SFE between March and June (Figure 7). This shift from fresh to brackish water is expected according to life stage-specific thermal and salinity preferences (Wang 1986). The average surface water temperature increased from 15.3°C in March to 21.8°C in June (Figure 8A) and the average surface specific conductivity increased from 5,530 µS in March to 10,117 µS in June (Figure 8B).



Current and past graphical data is available on the 20-mm Survey webpage at https://wildlife.ca.gov/Conservation/Delta/20mm-Survey. Data and metadata are available at https://filelib.wildlife.ca.gov/Public/Delta%20Smelt/.



Literature Cited

Damon L, Mora V. 2022. Memorandum: 2022 20-mm Survey Delta Smelt Index. California Department of Fish and Wildlife. Memorandum to Erin Chappell

United States Fish and Wildlife Service (USFWS). 2022. BY2021 ERTT Summary of Activities. Technical Report. p. 1-55 plus appendices.

Mora V. 2022 Spring Kodiak Trawl Summary. Interagency Ecological Program Newsletter. 41(3): 19-25.

Jimenez J. 2022 Smelt Larva Survey Summary. Interagency Ecological Program Newsletter. 41(3): 37-44.

Wang. 1986. Fishes of the Sacramento-San Joaquin Estuary and Adjacent Waters, California: A Guide to the Early Life Histories. Technical Report 9.

Survey	Stations Sampled	Tows Completed	Comments
1	47	141	All stations and tows completed.
2	44	132	Stations 344, 345, and 346 dropped due to excessive jellyfish.
3	44	131	Stations 344, 345, and 346 dropped due to excessive jellyfish. Tow 3 at station 910 dropped.
4	47	141	All stations and tows completed.
5	47	140	Tow 3 dropped at station 706 due to excessive vegetation.
6	45	133	Stations 796 and 707 dropped due to excessive vegetation. Tow 2 and 3 dropped at station 346 due to excessive jellyfish.
7	46	138	Station 726 not sampled.
8	47	139	Tows 2 and 3 dropped at station 901 due to excessive vegetation.

Table 1 Sampling effort for the California Department of Fish and Wildlife’s 2022 20-mm Survey. Alternative Text: This table shows eight out of the nine surveys were completed. Stations and samples dropped were mostly due to excessive vegetation and jellyfish by-catch. Survey 9 was dropped entirely due to vessel breakdowns.

Common Name	Total Catch (Number of individuals)	Percent of Catch
Tridentiger spp.	39,473	51.38%
Longfin Smelt	13,172	17.15%
Yellowfin Goby	10,634	13.84%
Northern Anchovy	3,015	3.92%
Striped Bass	2,975	3.87%
Threadfin Shad	2,624	3.42%
Prickly Sculpin	2,401	3.13%
Pacific Herring	812	1.06%
Jacksmelt	570	0.74%
Arrow Goby	444	0.58%
Threespine Stickleback	111	0.14%
American Shad	74	0.10%
Shimofuri Goby	61	0.08%
Centrarchids (Unid)	58	0.08%
Wakasagi	54	0.07%
Shokihaze Goby	41	0.05%
Cheekspot Goby	38	0.05%
Bigscale Logperch	34	0.04%
Inland Silverside	34	0.04%
Bay Pipefish	33	0.04%
Unknown	30	0.04%
White Catfish	19	0.02%
Longjaw Mudsucker	17	0.02%
Starry Flounder	15	0.02%
Bay Goby	11	0.01%
Delta Smelt	9	0.01%
Pacific Staghorn Sculpin	8	0.01%
Topsmelt	8	0.01%
Rainwater Killifish	7	0.01%
Prickleback spp.	6	0.01%
Bluegill Sunfish	5	0.01%
Chinook Salmon	4	0.01%
Cyprinids (Unid)	4	0.01%
Largemouth Bass	3	< 0.01%
Atherinidae (Unid)	2	< 0.01%
Bluefin Killifish	2	< 0.01%

Common Name	Total Catch (Number of individuals)	Percent of Catch
English Sole	2	< 0.01%
River Lamprey	2	< 0.01%
Speckled Sanddab	2	< 0.01%
Tule Perch	2	< 0.01%
Fathead Minnow	1	< 0.01%
Plainfin Midshipman	1	< 0.01%
Spotted Bass	1	< 0.01%
White Crappie	1	< 0.01%

Table 2 Total catch and percent of species caught in the California Department of Fish and Wildlife's 2022 20-mm Survey. Alternative Text: This table shows Tridentiger spp., Longfin Smelt, and Yellowfin Goby catch totaled to 63,279 fish. The remaining species totaled to 13,541 fish.

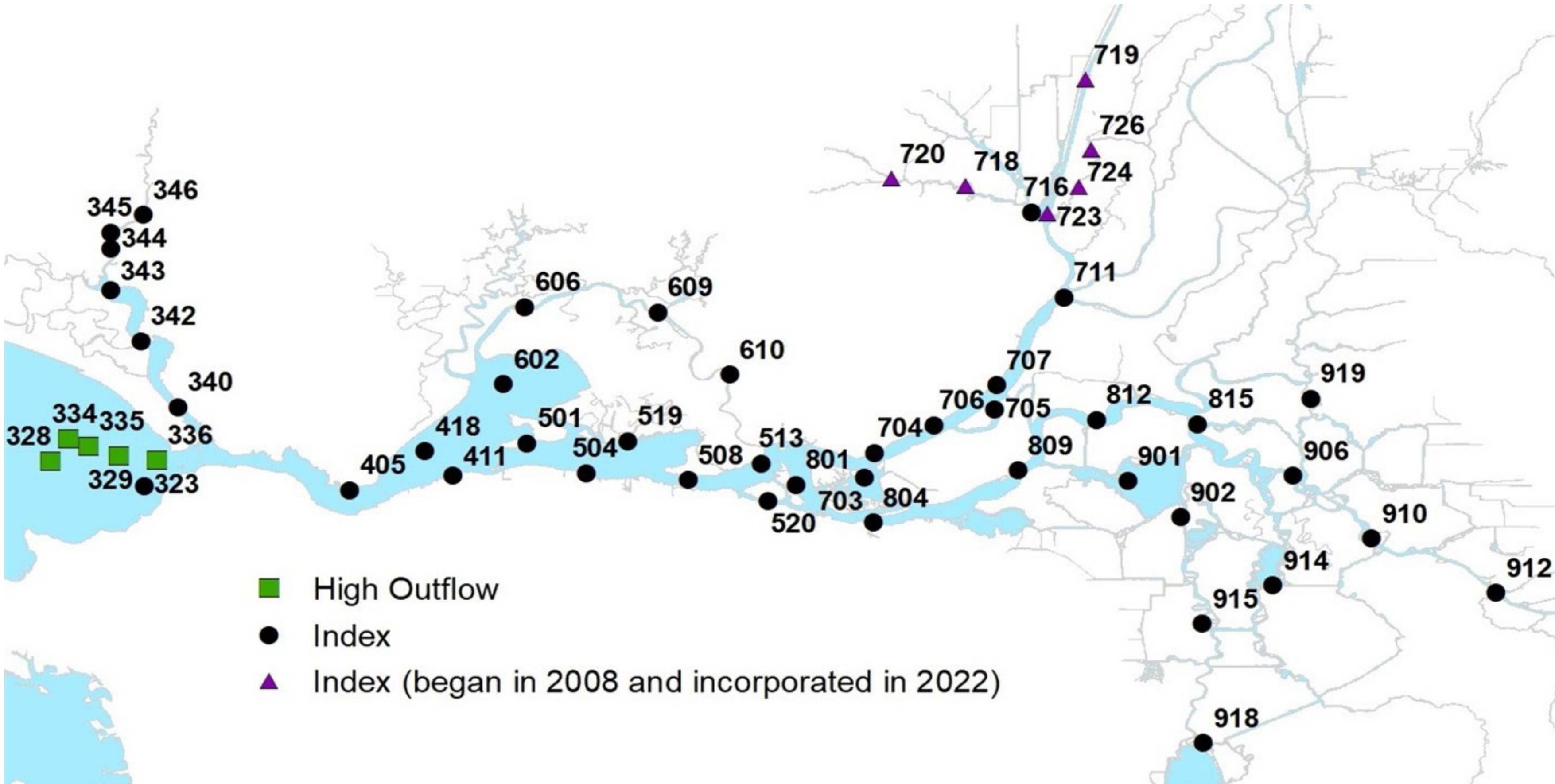


Figure 1 Map of the California Department of Fish and Wildlife's 20-mm Survey station locations within the upper San Francisco Estuary. Stations marked with a black dot are index stations. Stations marked with a purple triangle are non-index stations that were added in 2008. Stations marked with a green square are high-outflow stations. Alternative Text: Map of the 20-mm Survey station locations in the upper San Francisco Estuary. There are 41 index stations throughout the upper San Francisco Estuary, 6 non-index stations in the upper part of the Sacramento River, and 5 high-outflow stations in San Pablo Bay.

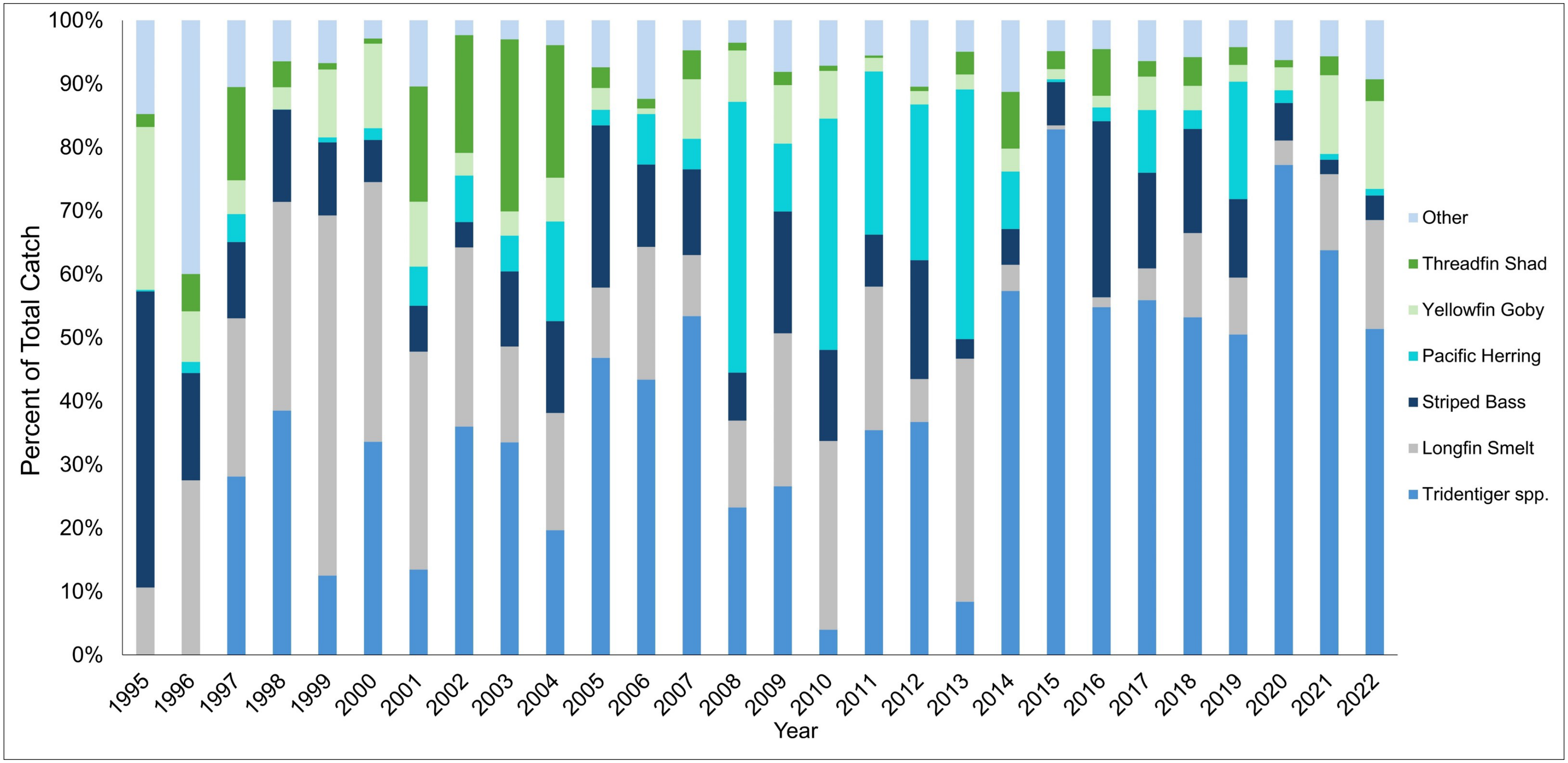


Figure 2 Annual percent species composition from the California Department of Fish and Wildlife's 20-mm Survey from 1995 to 2022. Alternative Text: This bar graph shows that Longfin Smelt and Tridentiger spp. have consistently made up most of the total catch since the 20-mm Survey began, but in 2014 Tridentiger spp. has made up more of the total catch than the other species.

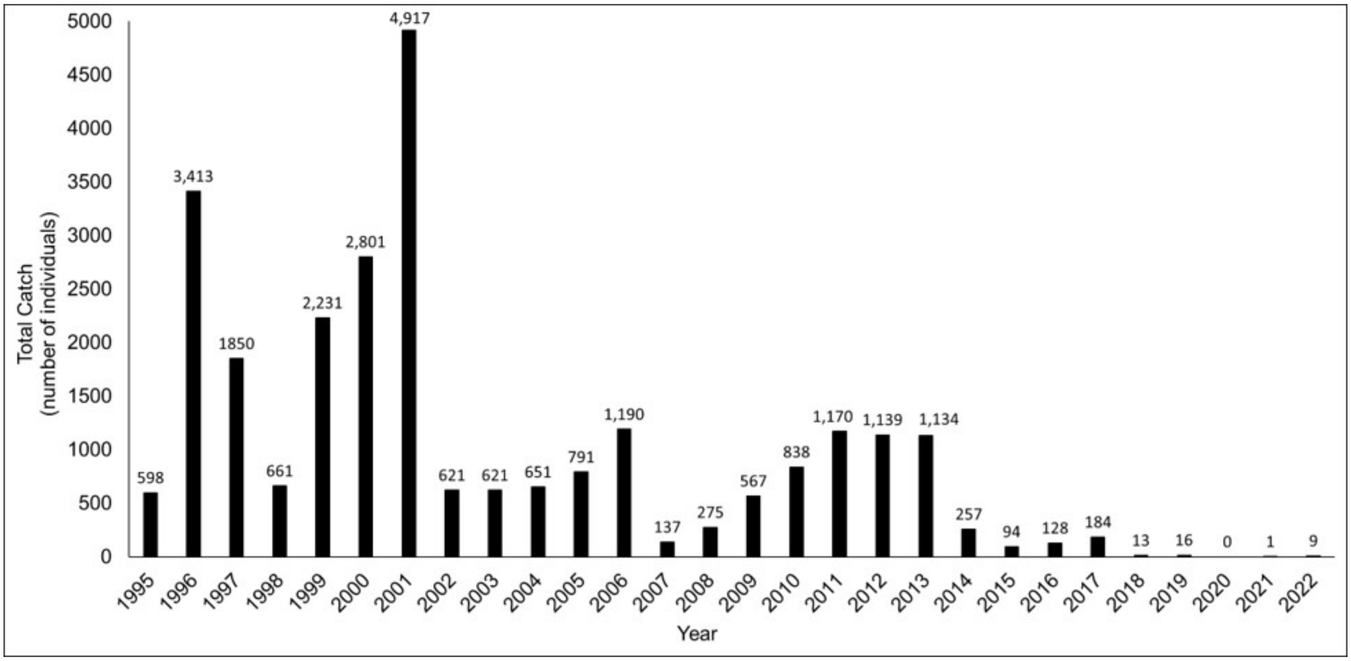


Figure 3 Annual Delta Smelt catch from the California Department of Fish and Wildlife's 20-mm Survey from 1995 to 2022. Alternative Text: This bar graph shows the number of Delta Smelt catch has dramatically dropped since 2001. Only 9 Delta Smelt were caught in 2022.

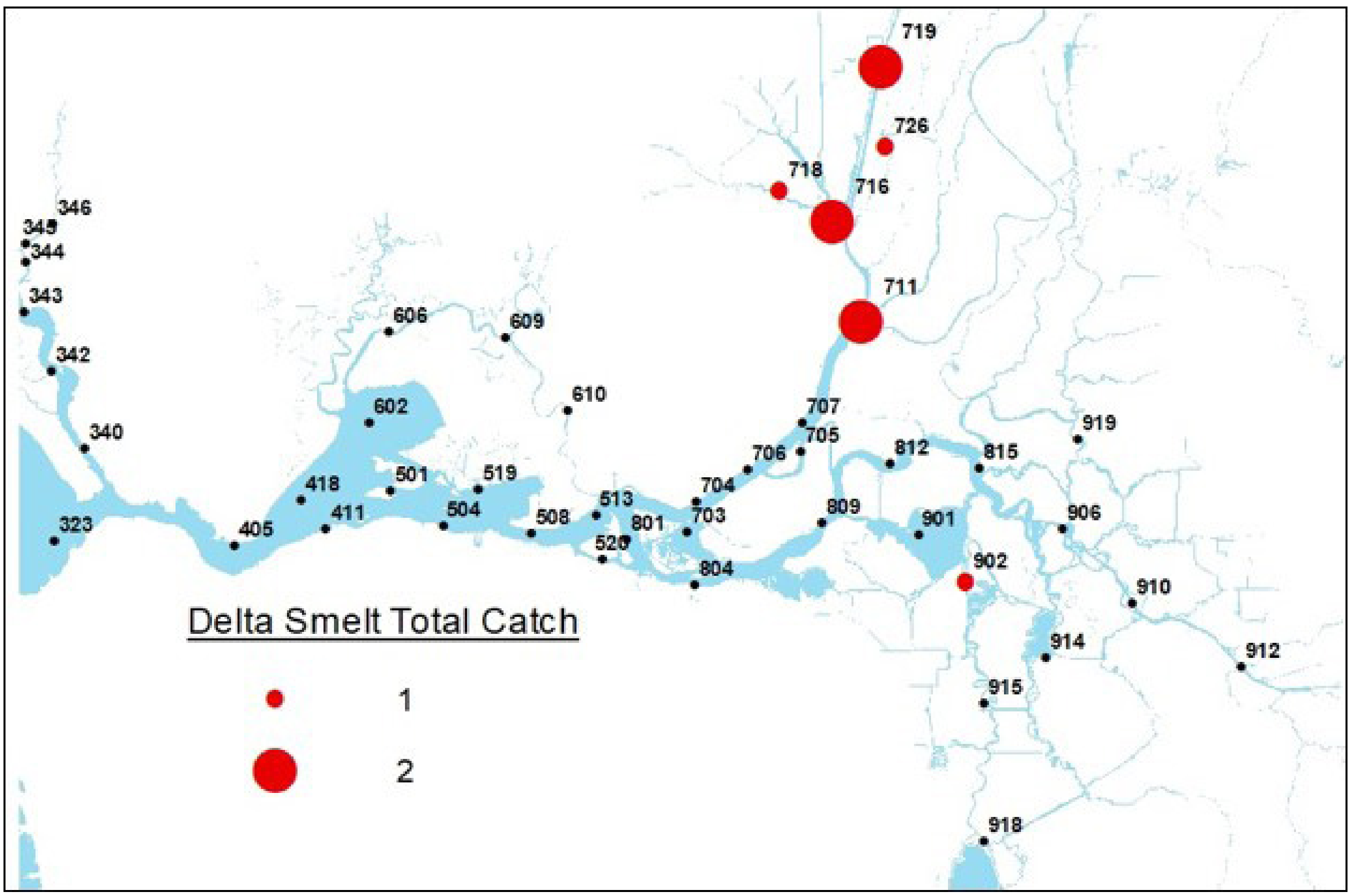


Figure 4 Bubble plot of total Delta Smelt catch throughout the San Francisco Estuary from the California Department of Fish and Wildlife's 2022 20-mm Survey. Bubble size indicates magnitude of total Delta Smelt catch at each station. Alternative Text: This map shows seven Delta Smelt were caught in the upper part of the Sacramento River and one individual was caught in the South Delta at station 902.

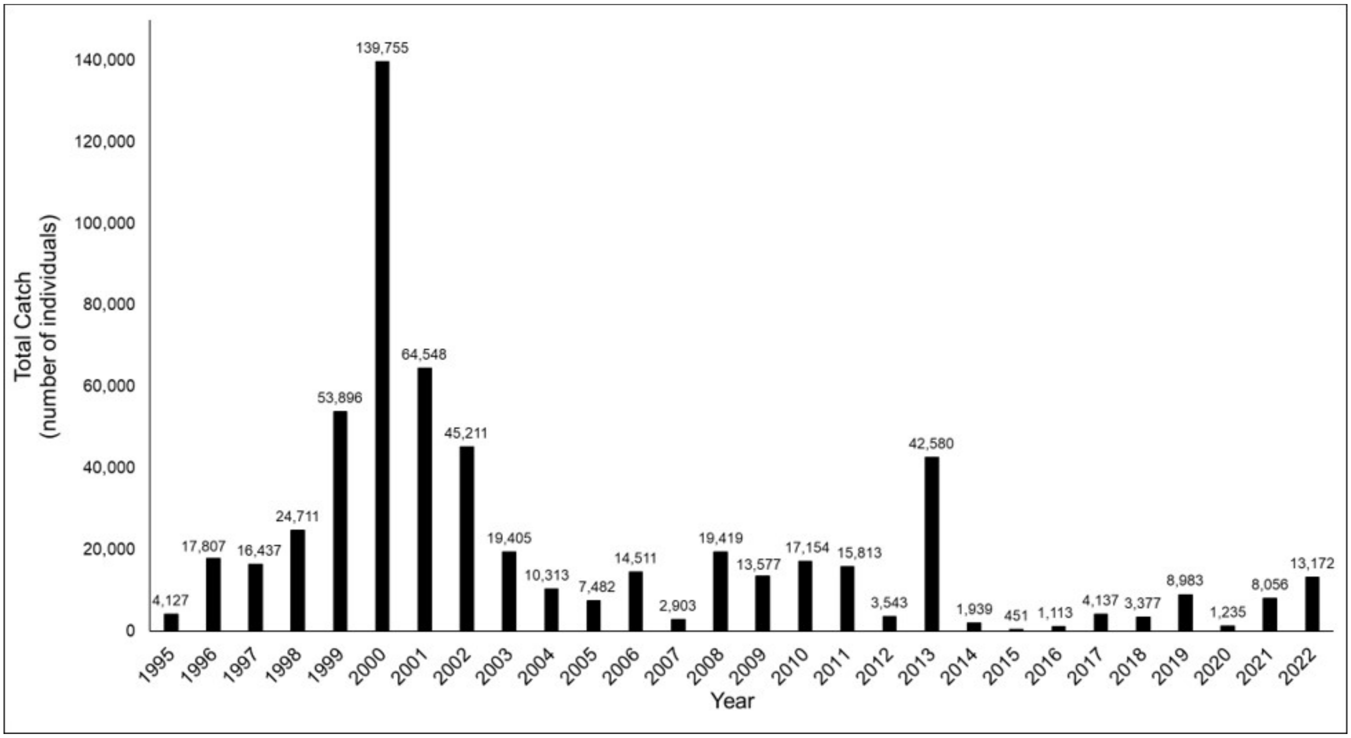


Figure 5 Annual Longfin Smelt catch from the California Department of Fish and Wildlife's 20-mm Survey from 1995 to 2022. Alternative Text: This bar graph shows the number of Longfin Smelt caught has continued to decrease after 2000. There was a high catch in 2013, but Longfin Smelt catch has been low since 2014.

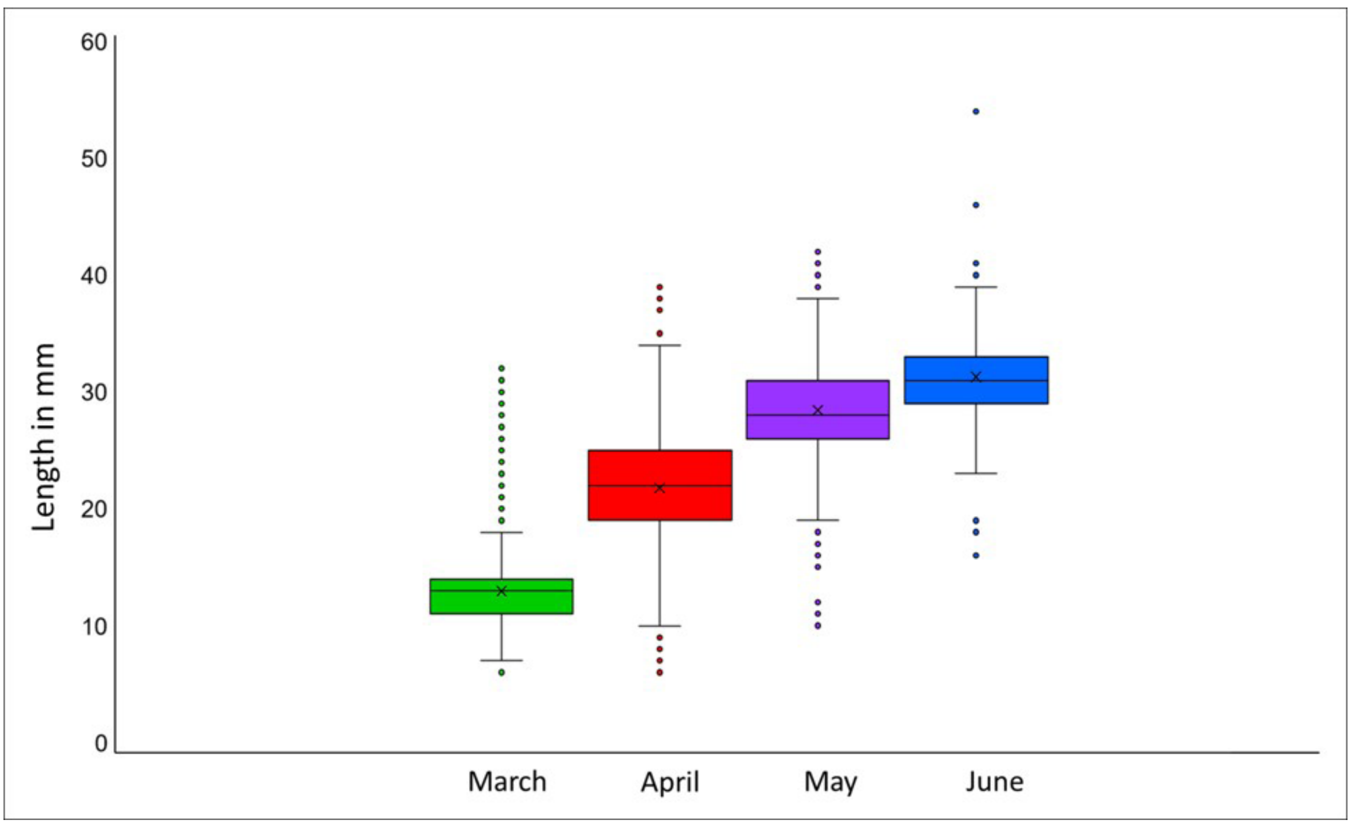


Figure 6 Boxplot of larval and juvenile Longfin Smelt length frequencies caught in each month of the California Department of Fish and Wildlife's 2022 20-mm Survey. March data in green, April data in red, May data in purple, and June data in blue. Alternative Text: This boxplot shows an increase in the average length in millimeters from March to June.

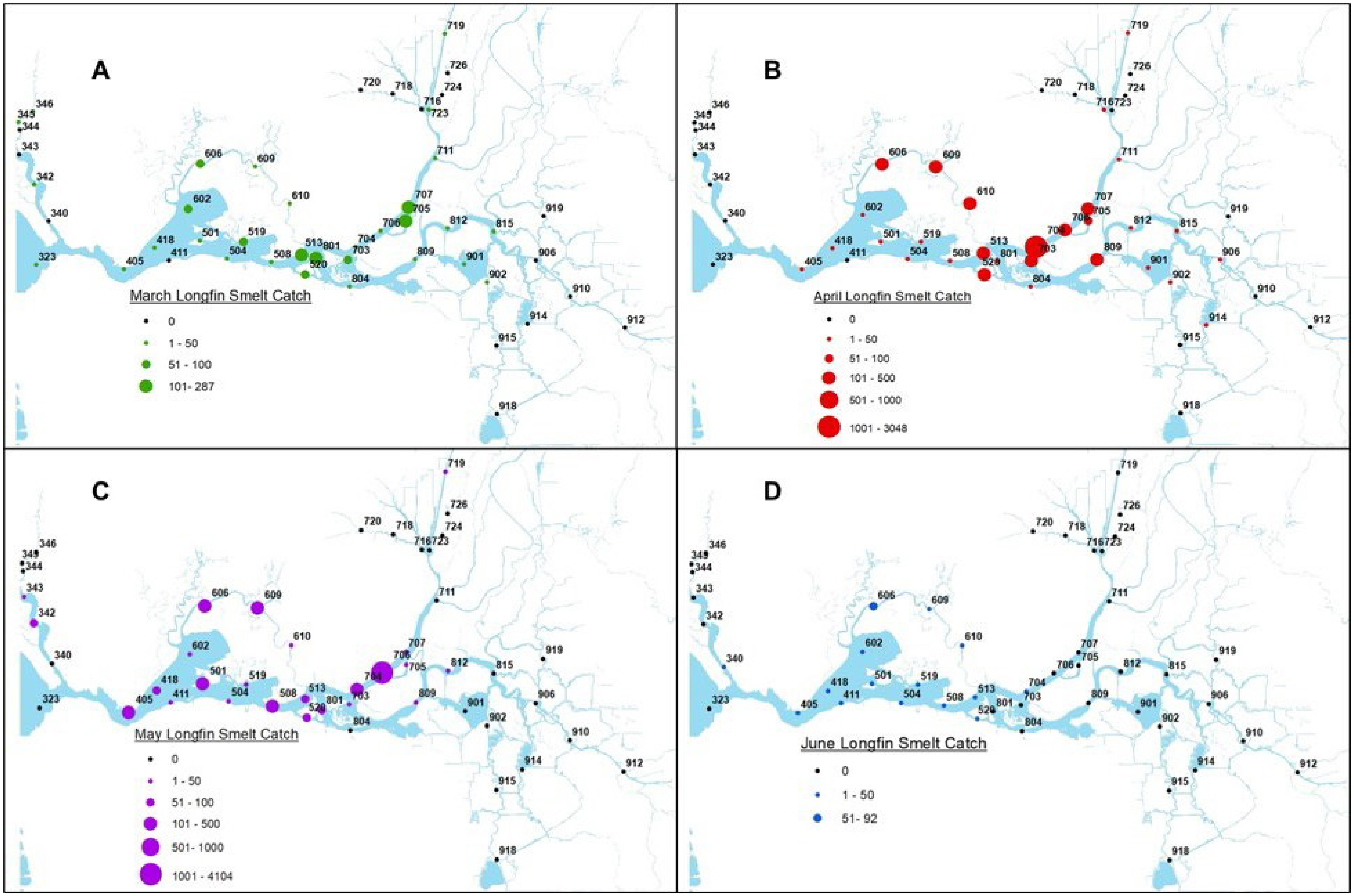


Figure 7 Bubble plot of total Longfin Smelt catch per month throughout the upper San Francisco Estuary from the California Department of Fish and Wildlife's 2022 20-mm Survey. Bubble size indicates magnitude of total Longfin Smelt catch at each station. A) March catch in green B) April catch in red C) May catch in purple D) June catch in blue. Alternative Text: These bubble plots show westward shift of Longfin Smelt catch. The highest catches were observed in April and May.

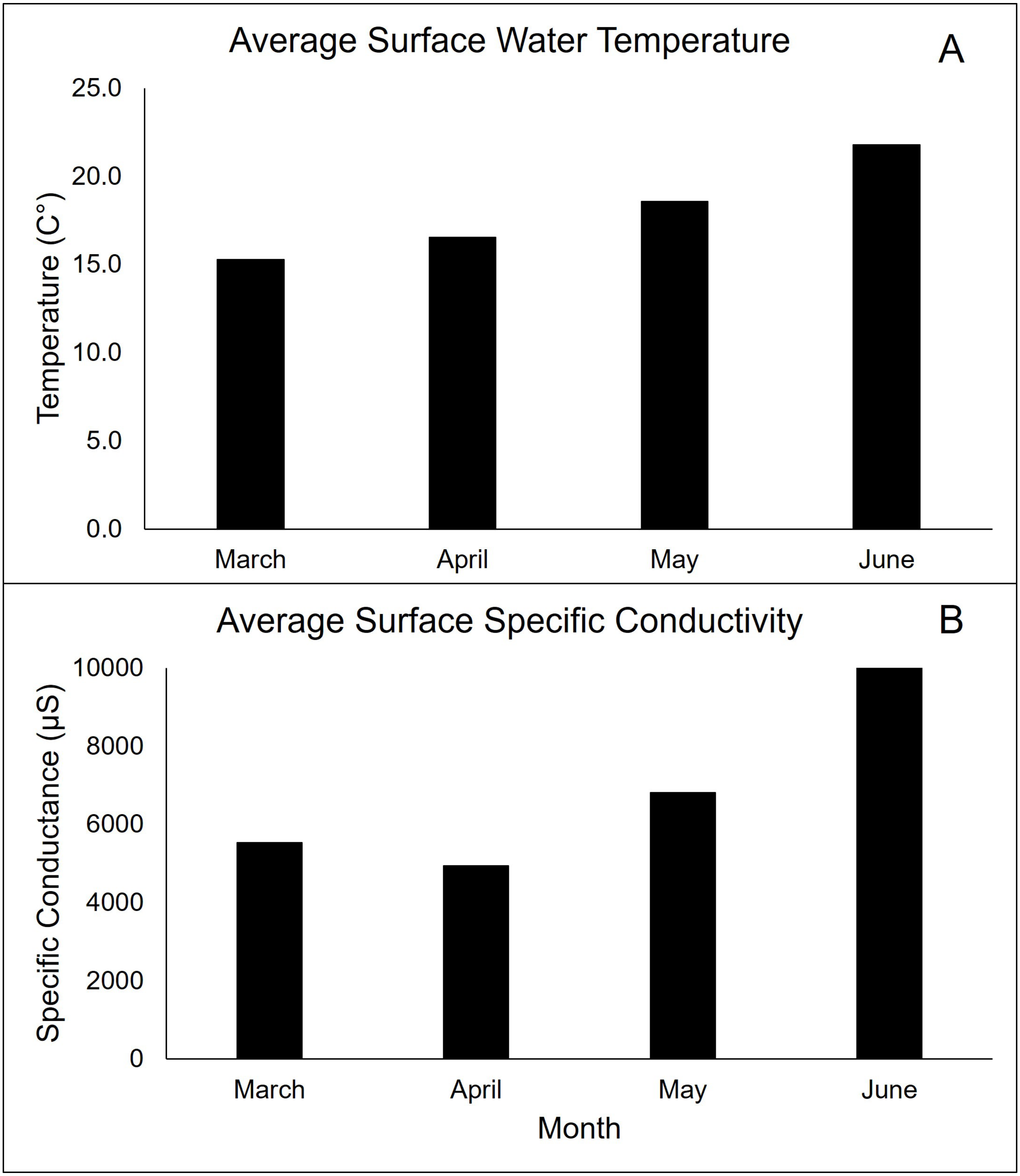


Figure 8 Monthly average A) surface water temperature and B) surface water specific conductivity measured in the upper San Francisco Estuary by the California Department of Fish and Wildlife's 2022 20-mm Survey between March and June. Alternative Text: This bar graph shows the average surface water temperature and specific conductivity for all stations combined increased from March to June.

2022 Smelt Larva Survey Summary

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The California Department of Fish and Wildlife (CDFW) annually conducts the Smelt Larva Survey (SLS) (https://wildlife.ca.gov/Conservation/Delta/Smelt-Larva-Survey)to monitor the distribution and relative abundance of larval Longfin Smelt (*Spirinchus thaleichthys*) in the upper San Francisco Estuary (SFE). Near real-time catch data is provided to resource managers to assess the risk of entrainment of Longfin Smelt at water export facilities. The survey also collects data on other larval fishes in the upper SFE, including Delta Smelt (*Hypomesus transpacificus)*.

The SLS began in 2009 and currently samples 44 stations per survey. These stations are divided into four regions: the Napa River, Confluence and Downstream, Sacramento River Complex, and South and Central Delta (Figure 1). Historically, six surveys were conducted every other week from January through March, but two surveys were added in December 2020 to better inform water operations management. Currently, eight surveys are conducted from December to March. This is the period when larval Longfin Smelt are most likely to be present in the SFE. An oblique tow is conducted at each station using a rigid-framed, plankton-style net with 500-micron Nitex mesh. All samples are preserved in 10% buffered formalin and then identified and enumerated in the laboratory. The presence or absence of a yolk-sac or oil globule is noted for larval Osmerids.

The 2022 SLS ran from December 13, 2021, through March 24, 2022. COVID-19 safety precautions prevented sampling at 32 stations in survey 1 and excessive vegetation prevented sampling at Frank's Tract (station 901) in survey 3. A complete list of sampling effort for the 2022 season can be found in Table 1. A total 32,367 fish comprising 21 taxa were captured during a total of 319 sampling events (Table 2). Four species made up 98% of the total SLS catch for the 2022 sampling season (Figure 2): Yellowfin Goby (*Acanthogobius flavimanus*), Prickly Sculpin (*Cottus asper*), Longfin Smelt, and Pacific Herring (*Clupea pallasi*).

Longfin Smelt catch in 2022 (n=3,246) was over twice as much as that in 2021 (n=1,506), but still only comprised 10% of the 2022 total catch (Figure 3, Table 1). Larval Longfin Smelt were collected in each of the eight surveys, with the first one caught on December 13, 2021, and the highest catch observed in February (n=1,387). Yolk-sac larvae were also observed in each survey (Figure 4). The highest number of Longfin Smelt with a yolk-sac were caught in February between 7 mm and 8 mm in length (Figure 4C). Although larval Longfin Smelt were present throughout the SFE, the highest numbers of larvae with a yolk-sac present were found in the Confluence and downstream (Figure 5). Stations 513, 606, 504, 501, and 519 had the greatest numbers of Longfin Smelt with yolk-sacs and, while stations 801, 906, 804, 703, 704, and 812 had relatively low catch, they yielded a higher percentage of larvae with a yolk-sac.

This was the first year of a multi-year experimental release effort where a total of 55,733 marked adult hatchery-origin Delta Smelt were released into the Sacramento River, Montezuma Slough, and the Sacramento Deepwater Shipping Channel (SDWSC) between December 2021 and February 2022 (USFWS 2022). Despite this effort, only one larval Delta Smelt (10 mm) was caught at SLS station 815 on March 21, 2022 (Figure 6). Delta Smelt have an embryo development period of 10 to 13 days and can measure 10.5 mm on day 20 post-hatch (Mager 2004). This suggests that the spawning of this fish's parents likely occurred in late February. Larval Delta Smelt were also detected in late March by the 2022 20-mm Survey (n=9), which provides additional evidence that spawning likely began in late February or early March (Jimenez 2022).

For additional information on SLS methods, sampling design, and prior year summary reports, see our online bibliography: https://wildlife.ca.gov/Conservation/Delta/Smelt-Larva-Survey or Data Portal - Data Package Summary | Environmental Data Initiative (EDI) (edirepository.org). For survey data visit: filelib.wildlife.ca.gov - /Public/Delta Smelt/

Literature Cited

Jimenez J. 2022. 20-mm Survey Summary. Interagency Ecological Program Newsletter. 41(3): 26-36.

Mager RC. 2004. Early Life Stages of Delta Smelt. American Fisheries Society Symposium 39:169-180.

United States Fish and Wildlife Service (USFWS). 2022. BY2021 ERTT Summary of Activities. Technical Report. p. 1-55 plus appendices.

Chelmon rostratus

Common Name	Total Catch (Number of individuals)	Percent of Catch
Yellowfin Goby	18,772	58%
Prickly Sculpin	8,596	27%
Longfin Smelt	3,246	10%
Pacific Herring	1,061	3%
Arrow Goby	481	1%
Longjaw Mudsucker	103	0.32%
Cheekspot Goby	54	0.17%
Jacksmelt	17	0.05%
Pacific Staghorn Sculpin	6	0.02%
Rainwater Killifish	5	0.02%
Bigscale Logperch	4	0.01%
Northern Anchovy	4	0.01%
Shimofuri Goby	4	0.01%
Threespine Stickleback	3	0.01%

Table 1 Sampling effort for the California Department of Fish and Wildlife's 2022 Smelt Larva Survey. Alternative text: The table shows all 44 samples were collected in surveys 12, 13, 2, 4, 5, and 6. Survey 1 only collected 12 samples due to COVID-19. One sample was not collected in Survey 3 due to excessive vegetation at the sampling station.

Common Name	Total Catch (Number of individuals)	Percent of Catch
Yellowfin Goby	18,772	58%
Prickly Sculpin	8,596	27%
Longfin Smelt	3,246	10%
Pacific Herring	1,061	3%
Arrow Goby	481	1%
Longjaw Mudsucker	103	0.32%
Cheekspot Goby	54	0.17%
Jacksmelt	17	0.05%
Pacific Staghorn Sculpin	6	0.02%
Rainwater Killifish	5	0.02%
Bigscale Logperch	4	0.01%

Table 2 Total number and percent of species caught in the 2022 California Department of Fish and Wildlife's Smelt Larva Survey. Data includes the December surveys for the 2022 sampling season. Alternative text: Table showing Yellowfin Goby, Prickly Sculpin, Longfin Smelt, and Pacific Herring totaled to 31,676 fish. The remaining species totaled to 691 fish observed.

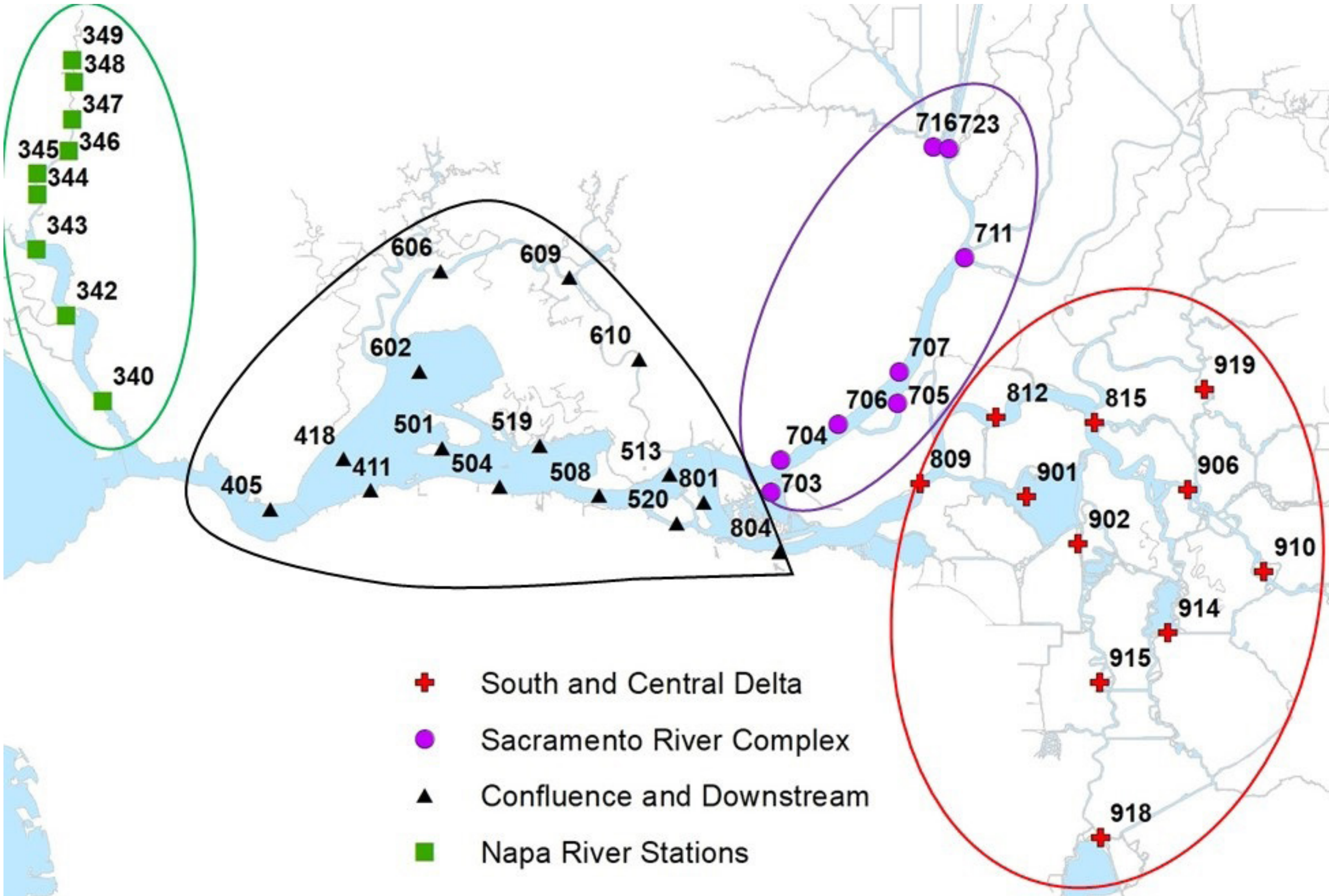

Figure 1 Map of the 40 Smelt Larva Survey station locations sampled by the California Department of Fish and Wildlife. Station locations are grouped into four regions: Napa River (green squares), Confluence and Downstream (black triangles), Sacramento River Complex (purple circles), and San Joaquin River Complex (red plus signs). Alternative text: The map displays 40 stations grouped into four regions. Water export facilities are located in the

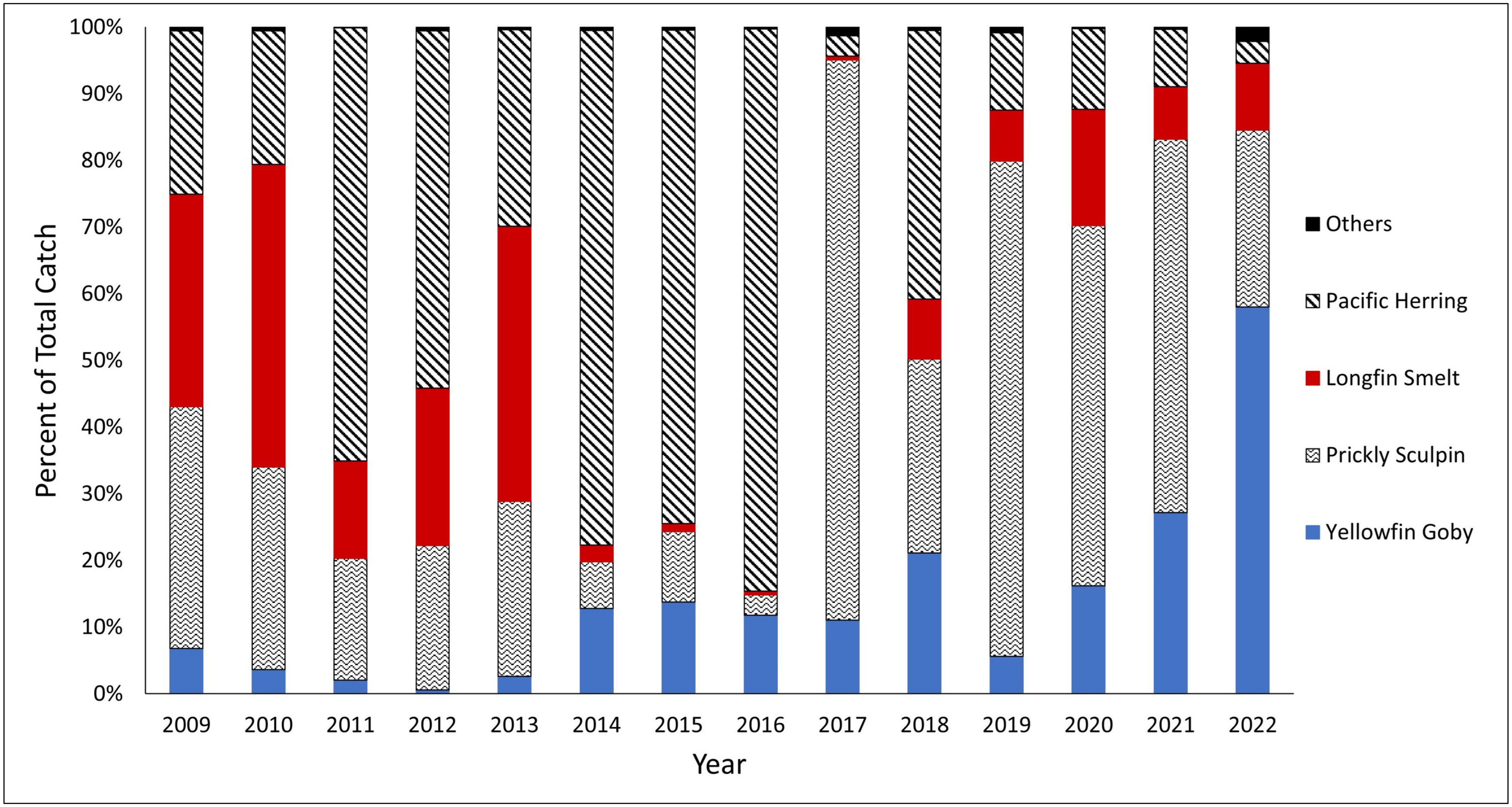

Figure 2 Annual percent species composition from the California Department of Fish and Wildlife's Smelt Larva Survey. Data includes the December surveys for the 2021 and 2022 sampling seasons. Alternative text: The bar graph displays a change in the species composition. Pacific Herring was the dominant species until 2016. In 2017 and in recent years, Prickly Sculpin has become the dominant species in the Smelt Larva Survey catch.

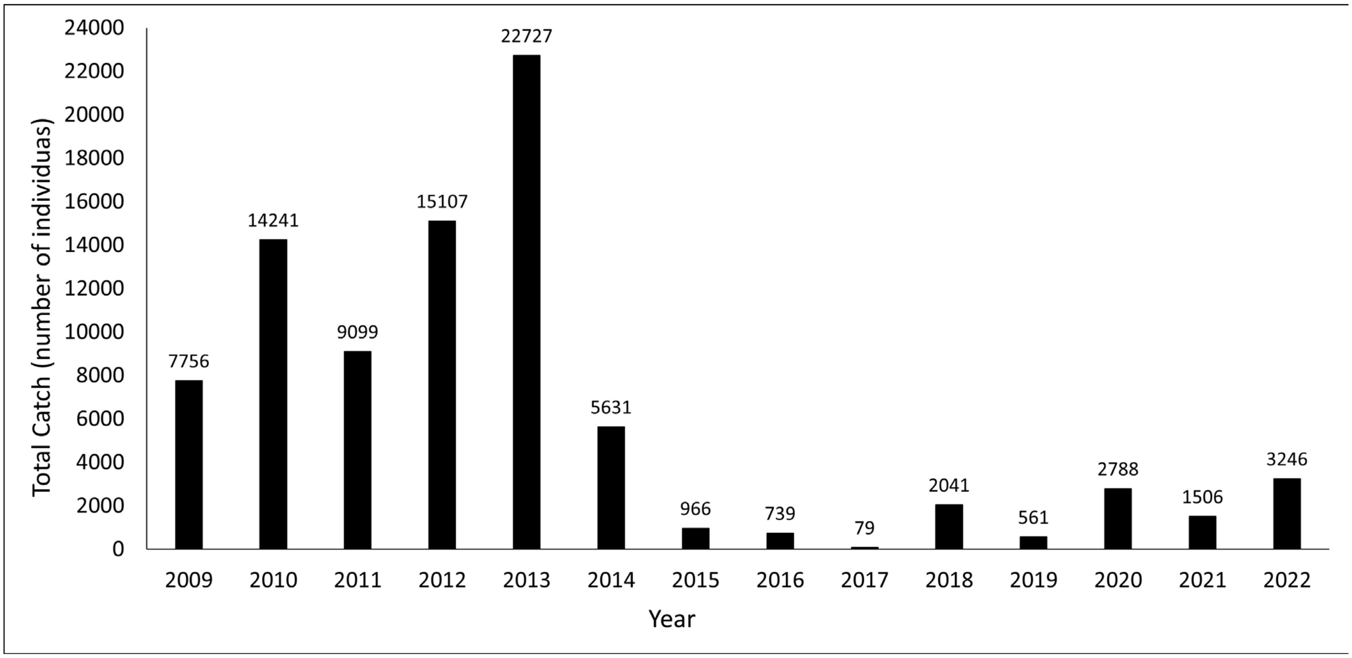

Figure 3 Annual Longfin Smelt catch from 2009 to 2022 sampled by the California Department of Fish and Wildlife's Smelt Larva Survey. Data includes the December surveys for the 2021 and 2022 sampling seasons. Alternative text: The bar graph shows the number of Longfin Smelt caught has dropped dramatically from 22,727 in 2013 to 3,246 in 2022.

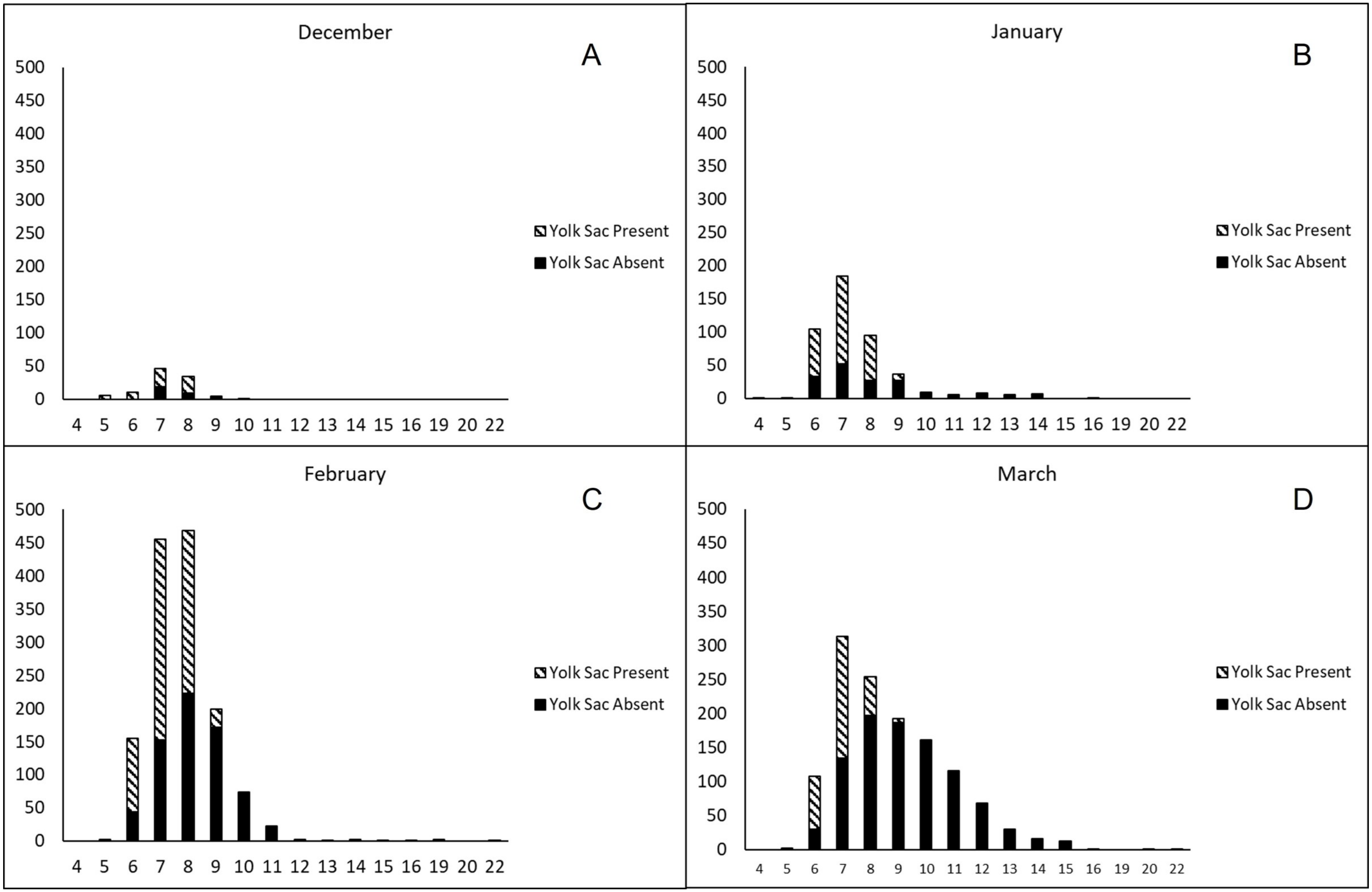

Figure 4 Length frequency with proportion of yolk sac presence and absence of larval Longfin Smelt caught during each month of the 2022 California Department of Fish and Wildlife's Smelt Larva Survey. (A) December 2021 (B) January 2022 (C) February 2022 (D) March 2022. Alternative text: Each bar graphs shows a normal distribution of lengths ranging between 4 mm and 22 mm long centered at 7mm. The highest catch of larval Longfin Smelt with yolk sacs were observed in February.

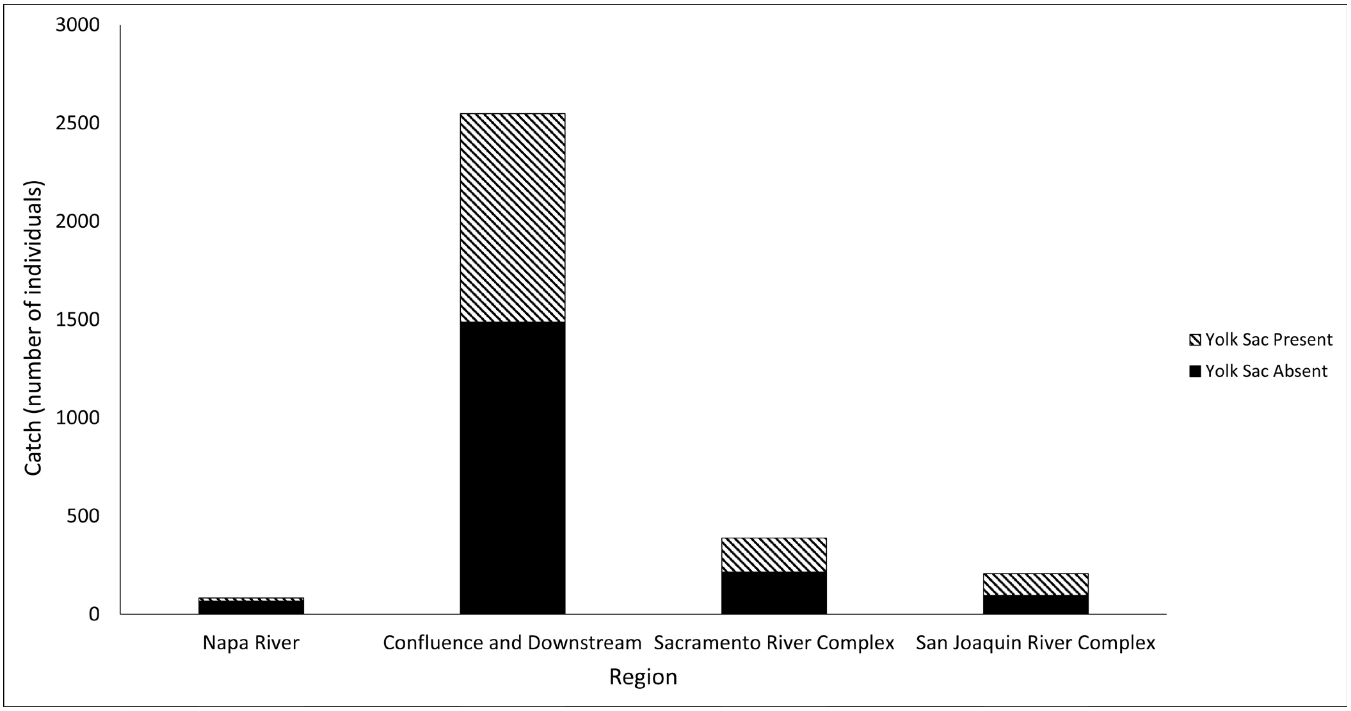

Figure 5 Number of larval Longfin Smelt and proportion of yolk sac presence and absence caught within each region of the 2022 California Department of Fish and Wildlife's Smelt Larva Survey. Data includes December surveys for the 2022 sampling season. Alternative text: Bar graph shows the majority of larval Longfin Smelt in the Confluence and downstream totaling about 2,500 individuals with about 1,000 individuals with a yolk sac present.

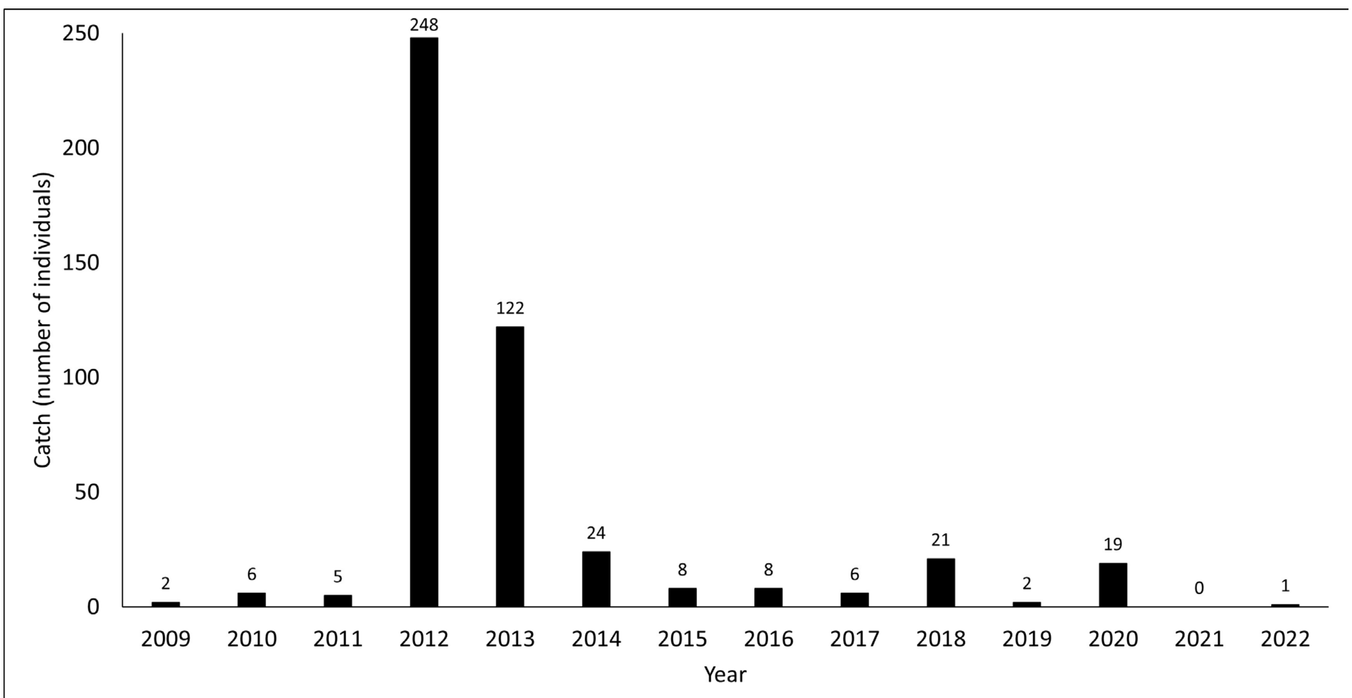

Figure 6 Annual Delta Smelt catch from the California Department of Fish and Wildlife's Smelt Larva Survey from 2009 to 2022. Data includes the December surveys for the 2021 and 2022 sampling seasons. Alternative text: The bar graph displays a peak in catch of Delta Smelt in 2012 and continuously low catch in recent year, with only one induvial observed in the 2022 Smelt Larva Survey season.

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

DWR • USBR • USFWS • SWRCB • CDFW • USGS • NMFS • USACE • USEPA

Interagency Ecological Program

COOPERATIVE ECOLOGICAL INVESTIGATIONS SINCE 1970