Interagency Ecological Program for the San Francisco Estuary

# IEP NEWSLETTER

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# Of Interest to Managers

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This issue of the Interagency Ecological Program (IEP) Newsletter includes two highlights articles, one status and trends article, and three contributed papers. The first article captures recent changes to a long-term IEP monitoring study with expansion of effort, data generated, and addition of a new sampling platform. Following articles report on biological and water quality trends in the upper San Francisco Estuary, during a period of transition to high flow following years of extreme drought. Several analysis and synthesis articles use existing IEP data to address management questions and help inform proposed actions, along with a consideration of how to address future questions.

**Morgan Martinez** and **Michelle Nelson** (DWR) report recent changes to the multi-decadal Department of Water Resources (DWR) Environmental Monitoring Program (EMP) in the first highlights article. EMP has been essential in the understanding of biological and water quality conditions in the estuary since the 1970s. Notable are the recent addition of new stations, expansion of a full suite of chemical, physical and biological parameters at all 24 discrete water quality stations, and the acquisition of the new research vessel, *Sentinel*. The additional stations and comprehensive suite of variables sampled along with the new research platform will benefit monitoring efforts into the future.

In the second highlights article, **Emma Siegfried** and **Brett Harvey** (DWR) provide a summary of mid-channel turbidity monitoring conducted in 2016. This information supplements the existing continuous water quality station network. The in-channel turbidity monitoring provided high resolution information to help inform Delta Smelt entrainment risk from December 2016 through February 2017. Data was shared with the Smelt Working Group and State Water Project Operational Management within 24 hours of collection, and additional efforts are underway to develop near real-time visualization tools.

In the status and trends article, **April Hennessy** (CDFW) reports on the relative abundance and distribution of zooplankton in recent drought years (2013–2015) with comparison to long-term trends. Seasonal zooplankton densities (number per cubic meter) of calanoid copepods, cladocerans, and mysids, important food for native fish, in recent drought years were similar in the range of values detected since 2002. The introduced cyclopoid copepod *Limnoithona* spp. had high densities during the recent drought, with a record high in 2015. *Limnoithona* spp. are selected against by young Delta Smelt, yet these cyclopoid copepods are used as food by introduced fish (e.g., Mississippi Silversides).

In the first contributed paper, **Trishelle Tempel** (CDFW) evaluated the addition of new stations in calculation of the 20-mm Survey annual Delta Smelt index. The 20-mm Survey monitors the distribution and abundance of post-larval and juvenile Delta Smelt (*Hypomesus transpacificus*), a State and federally listed species. An annual index is calculated with the data from the historic 41 stations sampled since 1995. In 2008, six stations were added in the North Delta, an area recognized for presence of Delta Smelt. This evaluation between indices with only historic and historic with addition of new stations found that historic index stations continue to be an appropriate way to calculate the annual index. The addition of new stations shifted the relative abundance up for the period 2008–2016, but did not change the pattern between years. Sampling of new stations will continue to increase our understanding of presence and distribution, but the new stations will not be included in calculation of the annual index.

In the second contributed paper, **Brian Mahardja** and **Ted Sommer** (DWR) share the results of their exploratory analysis on the removal of predators at fish salvage facilities. The goal of this exercise was to inform management actions, such as the California Natural Resources Agency Delta Smelt Resiliency Strategy proposed adjustment of salvage operations during summer to remove non-native fishes to reduce predation and competition with Delta Smelt. The authors used salvage data from 1993–2003 to estimate biomass from length data, then examined the recommended action. The authors found modest biomass levels removed during July–September and a benefit for native fishes might be possible. Nonetheless, the removal would not likely have a population level impact on non-native fishes in the estuary. Lessons learned from this analysis can help inform future exploratory work on risks and impacts of proposed actions.

In the final contributed paper, **Christina Parker**, **James Hobbs**, **Micah Bisson**, and **Arthur Barros** (UCD) report on their assessment of Longfin Smelt distribution and spawning locations in San Francisco (SF) Bay tributaries. Longfin Smelt is a native fish of management concern in the SF estuary. The bulk of Longfin Smelt sampling by IEP occurs upstream of San Pablo Bay. This work expands on the geographic range and habitat types sampled for Longfin Smelt in northern and southern regions of San Francisco Bay. It utilizes a variety of gear types over time to collect fish as they grow from young larvae into juveniles, and to adults. This effort will help inform Longfin Smelt distributions downstream of the main IEP sampling footprint, notably during a period of high outflow experienced in 2016–2017.

Did you know that quarterly highlights about current IEP science can be found on the IEP webpage along with a new calendar that displays IEP Project Work Team and other IEP-related public meetings? To view these features see the links below:

http://www.water.ca.gov/iep/activities/calendar.cfm
http://www.water.ca.gov/iep/highlights/index.cfm

# Highlight Article

## All Hands on Deck: Revamping the Discrete Water Quality Blueprints of the IEP's Environmental Monitoring Program

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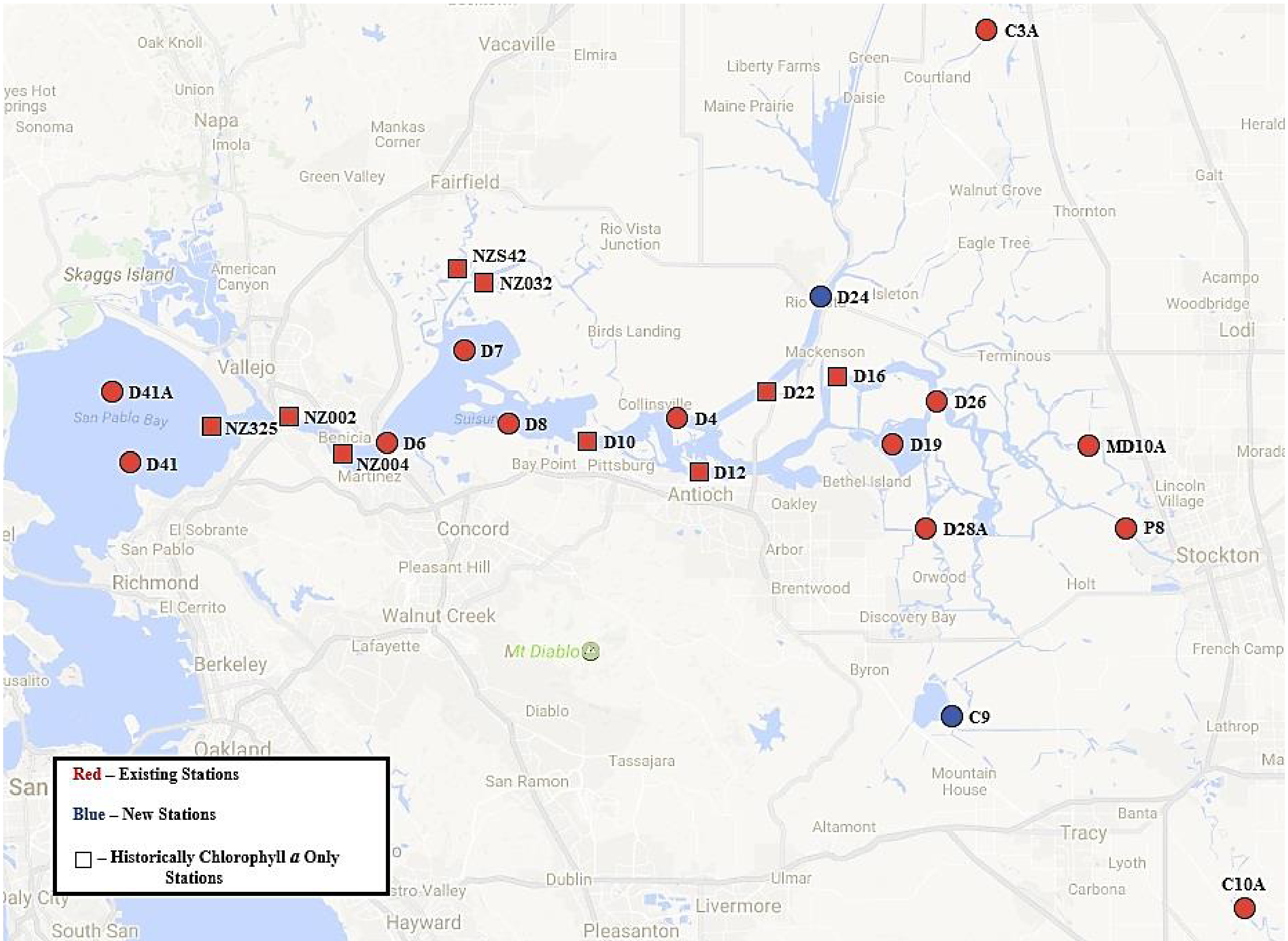
The Environmental Monitoring Program (EMP) has collected biological and water quality data throughout the Bay-Delta since 1975, providing essential information for resource management and documenting compliance with State Water Resources Control Board Water Right Decision 1641. The EMP recently made integral improvements to the discrete water quality component of the program as a response to program reviews and data gaps. These changes include the addition of new monitoring stations, an increase in the amount of data collected at each station, and the procurement of a new research vessel with a monitoring platform more adequately suited for the future of the program.

Prior to 2014, the EMP monitored twenty-two fixed location stations (Figure 1) and two "floating" stations. The two floating stations indicate the upper and lower boundaries of the entrapment zone and are located when the bottom specific conductance values are within 10 percent of 2,000 and 6,000 microSiemens per centimeter (µS/cm), respectively. In 2014, the effects of the drought pushed this area of lower salinity further upstream into both the Sacramento and San Joaquin rivers. To account for this divergence, the EMP enhanced its monitoring with two additional "floating" stations in the San Joaquin River, so that the water quality, phytoplankton, and zooplankton can be documented during dry conditions when the entrapment zone

**Figure 1 Map of the EMP discrete water quality monitoring fixed stations showing new additions and stations historically sampled for chlorophyll-*a* only.**




is present in both rivers. The EMP fixed station list has also expanded to include D24 (Sacramento River below the Rio Vista Bridge) and C9 (West Canal at the mouth of the Clifton Court Forebay intake), which were previously visited for the benthic monitoring component only. These two stations were introduced as land-based stations that are accessed by vehicle once a month. With these new additions, discrete water quality data is now collected at a total of twenty-four fixed stations. This coordination between EMP projects provides information to better understand the interaction between the lower food web and the nutrient composition of the corresponding environment throughout the Bay-Delta.

Historically, nine out of the 22 fixed stations were only sampled for chlorophyll-*a*, while the remaining 13 stations were sampled for a suite of physical and chemical constituents, including a full nutrient analysis (Figure 1). In 2016, the EMP began collecting nutrient data at stations D12, D16, and D22 in coordination with the Special Studies' *Microcystis* pilot monitoring program, which increased the number of full nutrient stations from thirteen to sixteen. As of February 2017, the EMP now collects the full suite of chemical, physical and biological parameters at all twenty-four discrete water quality stations to maintain data consistency and cohesiveness between each of the monitoring projects within the program.

In previous years, the EMP managed their discrete water quality data in a Microsoft Access database and made it publicly available as a single-year Excel or comma separated values (CSV) file on their website. To simplify user analysis and synthesis, the EMP recently imported their discrete water quality data into the Department of Water Resources Water Data Library (WDL). This online public database stores the most up-to-date, quality assured data that is readily available in compliance with program mandates. The WDL features capabilities that allow users to select time series data that can be exported into multiple formats. Users also have the ability to perform queries that are specific to a single station or more generally as a collective project, and can filter by laboratory analyte type, making the process more efficient. A link to the database and instructions on how to export discrete water quality data from the WDL will be posted on the EMP's website (http://www.water.ca.gov/bdma/meta/) along with EMP contact information for any additional questions. Additionally, a web portal is currently under development that provides users with annual reports and interactive graphing tools for better data visualization of discrete water quality data. The portal will also incorporate reporting information and data visualization tools for the phytoplankton, zooplankton, and benthic monitoring components of the program.

Since 1975, discrete water quality monitoring has predominantly been conducted aboard the 56-foot research vessel (RV) *San Carlos*, but the EMP plans to replace the vessel with the new 60-foot RV *Sentinel* received by DWR in December 2016. The RV *Sentinel* has a maximum speed of 22 knots, doubling that of the RV *San Carlos*, and is equipped with a 266-square-foot laboratory, a 337-square-foot aft deck work area, and three 3,300-pound-capacity cranes. This new vessel was designed to better fit the current and future needs of the program by incorporating state-of-the-art features such as a Thermo-Scientific B-Pure Water Purification System, laboratory grade refrigerator and freezer, laboratory ice maker, and a flammable chemical storage cabinet. In comparison to the RV *San Carlos*, the RV *Sentinel* has the ability to house a larger crew, travel across a greater geographic range, and provide overnight accommodations for up to five people during extended studies. The RV *Sentinel* provides the EMP with a safe and efficient method of conducting monthly monitoring and encourages scientific research for years to come.

In summary, the EMP has enhanced its discrete water quality monitoring design to include more fixed and floating stations, increase the amount of sampling performed at each station, and provide users with quality assured data that is easily accessible. These changes have been made in coordination with other projects within EMP to better synchronize monitoring efforts and to ultimately understand the ecological relationships throughout the Bay-Delta.

## Summary of DWR Old-Middle River Turbidity Transects

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Turbidity is a key habitat condition associated with the occurrence of endangered Delta Smelt, particularly during upstream spawning migrations (Grimaldo et al. 2009; Sommer and Meija 2013; Bennett and Burau 2015). For this reason, turbidity (≥ 12 nephelometric turbidity units [NTU]) is an environmental trigger for actions regulating water project operations in the 2008 U.S. Fish and Wildlife Service (USFWS) Biological Opinion. Because of the difficulty in recent years detecting Delta Smelt in traditional trawl surveys, turbidity distribution in the south Delta has been used to estimate the upstream limit of Delta Smelt distribution during spawning migrations and to assess risk for scenarios of water project operations (U.S. Fish and Wildlife Service 2016). Higher Delta Smelt entrainment risk exists for upstream migrants that enter the Old River corridor and move south towards Clifton Court Forebay, particularly during winter turbidity pulses. To assist Delta Smelt assessments and water management decisions intended to minimize fish entrainment at the State and federal south Delta pumping facilities, the California Department of Water Resources

(DWR), Division of Environmental Services (DES) has conducted turbidity transects in the Old and Middle rivers since Water Year (WY) 2015.

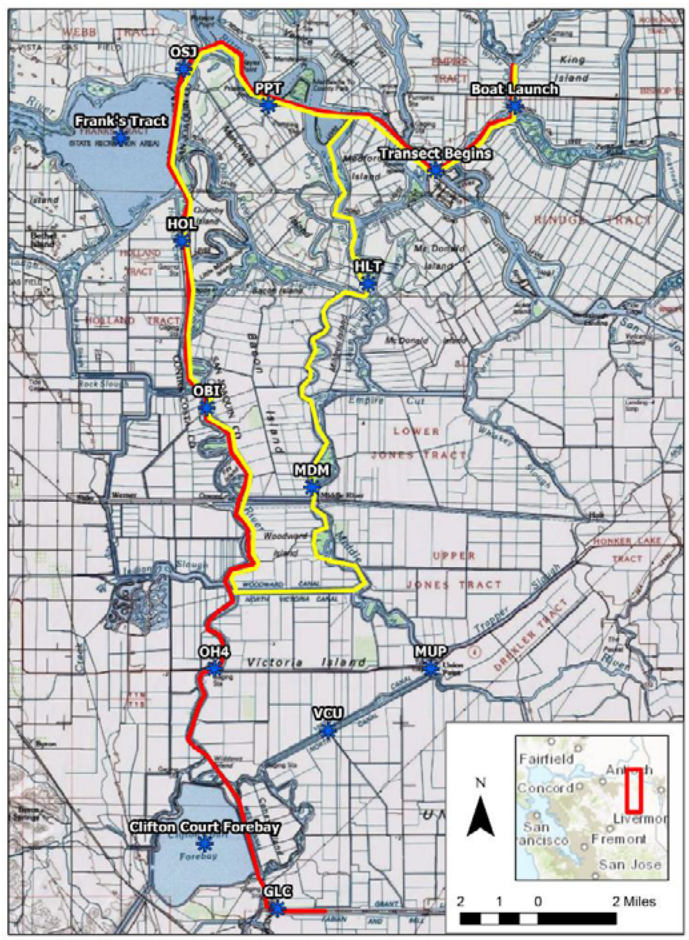
The mid-channel turbidity monitoring provides a supplement to the existing continuous water quality station network in the central and south Delta. Over the last three water years, including WY 2017, turbidity transects have begun in late December following the first winter system flush, when major land-runoff produced by a winter rainstorms carried pulses of turbid water into the estuary. Each year, transects have extended through early March, keeping with the rainy season and Delta Smelt migration period. Transects occur two to three times per week. The specific route is based on observed turbidity conditions and recommendations from the Smelt Working Group (SWG).

The Smelt Working Group is a team of federal and State agency biologists organized by the U.S. Fish and Wildlife Service to advise management on Delta Smelt and Longfin Smelt biology, entrainment risk into the South Delta, and prevention of loss to the pumps. During the upstream Delta Smelt spawning migrations, the general advice by SWG is to manage pumping in order to minimize turbidity intrusion into Old River during the most active period of Delta Smelt migration. Prior to WY 2015, turbidity measurements were only available from continuous water quality stations distributed at fixed locations throughout the Delta. As the detection of Delta Smelt declined with the species' waning abundance, Delta Smelt risk management relied more heavily on turbidity as an indicator of Delta Smelt distribution. Turbidity transects provide a higher-resolution complement to the broadly spaced, continuous water-quality-station network. Each turbidity map produced from the turbidity transects for SWG and DWR highlights fixed water-quality station data and the linking mid-channel turbidity levels recorded during the relevant transect.

The higher resolution assists in understanding regional and localized turbidity movement. Turbidity often differs across a channel, particularly in locations with a high longitudinal turbidity gradient. In such locations, differences in cross-channel velocity, particulate advection potential, and vegetation density can lead to a time lag in turbidity values between the channel center, where currents are stronger, and the channel margins, where fixed water quality stations are typically located. For these reasons, turbidity transects follow the channel center and, as much as possible, are timed to coincide with high slack tide. The transect data provides a representation of turbidity intrusion between stations in regions considered high entrainment risk for Delta Smelt adults and subsequently spawned Delta Smelt larvae.

The WY 2015 and 2016 transect routes ran along the southern portions of Middle and Old rivers until the intersection with Grant Line Canal (Figure 1).

**Figure 1 Turbidity transect route area.**

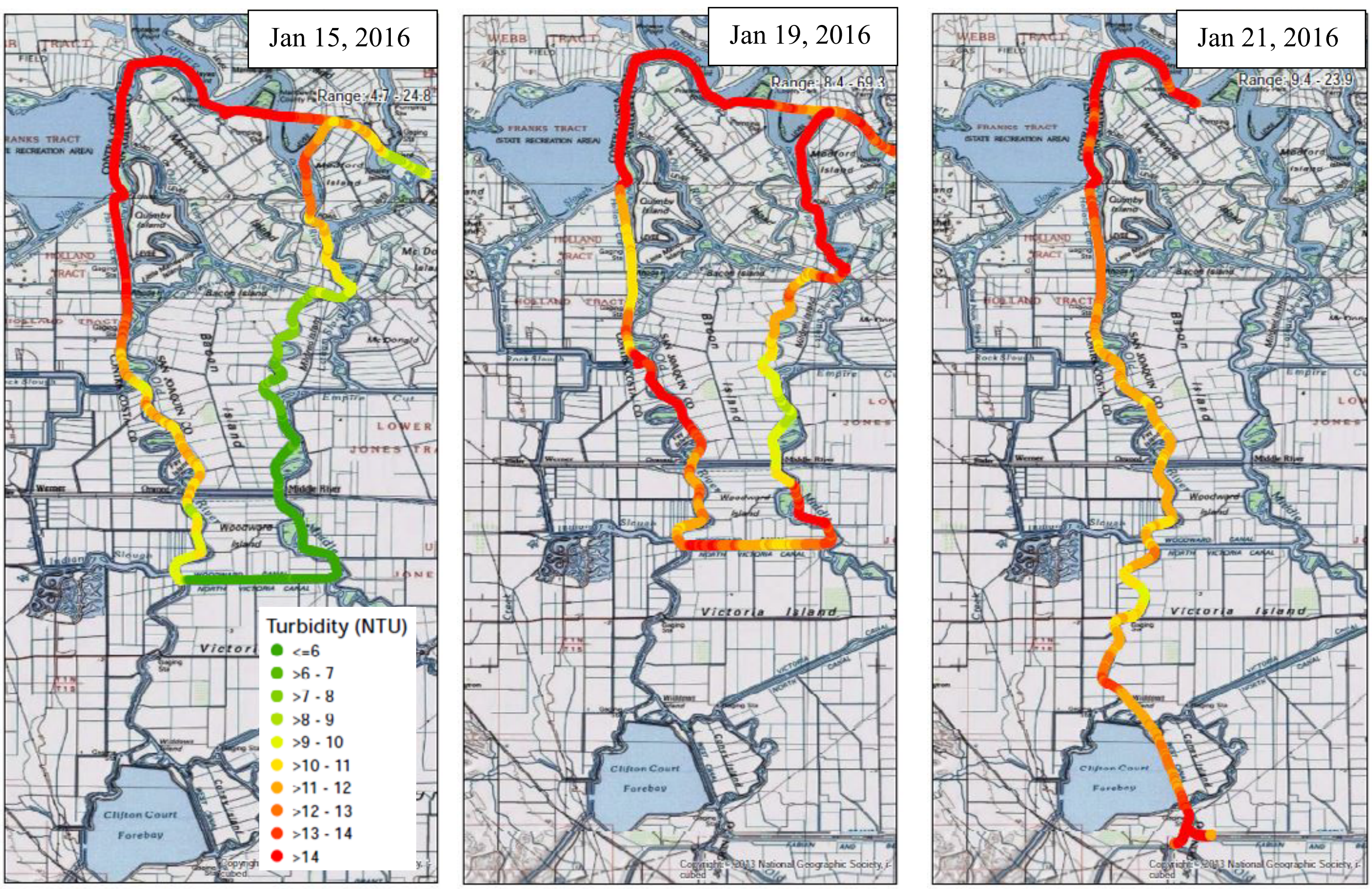



Note: The yellow route displays the initial loop monitored while turbidity levels remain below 12 NTU. Once turbidity levels rise, the red route is followed South to Clifton Court Forebay and Grantline Canal. Transect data was verified against the stations marked in blue. All station data is found on California Data Exchange Center (cdec.water.ca.gov) and translate to (counterclockwise from North to South): Prisoner's Point; Holland Cut; Old River at Bacon Island; Old River at Highway 4; Grantline Canal; Victoria Cut; Middle River at Union Point; Middle River at Middle River; and Middle River near Holt.

This area was selected because of its importance in the assessment of Delta Smelt entrainment risk. Transects were conducted on a 19-foot Alumaweld Stryker boat with a two-person crew. In WY 2016, a calibrated YSI EXO2 multi-parameter sonde equipped with a turbidity probe was placed within a flow-through cell. The water was pumped from 1-meter below surface water, through a debubbler, and into the flow-through cell containing the probe. The boat traveled along the mid-channel between 10 and 15 knots to ensure sonde GPS recordings were in close proximity to the water intake locations. As the boat passed fixed water quality stations, turbidity readings were collected using a Hach 2100P turbidimeter both to validate fixed station readings and to compare with center channel transect data.

The transects (Figure 1) began along the San Joaquin River and continued west to the Old River intersection, then turned south, following the Old River past Franks Tract towards Clifton Court Forebay. Early in the transect season, runs continued down Old River and looped across Woodward Canal and up Middle River back to the San Joaquin River, as shown in yellow on Figure 1. When an elevated turbidity front (≥ 12 NTU) reached the junction at Woodward Canal, transects continued south along Old River, past Clifton Court Forebay, and ended on Grant Line Canal (shown in red on Figure 1). The movement of high turbidity over time is displayed in Figure 2, where the elevated turbidity moved past Woodward Canal and prompted the following transect to continue further south.

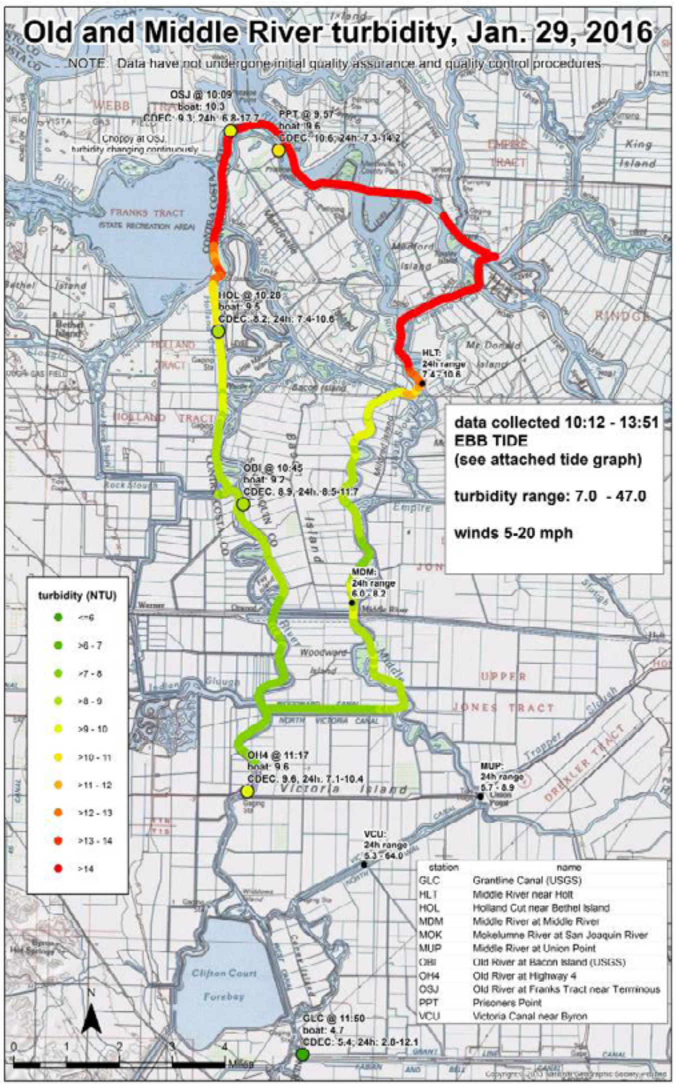
**Figure 2 Advection of a turbidity pulse from the San Joaquin River into the south Delta along the Old and Middle rivers.**




Note: This is represented by a time series of turbidity distribution graphs generated from Turbidity Transect data during January 2016. In the above cases, transect timing spanned the period of high tide when the region of elevated turbidity was at its southernmost distribution. With each represented day, turbidity moved further south towards Clifton Court Forebay. Note that on January 19 the turbidity pulse had advanced down Old River to the junction with Woodward Canal, prompting the next transect to continue down Old River to Clifton Court Forebay and Grantline Canal (January 21st panel).

Detailed maps produced following WY 2016 turbidity transects were referenced during water project operational meetings on turbidity distribution management. The turbidity maps (Figure 3) proved to be an excellent communication tool, as they combined fixed water quality station, transect, meteorological, and tidal data into an easily interpretable representation of incoming turbidity for risk assessment and operational decisions. All

**Figure 3 Old and Middle River turbidity transect map.**




Note: This Old and Middle River turbidity transect map was presented to SWG advisors and DWR management on January 29, 2016. Each turbidity transect map includes pertinent data from fixed water quality stations, along with tidal and meteorological information. This combination of data sources was appreciated during water project operational meetings, due to the ability to quickly interpret present conditions. In addition, a comparison with prior turbidity maps allowed for comprehension of regional turbidity movement over time.

turbidity data was processed and presented in ArcGIS with color-coded turbidity levels, transitioning from green (low turbidity) to red (high turbidity) at approximately 12 NTU (Figure 2). Data was distributed to the SWG and State Water Project operational management within 24-hours of each transect.

Method improvements between transect seasons enhanced the data continuity between runs and between boat operators. For example, the installation of a flow-through system, along with regulated flow diversion, on the study boat minimized data interference previously caused by bubble interference and submerged vegetation during the WY 2015 transect study. In the current WY 2017, turbidity transects began on December 13. The methodology primarily matches WY 2016, with the exception of utilizing a YSI EXO1 sonde in place of a YSI EXO2 sonde. This change minimizes instrument surface area within the flow-through while maintaining the sensor type. The smaller surface area is expected to lower bubble and debris interference.

The WY 2017 transect schedule extended from December 2016 through late February 2017. Because of the continued high outflow and highly positive combined flow in the Old and Middle rivers, a decision was made to end the turbidity transect monitoring effort early. During the short WY 2017 transect season, the routes continued to concentrate on the Old River corridor to improve coordination with the tidal stage. DWR is working toward minimizing tidal influence on estimates of slack/flood tide turbidity-distribution with the development of a real-time turbidity visualization tool based on fixed station data calibrated with transect data. An example of the initial stages of this tool is currently available at Bay-Delta Live (www.baydeltalive.com). Further information will be available late WY 2017.

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The IEP Newsletter is a quarterly publication that provides IEP program and science highlights as well as in-depth articles on important scientific topics for resource managers, scientists, and the public. Articles in the IEP newsletter are intended for rapid communication and do not undergo external peer review; all primary research results should be interpreted with caution.

If you would like to be notified about new issues of the quarterly IEP newsletter, please send an e-mail to Shaun Philippart (DWR), shaun.philippart@water.ca.gov, with the following information:

- Name
- Agency
- E-mail address

**Article Submission Deadlines for this Calendar Year**

| Issue | Article Submission Deadline |
|---|---|
| Issue 1 (Winter) | January 15, 2017 |
| Issue 2 (Spring) | April 15, 2017 |
| Issue 3 (Summer) | July 15, 2017 |
| Issue 4 (Fall) | October 15, 2017 |

Submit articles to Shaun Philippart.

# Status and Trends

## Zooplankton Monitoring 2013–2015

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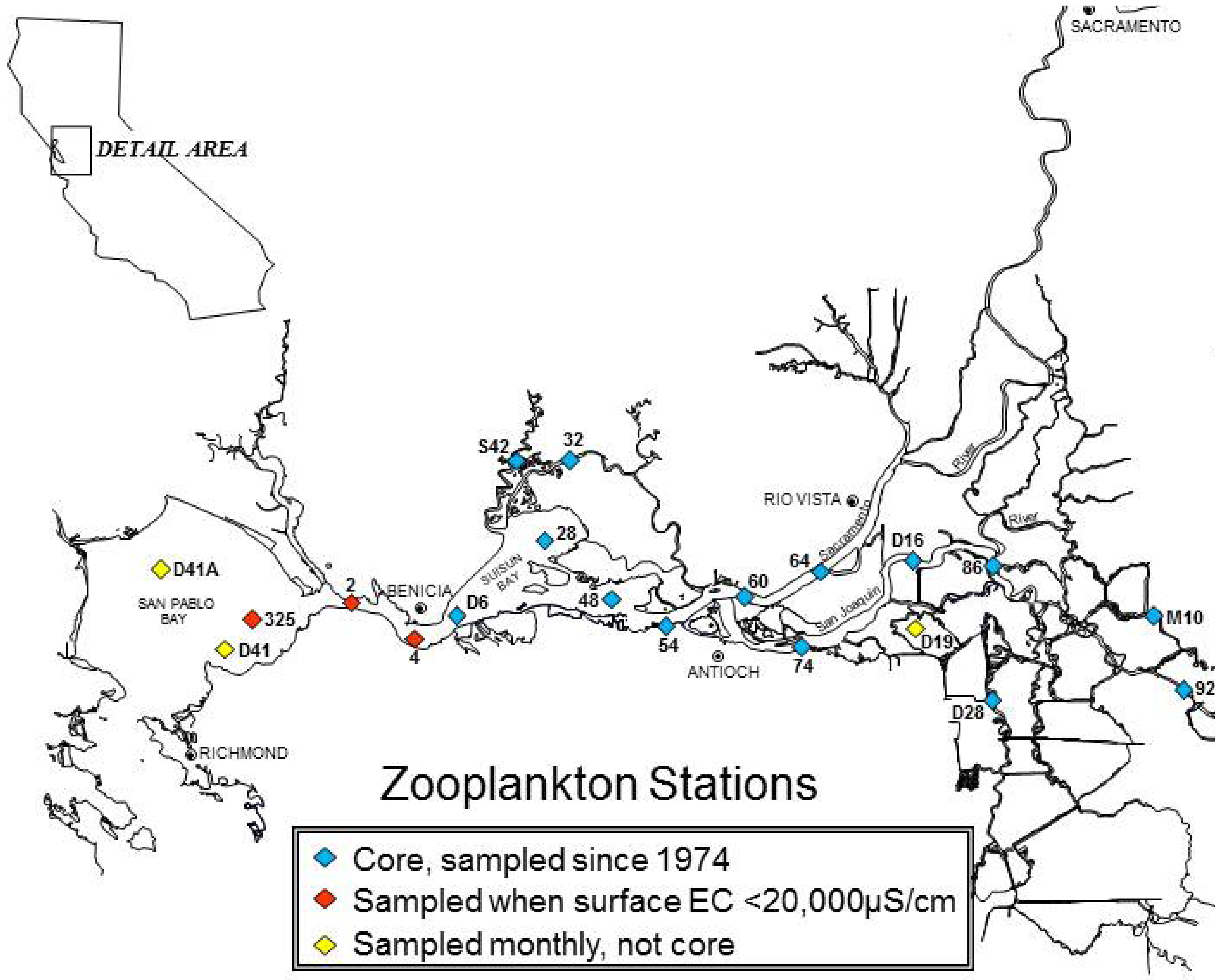
### Introduction

Zooplankton are an important component of the pelagic food web. They eat phytoplankton and in turn are eaten by other zooplankton, aquatic insects, and fish, thereby providing a vital trophic link between primary producers and fish. Most larval and juvenile fish eat zooplankton while some smaller fish, such as Delta Smelt and Longfin Smelt, rely on zooplankton for food throughout their lives. To assess trends in fish food resources, the Zooplankton Study has provided abundance estimates of zooplankton in the upper San Francisco Estuary (SFE) since 1972 and has assisted with the detection and monitoring of introduced zooplankton. Substantial changes in the zooplankton community composition and abundance have been linked to the decline of several pelagic fish species in the upper SFE (Sommer et al. 2007, Winder and Jassby 2010). Documenting these lower food web changes helps scientists understand the ecology of the SFE and the food resources available for fish. Here, zooplankton abundance indices are presented from 1974 through 2015 for the most common copepods, cladocerans, rotifers, and mysids. Seasonal trends are also provided for the more recent period 1995–2015.

### Methods

Zooplankton were sampled monthly from 1974 through 2015 at 20 fixed stations in the upper SFE, extending from eastern San Pablo Bay through the Sacramento-San Joaquin Delta (Delta) (Figure 1). At

**Figure 1 Map of fixed Zooplankton Study stations.**




each station, three gear types were used to collect zooplankton of various sizes: (1) a pump for sampling smaller zooplankton, including rotifers and copepods of the genus *Limnoithona*; (2) a modified Clarke-Bumpus (CB) net for sampling mid-sized zooplankton, including cladocerans and most copepods (net mesh 160 micron opening); and (3) a mysid net for sampling mysid shrimp (net mesh 505 micron opening). Abundance indices were calculated using data from the gear type that most effectively captured each organism, and were reported here as the mean number of each organism per cubic meter of water sampled (catch-per-unit effort, [CPUE]). Copepod abundance indices included adults only, as juvenile species were not always enumerated separately; all other taxa reported include both juveniles and adults combined.

For long-term trend analyses, annual mean abundance was calculated as the mean March through November CPUE, because these were the months consistently sampled throughout the entire study period. Seasonal mean abundance was calculated as the mean CPUE for each season: (1) winter, previous December through February; (2) spring, March through May; (3) summer, June through August; (4) fall, September through November. Winter months were not sampled consistently until 1995; therefore, long-term trends for all seasons are shown from 1995 through

2015 only. Sixteen stations were used to calculate abundance indices, including 14 fixed stations sampled consistently since 1974 (Figure 1) and two non-fixed stations sampled where bottom specific conductance was between 2 and 6 milliSiemens per centimeter (mS/cm) (approximate salinity of 1 and 3 practical salinity units [psu]).

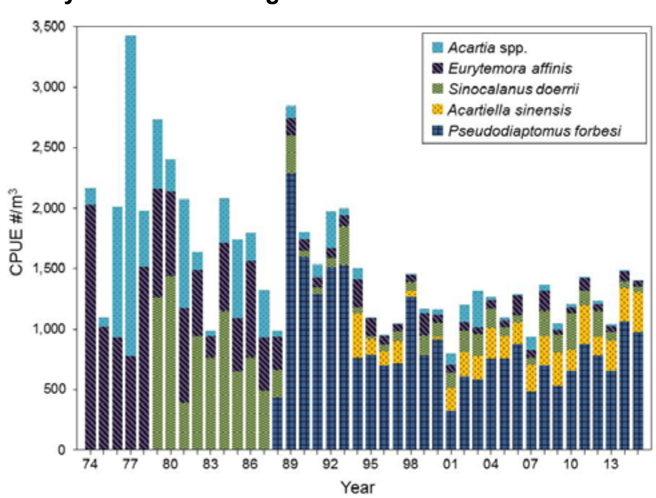
Bubble plot maps show the distribution of zooplankton at fixed stations for the survey when densities were highest from 2013 through 2015.

### Results and Discussion

#### *Calanoid Copepods — Time series*

Calanoid copepods in the upper SFE include *Eurytemora affinis*, *Acartia* spp., *Sinocalanus doerrii*, *Pseudodiaptomus forbesi*, *Tortanus* spp., and *Acartiella sinensis*. When monitoring began in the 1970s, *E. affinis* and *Acartia* spp. were the most abundant adult copepods (Figure 2). *E. affinis* was once a major food source for larval and juvenile fishes of many species as well as adult planktivores such as Delta Smelt and Threadfin Shad. But annual abundance of both *E. affinis* and *Acartia* spp. have since declined (Figure 2) as new species were introduced and became established in the estuary.

**Figure 2 Annual March-November mean adult calanoid copepod CPUE (catch-per-unit-effort in number m$^{-3}$) from the Zooplankton Study's Clarke-Bumpus net for the most abundant calanoid copepods in the upper San Francisco Estuary from 1974 through 2015.**




One of the first introductions was *Sinocalanus doerrii*, a freshwater calanoid copepod initially recorded by this study in late 1978 (Orsi et al. 1983). By summer 1979, *S. doerrii* abundance surpassed *E. affinis* summer abundance, and *S. doerrii* was the most abundant calanoid copepod in the upper estuary in most years from 1979 through 1984 (Figure 2).

In the late 1980s, two more introductions occurred that further changed the copepod community in the upper SFE. In 1986 the overbite clam, *Potamocorbula amurensis*, was introduced and in 1987, another calanoid copepod, *Pseudodiaptomus forbesi*, was introduced. Both *P. amurensis* and *P. forbesi* grazed on phytoplankton and thus competed with *E. affinis* for food (Kimmerer and Orsi 1996). Additionally, *P. amurensis* also grazed on copepod nauplii in the water column, thereby further reducing *E. affinis* abundance through predation (Kimmerer et al. 1994). Once common year-round throughout the upper estuary, *E. affinis* abundance declined after these introductions (Figure 2). Prior to these introductions, *E. affinis* abundance was usually highest during summer; however, since 1987, abundance has been highest in spring and dropping abruptly in summer when both *P. forbesi* abundance and *P. amurensis* grazing rates increased.

In the summer of 1993, the large brackish water calanoid copepod *Tortanus dextrilobatus* was first recorded by this study; another calanoid copepod, *Acartiella sinensis*, was also first recorded (Orsi and Ohtsuka 1999) later that same year. *A. sinensis* was the second-most abundant calanoid copepod in the upper estuary by 1994 (Figure 2), but spatially and seasonally most abundant in the low salinity zone during summer and fall (Orsi and Ohtsuka 1999). Yet *T. dextrilobatus* has never been as abundant in the study area as the other calanoid copepods, as abundance peaks further downstream in the lower estuary in highly brackish water (Orsi and Ohtsuka 1999).

#### *Calanoid Copepods — Abundance and Distribution 2013–2015*

*Pseudodiaptomus forbesi* was again the most abundant calanoid copepod from 2013 through

2015, as it had been since its introduction (Figure 2). Although *P. forbesi* is usually most abundant during summer, fall abundance in 2014 and 2015 exceeded summer abundance (Table 1). Additionally, spring abundance was higher than average from 2013 through 2015, and *P. forbesi* was the most abundant calanoid copepod in the upper estuary in spring 2013 and 2015 (Table 1). From 2013 through 2015, *P. forbesi* abundance was highest in the central and eastern Delta during summer and fall. Abundance peaked in this period in August of 2014 in the eastern Delta (Figure 3).

In 2013 through 2015, *Acartiella sinensis* was the second-most abundant calanoid copepod (Figure 2). *A. sinensis* abundance in each season from 2013 through 2015 was higher than each of the 1995 through 2012 seasonal means (Table 1). *A. sinensis* abundance was highest during fall from 2013 through 2015 (Table 1), and peak abundance occurred in the lower Sacramento River (Figure 4).

*Sinocalanus doerrii* was the third-most abundant calanoid copepod in 2013 and 2015, and in 2014 was the fourth most abundant (Figure 2). *S. doerrii* abundance was highest during spring from 2013 through 2015, but spring abundance was lower in these years than the mean spring abundance from 1995 through 2012 (Table 1). From 2013 through 2015, *S. doerrii* abundance peaked in May in the central and eastern Delta (Figure 5).

*Eurytemora affinis* was the fourth-most abundant calanoid copepod in 2013 and 2015, and was the third-most abundant in 2014 (Figure 2). *E. affinis* abundance was highest during spring from 2013 through 2015, but spring abundance was lower in these years than the mean spring abundance from 1995 through 2012 (Table 1). From 2013 through 2015, *E. affinis* abundance was highest during March and April in Suisun Marsh, with peak abundance occurring in April 2014 (Figure 6).

*Acartia* spp. was the fifth-most abundant calanoid copepod from 2013 through 2015 (Figure 2). Abundance in each season from 2013 through 2015 was lower than the 1995–2012 seasonal means (Table 1). In 2013, abundance was highest in spring,

**Table 1 Seasonal mean calanoid copepod CPUE (catch-per-unit-effort in number m$^{-3}$) from the Zooplankton Study's Clarke-Bumpus net for winter (previous December–February), spring (March–May), summer (June–August), and fall (September–November) from 2013, 2014, 2015, and 1995 through 2012.**

| | *Years* | *Pseudodiaptomus forbesi* | *Acartiella sinensis* | *Sinocalanus doerrii* | *Eurytemora affinis* | *Acartia spp.* |
|---|---|---|---|---|---|---|
| **Winter** | 2015 | 30 | 109 | 4 | 53 | 6 |
| | 2014 | 62 | 83 | 24 | 148 | 99 |
| | 2013 | 30 | 64 | 5 | 35 | 24 |
| | 1995 to 2012 | 36 ± 13 | 52 ± 18 | 15 ± 7 | 55 ± 18 | 125 ± 54 |
| **Spring** | 2015 | 713 | 34 | 118 | 86 | 5 |
| | 2014 | 200 | 34 | 115 | 210 | 37 |
| | 2013 | 285 | 50 | 159 | 125 | 40 |
| | 1995 to 2012 | 176 ± 90 | 9 ± 5 | 222 ± 64 | 223 ± 67 | 111 ± 98 |
| **Summer** | 2015 | 1014 | 133 | 25 | 4 | 0.4 |
| | 2014 | 1413 | 241 | 35 | 2 | 1 |
| | 2013 | 866 | 275 | 23 | 1 | 2 |
| | 1995 to 2012 | 1395 ± 210 | 125 ± 53 | 159 ± 65 | 17 ± 12 | 11 ± 9 |
| **Fall** | 2015 | 1213 | 745 | 3 | 37 | 2 |
| | 2014 | 1590 | 539 | 9 | 33 | 2 |
| | 2013 | 819 | 426 | 21 | 24 | 11 |
| | 1995 to 2012 | 622 ± 113 | 377 ± 95 | 10 ± 7 | 21 ± 9 | 38 ± 16 |

Note: 1995–2012 reported as mean ± 95% CI, n = 18 for all.

**Figure 3 Map of *Pseudodiaptomus* abundance and distribution from the Zooplankton Study's Clarke-Bumpus net from August 2014, which had the highest abundance of any survey during 2013 through 2015.**

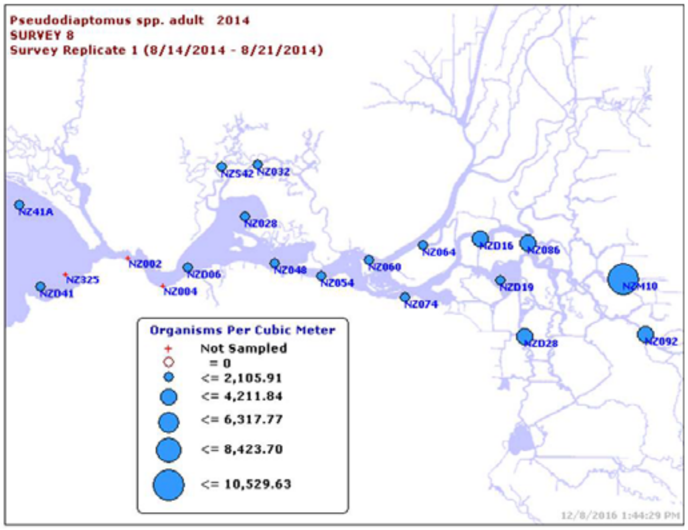
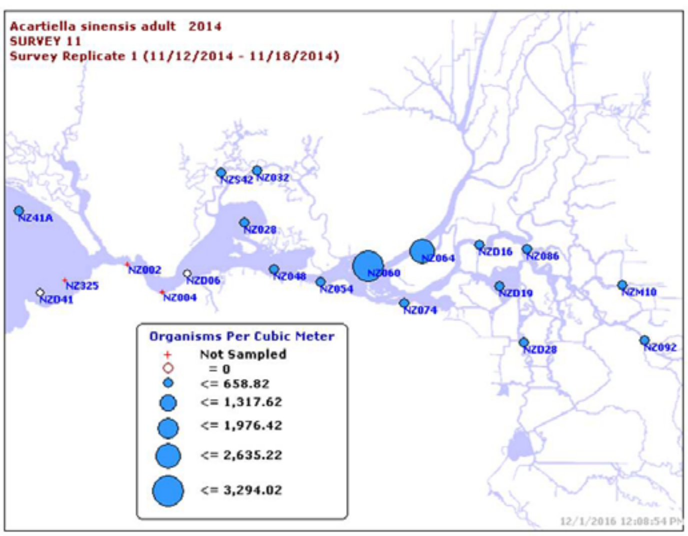
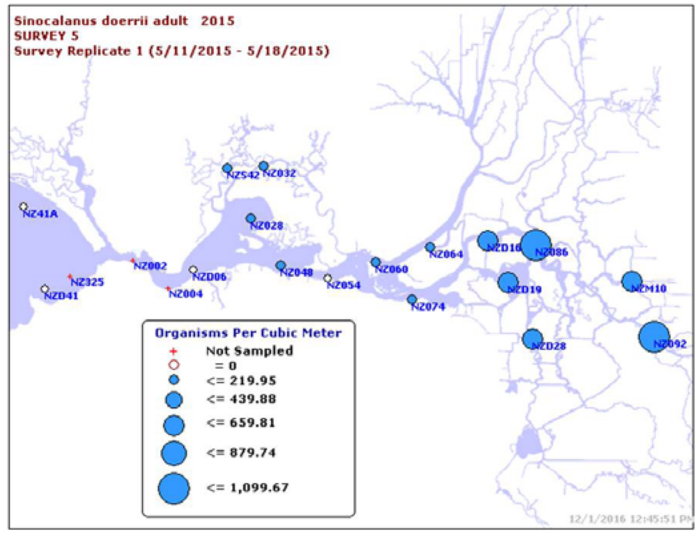



**Figure 4 Map of *Acartiella sinensis* abundance and distribution from the Zooplankton Study's Clarke-Bumpus net from November 2014, which had the highest abundance of any survey during 2013 through 2015.**




whereas in 2014 and 2015 abundance was highest in winter (Table 1). *Acartia* spp. was most abundant in San Pablo Bay from 2013 through 2015, but abundance may have been higher downstream of the sampling area.

**Figure 5 Map of *Sinocalanus doerrii* abundance and distribution from the Zooplankton Study's Clarke-Bumpus net from May 2015, which had the highest abundance of any survey during 2013 through 2015.**




## *Cyclopoid Copepods — Time series*

Cyclopoid copepods in the upper SFE include *Limnoithona sinensis*, *Limnoithona tetraspina*, and the much less abundant *Acanthocyclops* spp. and *Cyclops* spp. (not reported here). In 1979, the cyclopoid copepod *L. sinensis* was introduced (Ferrari and Orsi 1984). Smaller than the calanoid copepods that inhabited the estuary, *L. sinensis* wasn't retained well by the CB net, but abundance estimates from the pump samples quickly became comparable to *E. affinis* and *S. doerrii* abundance estimates from the CB samples (Figure 7) (*L. sinensis* was recorded as *Limnoithona* spp. through 2006). Abundance indices for the two species of *Limnoithona* are reported together until 2007, when they were identified and enumerated separately.

*Limnoithona tetraspina*, another small cyclopoid copepod, was first recorded by this study in 1993 (Orsi and Ohtsuka 1999). It replaced the historically common and slightly larger *L. sinensis* and became the numerically dominant copepod in the upper estuary by 1994 (figures 2 and 7). Despite extremely high densities of *L. tetraspina* in the estuary, it may not be a readily available food source for visual predators like Delta Smelt because of its small size and relatively motionless behavior in the water column (Bouley and Kimmerer 2006).

## *Cyclopoid Copepods — Abundance and Distribution 2013–2015*

*Limnoithona tetraspina* has been the most abundant copepod in the upper estuary since 1994, and annual abundance from 2013 through 2015 were the highest recorded (Figure 7). Abundance was highest in summer, and in 2014 and 2015 summer abundance were the highest recorded (Figure 8C). Winter *L. tetraspina* abundance was higher from 2013 through 2015 than in previous years (Figure 8A). Spring abundance was higher in 2013 and 2014 than it had been since 1998, and in 2015 spring abundance was the highest recorded (Figure 8B).

Although annual abundance of *L. sinensis* was much lower than *L. tetraspina*, *L. sinensis* was relatively abundant compared to other copepods in the upper estuary (figures 2 and 7). *L. sinensis* abundance was low in winter and spring 2013 through 2015, and increased slightly in summer and fall (Figures 8A–8D).

**Figure 6 Map of *Eurytemora affinis* abundance and distribution from the Zooplankton Study's Clarke-Bumpus net from April 2014, which had the highest abundance of any survey during 2013 through 2015.**

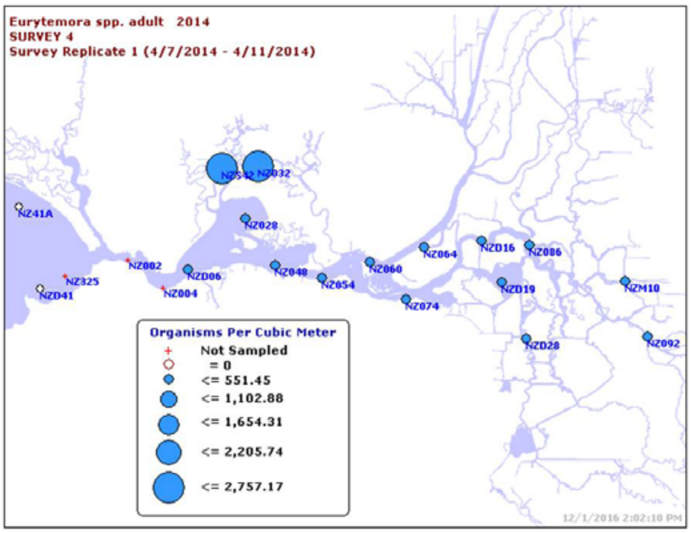
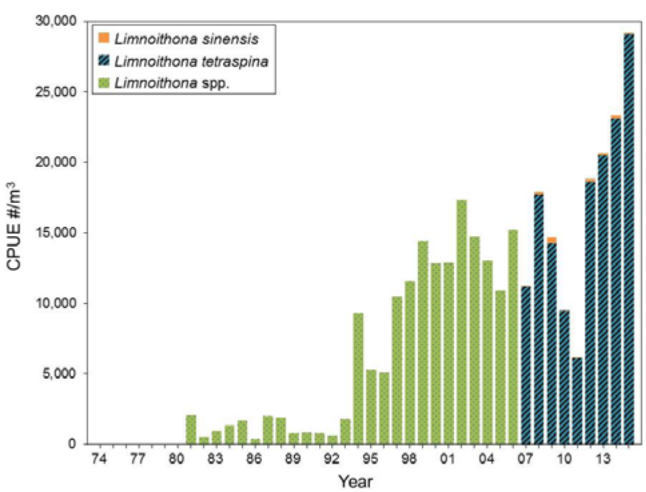
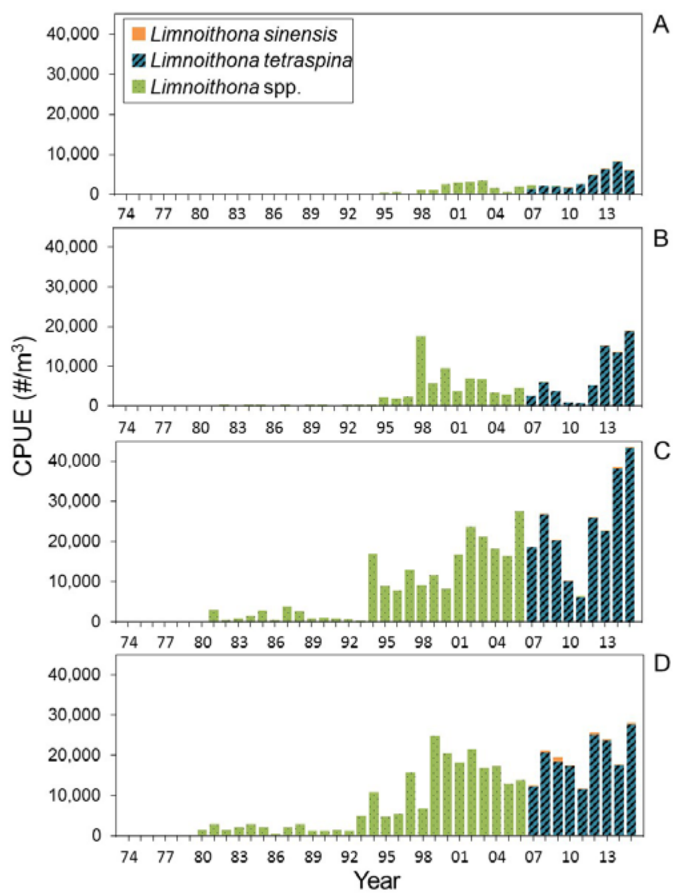



**Figure 7 Annual March-November mean cyclopoid copepod CPUE (catch-per-unit-effort in number m$^{-3}$).**




Note: This information is from the Zooplankton Study's pump samples for the most abundant cyclopoid copepods in the upper San Francisco Estuary from 1974 through 2015. *Limnoithona sinensis* was originally recorded as *Limnoithona* spp., then in 1993 *Limnoithona tetraspina* was introduced and mostly supplanted *L. sinensis*, but the genus wasn't identified to species in samples until 2007.

**Figure 8 Seasonal mean cyclopoid copepod CPUE (catch-per-unit-effort in number m$^{-3}$) from the Zooplankton Study's pump samples from 1974 through 2015 for (A) winter (previous December–February), (B) spring (March–May), (C) summer (June–August), and (D) fall (September–November).**



Although common throughout the sampling area in 2013, 2014, and 2015, *Limnoithona* abundance was highest in Suisun Bay, Suisun Marsh, and the lower Sacramento River during summer and fall. The highest *Limnoithona* abundance from 2013 through 2015 occurred in April 2015 in Grizzly Bay (Figure 9).

### *Cladocerans*

*Bosmina*, *Daphnia*, and *Diaphanosoma* are the most abundant cladoceran genera in the upper SFE. Combined, these native freshwater cladocerans had an overall downward trend since the early 1970s (Figure 10). Winter abundance, although always much lower than the other seasons, has been extremely low since 2010 (Figure 11A). Despite small increases in 2013 and 2015, spring abundance remained low, and in 2014 spring abundance was the lowest recorded (Figure 11B). Summer abundance increased in 2014, and in 2015 was the highest summer abundance since 2004 (Figure 11C). Fall abundance also increased in 2014, and in 2015 reached the highest fall abundance since 1992 (Figure 11D). In winter and spring 2013 through 2015, cladocerans were common throughout the Delta, Suisun Bay, and Suisun Marsh. In summer and fall, as outflow decreased, distribution shifted

**Figure 9 Map of Limnoithona abundance and distribution from the Zooplankton Study's pump samples from April 2015, which had the highest abundance of any survey during 2013 through 2015.**

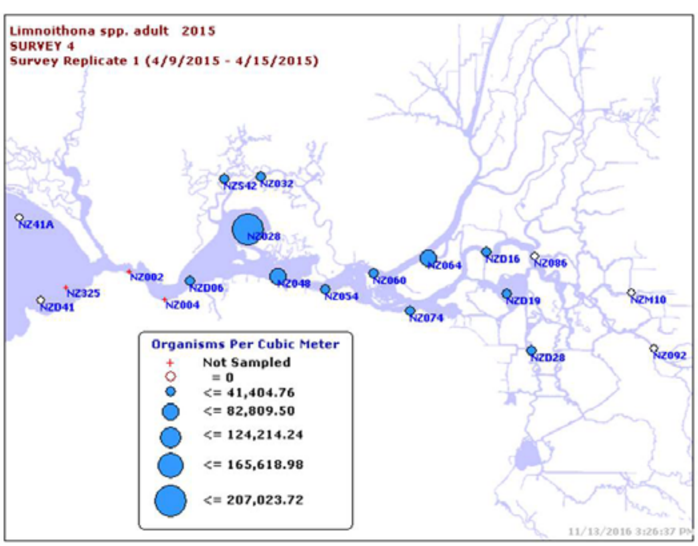



**Figure 10 Annual March–November mean cladoceran CPUE (catch-per-unit-effort in number m$^{-3}$) from the Zooplankton Study's Clarke-Bumpus net from 1974 through 2015.**

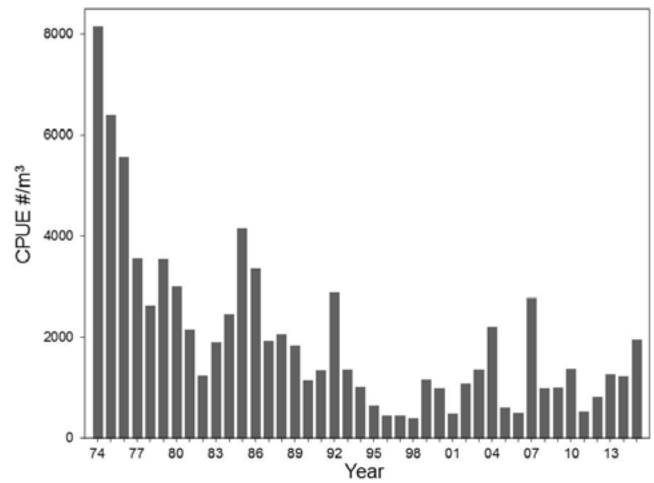
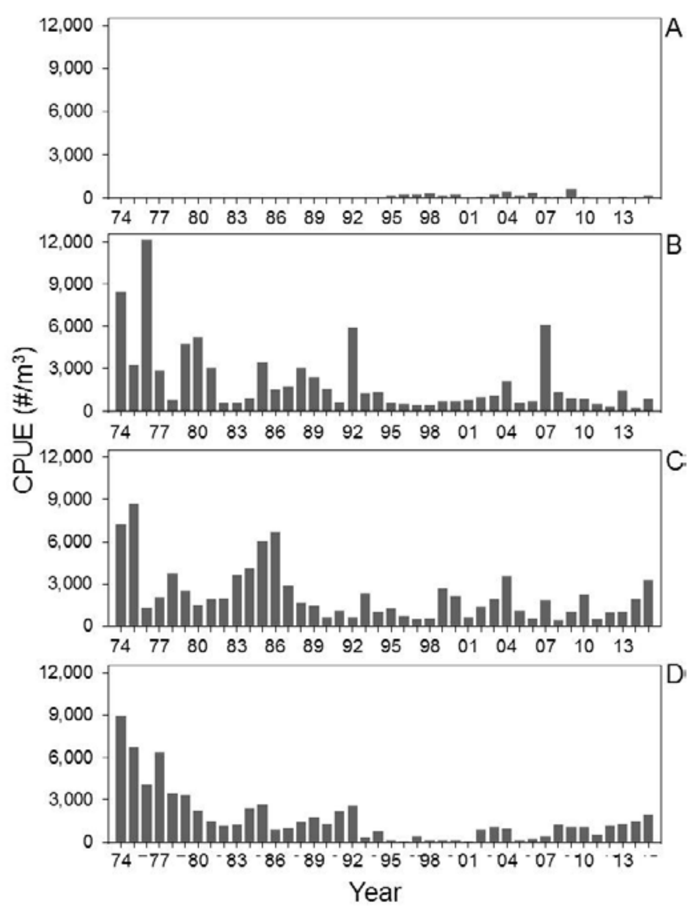



**Figure 11 Seasonal mean cladocerans CPUE (catch-per-unit-effort in number m$^{-3}$) from the Zooplankton Study's Clarke-Bumpus net from 1974 through 2015 for (A) winter (previous December–February), (B) spring (March–May), (C) summer (June–August), and (D) fall (September–November).**



upstream and most cladocerans were found in the Delta. The highest abundance from 2013 through 2015 occurred during June 2015 in Disappointment Slough in the eastern Delta (Figure 12).

### *Rotifers*

Rotifers in the upper SFE include the freshwater *Asplanchna* spp., *Keratella* spp., *Polyarthra* spp., *Synchaeta* spp., and *Trichocerca* spp., as well as the brackish-water *Synchaeta bicornis*. Similar to past zooplankton status and trends reports, the rotifers are reported here as *Synchaeta bicornis* and other rotifers. *Synchaeta bicornis* is a native brackish-water rotifer that is usually most abundant in the upper estuary in summer and fall, when salinity increases. The long-term annual abundance of *S. bicornis* has declined since the 1970s (Figure 13). In 2011, annual abundance was higher than it had been since 1985, but returned to previously low levels from 2012 through 2015 (Figure 13). From 2013 through 2015, *S. bicornis* abundance peaked in summer (Table 2). Spring abundance from 2013 through 2015 was higher than the spring mean from 1995 through 2012, whereas fall abundance from 2013 through 2015 was lower than the fall mean from 1995 through 2012 (Table 2). *S. bicornis* was common from May through October in 2013 through 2015, from the western Delta through Suisun Bay and Suisun Marsh. From 2013 through 2015, the highest abundance occurred in June 2014 in Montezuma Slough in Suisun Marsh (Figure 14).

**Figure 12 Map of cladocerans abundance and distribution from the Zooplankton Study's Clarke Bumpus net from June 2015, which had the highest abundance of any survey during 2013 through 2015.**

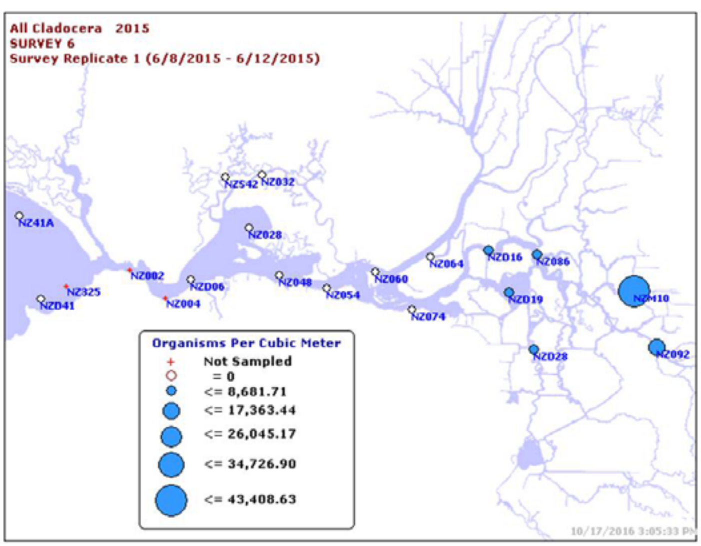



**Figure 13 Annual March-November mean rotifers CPUE (catch-per-unit-effort in number $m^{-3}$) from the Zooplankton Study's pump samples from 1974 through 2015.**

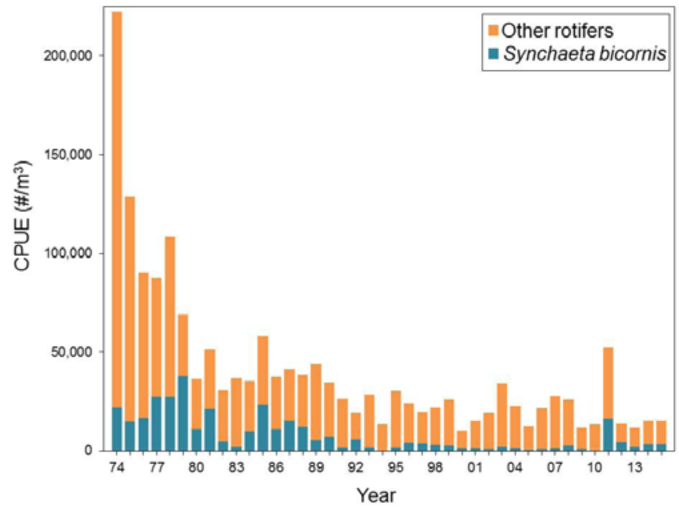



**Table 2 Seasonal mean rotifers CPUE (catch-per-unit-effort in number $m^{-3}$) from the Zooplankton Study's pump samples for winter (previous December–February), spring (March–May), summer (June–August), and fall (September–November) from 2013, 2014, 2015, and 1995 through 2012.**

| | *Years* | *Synchaeta bicornis* | *Other Rotifers* |
|---|---|---|---|
| ***Winter*** | 2015 | 4 | 14,742 |
| | 2014 | 0 | 12,578 |
| | 2013 | 0 | 21,710 |
| | 1995 to 2012 | 16 ± 14 | 21,202 ± 3,803 |
| ***Spring*** | 2015 | 163 | 16,464 |
| | 2014 | 439 | 11,548 |
| | 2013 | 1,856 | 12,728 |
| | 1995 to 2012 | 57 ± 78 | 31,457 ± 9,203 |
| ***Summer*** | 2015 | 9,252 | 7,751 |
| | 2014 | 9,675 | 7,939 |
| | 2013 | 3,234 | 6,581 |
| | 1995 to 2012 | 3,045 ± 1,490 | 13,535 ± 3,589 |
| ***Fall*** | 2015 | 2,154 | 10,700 |
| | 2014 | 50 | 16,154 |
| | 2013 | 477 | 10,029 |
| | 1995 to 2012 | 4,973 ± 4,503 | 14,227 ± 2,717 |

Note: 1995–2012 reported as mean ± 95% CI, n = 18 for all.

Abundance of all other rotifers, without *S. bicornis*, declined from the early 1970s through the 1980s, but has stabilized since the early 1990s (Figure 13). In 2011, annual abundance was higher than it had been since 1989, but declined in 2012 and remained low through 2015 (Figure 13). Rotifer abundance usually peaks in spring, as it did in 2015; however, in 2013 rotifer abundance peaked in winter and in 2014 abundance was highest in fall (Table 2). Rotifers were common throughout the study area in every season during 2013 through 2015. From 2013 through 2015 abundance was highest during winter of 2013 and peak abundance occurred in February of 2013 in Suisun Marsh (Figure 15).

### *Mysids — Time series*

Mysids in the upper SFE include *Neomysis mercedis*, *Neomysis kadiakensis*, *Alienacanthomysis macropsis*, *Hyperacanthomysis longirostris*, and *Acanthomysis aspera* (with the lesser abundant *Acanthomysis hwanhaiensis* not reported here). *N. mercedis* was the only mysid commonly found in the upper estuary when monitoring began in the 1970s. Similar to *E. affinis*, *N. mercedis* abundance dropped in the early 1990s after the introduction of the overbite clam, *P. amurensis* (Figure 16). This decline was caused by competition with *P. amurensis* for phytoplankton, a shared food resource (Orsi and Mecum 1996). Shortly after *N. mercedis* abundance began declining, two newly introduced mysids were collected by this study: *A. aspera* was first collected in 1992, and *H. longirostris* (formerly *Acanthomysis bowmani*) was first collected in 1993 (Modlin and Orsi 1997). *H. longirostris* abundance increased

**Figure 15 Map of rotifers abundance and distribution from the Zooplankton Study's pump samples from April 2013, which had the highest abundance of any survey during 2013 through 2015.**

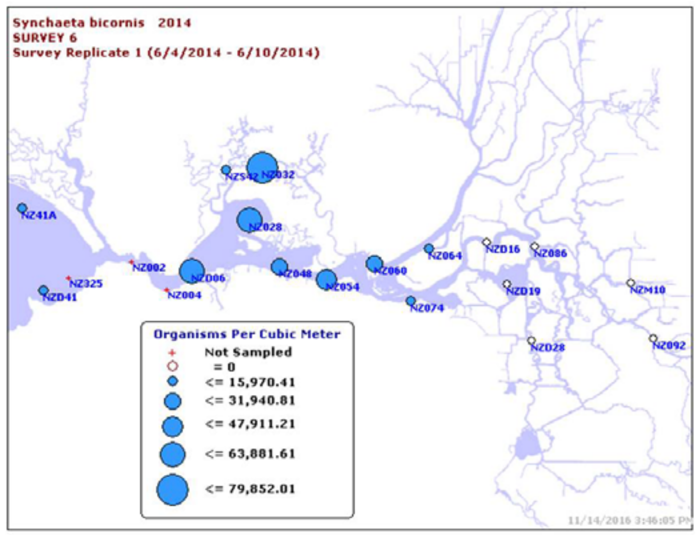



**Figure 14 Map of Synchaeta bicornis abundance and distribution from the Zooplankton Study's pump samples from June 2014, which had the highest abundance of any survey during 2013 through 2015.**

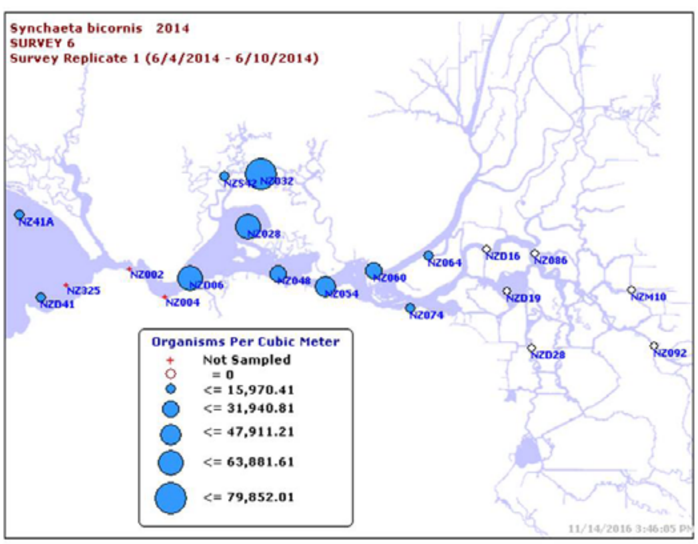
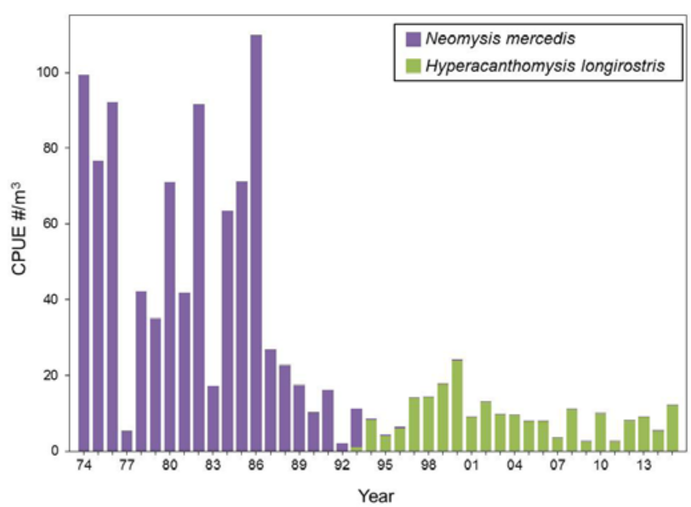



**Figure 16 Annual March–November mean mysids CPUE (catch-per-unit-effort in number m$^{-3}$) from the Zooplankton Study's mysid net for *Neomysis mercedis* and *Hyperacanthomysis longirostris* in the upper San Francisco Estuary from 1974 through 2015.**



rapidly after its introduction, and by 1994 it was the most abundant mysid in the upper estuary (Figure 16).

### *Mysids — Abundance and Distribution 2013-2015*

From 2013 to 2015, *Hyperacanthomysis longirostris* was again the most abundant mysid, as it had been since 1994 (Figure 16). In 2015, annual abundance was higher than it had been since 2002 (Figure 16). Although *H. longirostris* is usually most abundant in summer, in 2013 and 2015 it was most abundant in spring (Table 3). Summer abundance in 2014 and 2015 were among the lowest summer abundance recorded. From 2013 through 2015, *H. longirostris* was most abundant during spring and summer in Suisun Marsh, eastern Suisun Bay, and the lower Sacramento River. Peak abundance from 2013 through 2015 occurred in May 2015 in Suisun Marsh and the lower Sacramento River (Figure 17).

*Neomysis kadiakensis* is a native brackish-water mysid that regularly appeared in mysid samples beginning in 1995. Recently *N. kadiakensis* abundance has increased, and from 2013 through 2015 it was the second most abundant mysid in the upper SFE (figures 16 and 18). From 2013 through 2015, abundance was highest during spring and summer (Table 3). Seasonal abundance from 2013 through 2015 was higher than the mean 1995 through 2012 abundance for each season (Table 3). *N. kadiakensis* was most abundant during summer from 2013 through 2015 in Suisun Marsh, eastern Suisun Bay, and the lower Sacramento River. Peak abundance from 2013 through 2015 occurred in August 2014 in Suisun Marsh (Figure 19).

*Acanthomysis aspera*, a brackish-water mysid with historically low abundance when compared with other mysids in the upper estuary, recently increased in abundance (Figure 18). From 2013 through 2015, *A. aspera* had the third highest mean annual mysid abundance and so their abundance indices are

**Table 3 Seasonal mean mysid CPUE (catch-per-unit-effort in number m$^{-3}$) from the Zooplankton Study's mysid samples for winter (previous December–February), spring (March–May), summer (June–August), and fall (September–November) from 2013, 2014, 2015, and 1995 through 2012 (reported with ± 95% confidence intervals, n = 18 for all).**

| | *Years* | *Hyperacanthomysis longirostris* | *Neomysis kadiakensis* | *Acanthomysis aspera* | *Alienacanthomysis macropsis* | *Neomysis mercedis* |
|---|---|---|---|---|---|---|
| **Winter** | 2015 | 0.666 | 0.338 | 0.001 | 0.010 | 0 |
| | 2014 | 0.408 | 0.457 | 0.008 | 0.372 | 0.001 |
| | 2013 | 1.254 | 0.103 | 0.002 | 0.069 | 0.003 |
| | 1995 to 2012 | 0.670 ± 0.352 | 0.083 ± 0.053 | 0.002 ± 0.001 | 0.229 ± 0.180 | 0.007 ± 0.005 |
| **Spring** | 2015 | 26.588 | 0.700 | 0.004 | 0.010 | 0.004 |
| | 2014 | 4.812 | 0.539 | 0.034 | 0.023 | 0.006 |
| | 2013 | 13.649 | 0.465 | 0.016 | 0.026 | 0.013 |
| | 1995 to 2012 | 6.676 ± 3.385 | 0.223 ± 0.153 | 0.002 ± 0.002 | 0.026 ± 0.019 | 0.241 ± 0.129 |
| **Summer** | 2015 | 6.619 | 1.768 | 0.131 | <0.001 | 0.001 |
| | 2014 | 7.115 | 0.774 | 0.364 | 0.002 | 0.002 |
| | 2013 | 10.916 | 0.449 | 0.077 | 0.003 | 0.004 |
| | 1995 to 2012 | 16.863 ± 4.862 | 0.251 ± 0.116 | 0.004 ± 0.005 | 0.001 ± 0.0005 | 0.208 ± 0.161 |
| **Fall** | 2015 | 2.633 | 0.388 | 0 | 0 | 0 |
| | 2014 | 3.935 | 0.649 | 0.012 | 0.006 | 0 |
| | 2013 | 2.495 | 0.403 | 0.003 | 0.035 | <0.001 |
| | 1995 to 2012 | 5.663 ± 2.424 | 0.174 ± 0.093 | 0.010 ± 0.007 | 0.034 ± 0.028 | 0.002 ± 0.003 |

**Figure 17 Map of *Hyperacanthomysis longirostris* abundance and distribution from the Zooplankton Study's mysid samples from May 2015, which had the highest abundance of any survey during 2013 through 2015.**

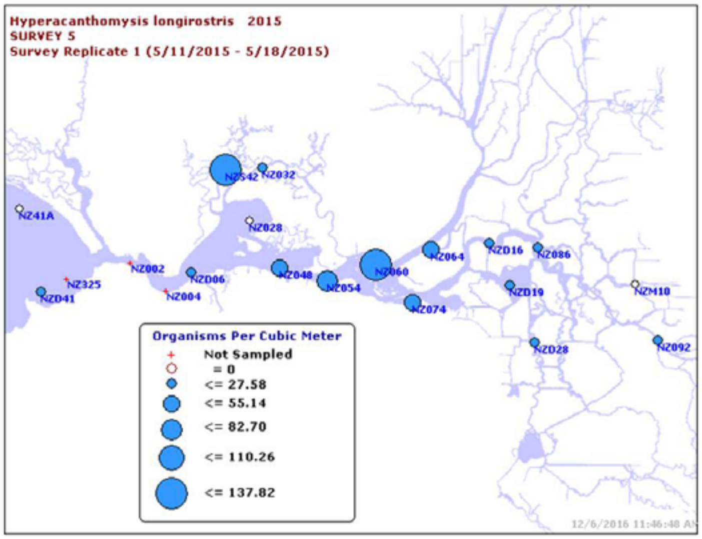
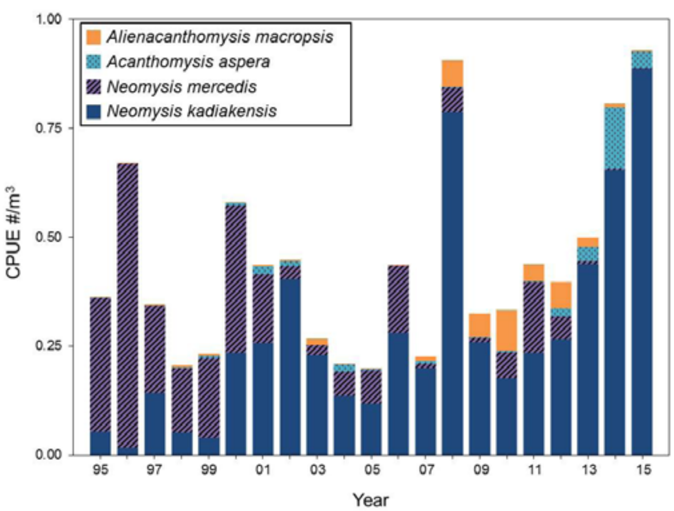
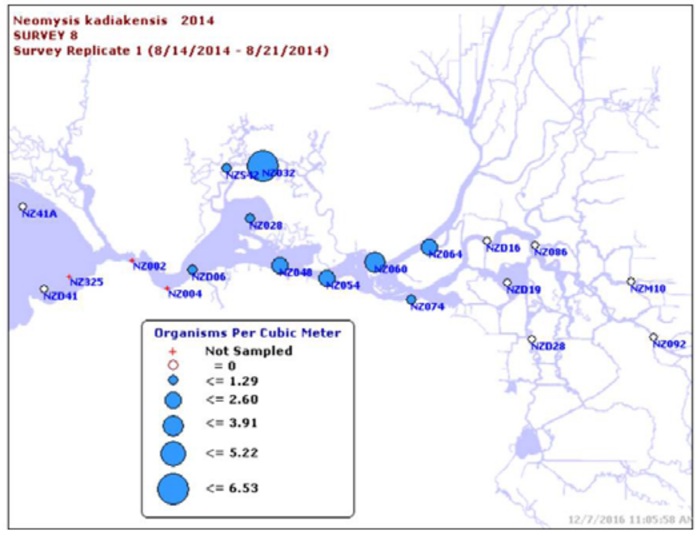



**Figure 18 Annual March-November mean mysids CPUE (catch-per-unit-effort in number m$^{-3}$) from the Zooplankton Study's mysid net for the lesser abundant mysid species in the upper San Francisco Estuary from 1995 through 2015.**




presented here for the first time (figures 16 and 18). In 2014, mean annual abundance was the highest ever recorded for *A. aspera* (Figure 18). Although abundance is usually highest in fall, from 2013 through 2015 abundance was highest in summer (Table 3). Spring abundance from 2013 through 2015 was higher than the mean spring abundance from 1995 through 2012 (Table 3). From 2013 through

**Figure 19 Map of *Neomysis kadiakensis* abundance and distribution from the Zooplankton Study's mysid samples from August 2014, which had the highest abundance of any survey during 2013 through 2015.**




2015, *A. aspera* was found year round in Carquinez Strait and occasionally in low numbers in Suisun Bay. Peak abundance from 2013 through 2015 occurred in July 2014 (Figure 20).

*Alienacanthomysis macropsis* is a native brackish-water mysid usually found in San Pablo Bay and Carquinez Strait that was consistently enumerated by this study starting in 1995. *A. macropsis* was not common in the sampling area until recently, and therefore indices were not reported until 2007. *A. macropsis* was the fourth-most abundant mysid from 2013 through 2015, although it was less abundant than it had been from 2008 through 2012 (figures 16 and 18). *A. macropsis* is most abundant in winter (Table 3), and from 2013 through 2015 abundance peaked in winter in Carquinez Strait and Suisun Bay. Peak abundance from 2013 through 2015 occurred in February 2014 in Suisun Bay (Figure 21).

*Neomysis mercedis*, although historically abundant before 1994, was one of the least abundant mysids from 2013 through 2015 (figures 16 and 18). *N. mercedis* was most abundant in spring and summer, as it was historically, but spring and summer abundance from 2013 through 2015 were much lower than the mean spring and summer abundance

**Figure 20 Map of *Acanthomysis aspera* abundance and distribution from the Zooplankton Study's mysid samples from July 2014, which had the highest abundance of any survey during 2013 through 2015.**

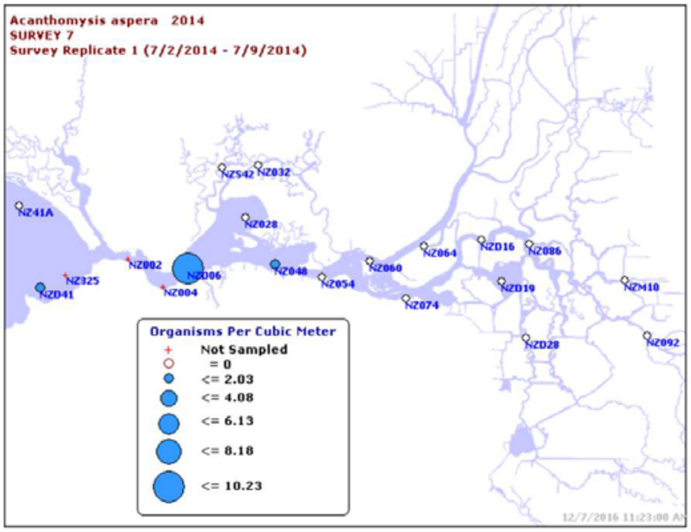
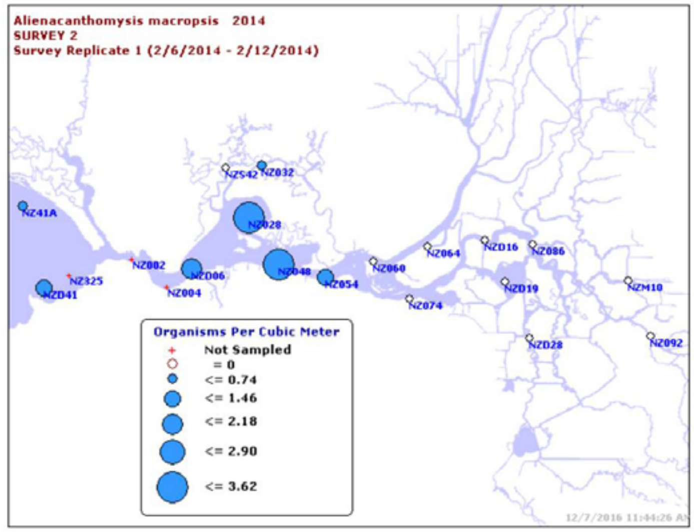



**Figure 21 Map of *Alienacanthomysis macropsis* abundance and distribution from the Zooplankton Study's mysid samples from February 2014, which had the highest abundance of any survey during 2013 through 2015.**




from 1995 through 2012 (Table 3). Since 1996, mean seasonal abundance has been less than 1 $m^{-3}$ in every season, rendering *N. mercedis* inconsequential as a reliable food source in most open-water areas of the upper estuary.

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# Contributed Papers

## Evaluation of Adding Index Stations in Calculating the 20-mm Survey Delta Smelt Abundance Index

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The California Department of Fish and Wildlife (CDFW) conducts the 20-mm Survey annually to monitor the distribution and abundance of post-larval and juvenile Delta Smelt (*Hypomesus transpacificus*), a State and federally listed species. The survey began in 1995, and in the early 2000s CDFW used this data to develop an annual spring abundance index of young Delta Smelt. This article examines the inclusion of additional stations in determination of the index.

Delta Smelt are exclusively found in the upper San Francisco Estuary (Estuary). The 20-mm Survey samples this region annually from mid-March to early July via biweekly surveys to provide near-real-time data to water managers as outlined in the U.S Fish and Wildlife Service (USFWS) biological opinion (U.S. Fish and Wildlife Service 2008). The 20-mm Survey provides spatial and temporal data for young of the year (YOY) Delta Smelt, and generates an index of relative abundance. The index is calculated and distributed each year to provide a means of comparing annual changes in the Delta Smelt population.

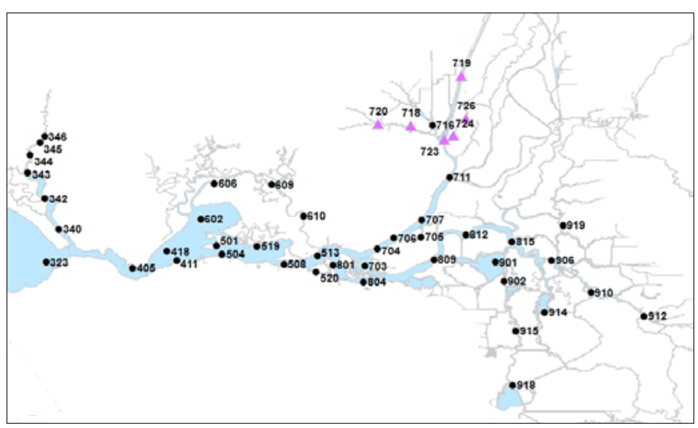
The index calculation uses data from 41 index stations, which are stations that have been routinely sampled since the inception of the Survey (Figure 1). In 2008, six stations in the north Delta were permanently added to the routine sampling regime, but in order to maintain consistency, data from these stations has not been included in the index calculation. Since 2008, 25–84 percent of the annual Delta Smelt catch has occurred at these non-index stations, with the highest proportions observed during drought years (Figure 2). Delta Smelt tend to spawn and rear further upstream during drought years (Wang 2007), as reflected in 20-mm Survey catches (Morris 2016). Recent low Delta Smelt catches, particularly at historic index stations, prompt an increasing need to understand Delta Smelt use of all regions of the estuary. This pattern asks the question, "How would the annual Delta Smelt index be affected if data from these non-index stations were included in the calculation?"

The index is calculated by summing the geometric means of Delta Smelt catch-per-unit-effort (CPUE) over four selected surveys (see steps below). To begin, the mean length of Delta Smelt is calculated for each survey. The index is composed of the two surveys just before and the two surveys just after the average fork length of Delta Smelt has reached 20 mm. The timing of this index period varies annually, but is always composed of the four surveys when YOY Delta Smelt are most efficiently retained by the gear. Once the index period is identified, the geometric mean is calculated for each of these four surveys. This is done taking the following steps:

For each of the four identified surveys:

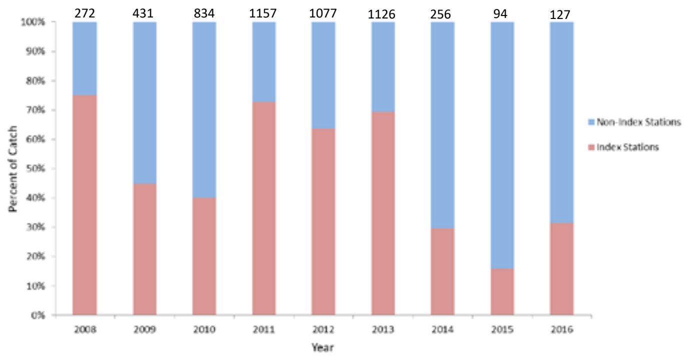
1. Calculate the Delta Smelt CPUE for each of the 41 index stations sampled as number

**Figure 1 The 2016 CDFW 20-mm Survey station map, showing current routine sampling locations in the upper San Francisco Estuary.**




Note: Stations marked with a black dot are index stations. Stations marked with a purple triangle are non-index stations.

**Figure 2 The proportion of Delta Smelt catch at index stations and non-index stations by year.**




Note: Data includes all surveys and annual catch is listed above the graph. Non-index stations have been sampled regularly since 2008.

of fish per 10,000 cubic meters of water sampled.

2. Add 1 to each station CPUE value and $\log_{10}$ transform the data.
3. Average all $\log_{10}$ transformed data in a survey to obtain one value.
4. Calculate the geometric mean of the survey by taking the back transformation of the single value and subtracting 1.

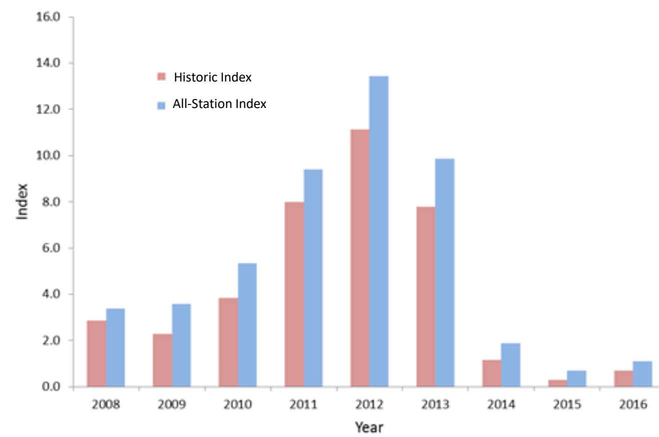
The annual index is the sum of these four geometric means.

Non-index stations were incorporated into the index calculation by making a single adjustment to the calculation. This was done by first calculating the Delta Smelt CPUE for all 47 routinely sampled stations, instead of just the 41 index stations. Then, the geometric mean was calculated for all routine stations sampled during each survey using the same equations described above (steps 2–4). For the purposes of this article, we define the index calculated with the 47 routinely sampled stations as the *all-station index*, and the index calculated with 41 index stations as the *historic index*.

I investigated how well the historic index can predict the all-station index for the 2008–2016 period. Specifically, I used least squares regression with the historic index as the independent variable and the all-station index as the dependent variable to examine the amount of variance explained by the coefficient of determination.

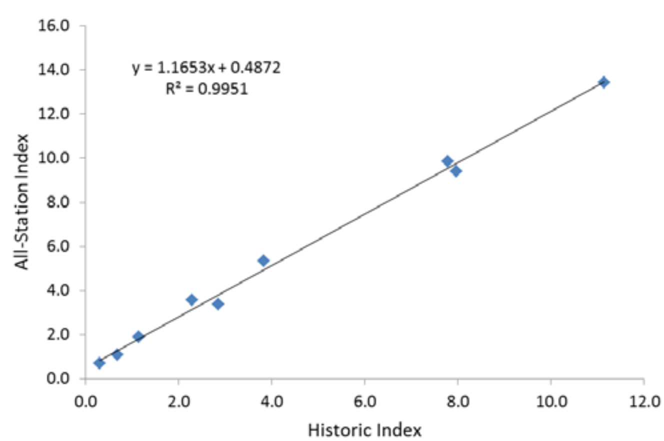
When all routinely sampled stations (n = 47) are incorporated into the index calculation, the index increases each year, but the overall trend does not change (Figure 3). For years 2008–2016, the results of the regression analysis revealed the dependent variable (historic index) could explain 99.5 percent of the variance in the all-station index (Figure 4) ($R^2 = 0.9951$, n = 9, P = < 0.0001). On average, the all-station index added a value of 1.2 to the historic index (Table 1). The percent change between the historic index and the all-station index was greatest during the drought years of 2014, 2015, and 2016, which may suggest that a higher proportion of Delta Smelt spawned and reared in the North Delta under those conditions.

**Figure 3 The historic index and the all-station index calculated for each year.**




Note: Non-index stations have been sampled regularly since 2008.

**Figure 4 Scatterplot of the annual historic index and the annual all-station index.**




Note: Non-index stations have been sampled regularly since 2008.

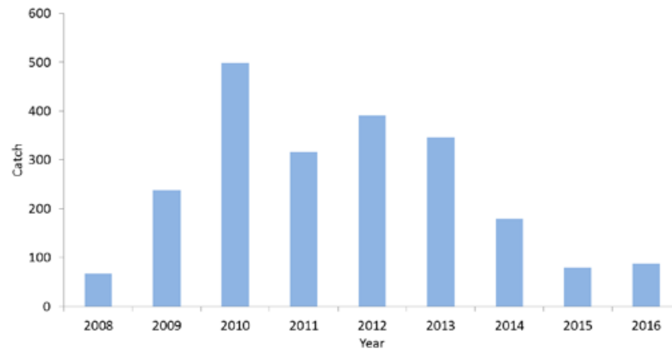
Table 1 Annual difference and percent change between the historic index and the all-station index.

| Year | Historic Index | New Index | Difference | Percent Change |
|---|---|---|---|---|
| 2008 | 2.9 | 3.4 | 0.5 | 18.7 |
| 2009 | 2.3 | 3.6 | 1.3 | 56.0 |
| 2010 | 3.8 | 5.3 | 1.5 | 39.0 |
| 2011 | 8.0 | 9.4 | 1.4 | 17.9 |
| 2012 | 11.1 | 13.4 | 2.3 | 20.5 |
| 2013 | 7.8 | 9.9 | 2.1 | 26.7 |
| 2014 | 1.1 | 1.9 | 0.7 | 65.1 |
| 2015 | 0.3 | 0.7 | 0.4 | 132.6 |
| 2016 | 0.7 | 1.1 | 0.4 | 60.6 |

Delta Smelt are regularly observed in the North Delta. In recent years, we have seen higher proportions of annual Delta Smelt catch at non-index stations; however, annual total Delta Smelt catch at these stations has generally decreased since 2012 (Figure 5). During the time of sampling, Delta Smelt abundance has decreased throughout the Estuary, but this decrease has been less extreme in the North Delta, including our non-index stations (Morris 2016). This suggests that Delta Smelt are likely facing similar, but possibly less extreme, challenges in the North Delta as they are throughout the Estuary during this time period.

Our data confirm that the use of historic 20-mm Survey index stations continues to be an appropriate way of calculating the annual Delta Smelt abundance index. Our current method allows for consistent calculations across the history of the survey, while simultaneously capturing the trends we see across the entire survey area. Because of the stability of

Figure 5 Delta Smelt catch at non-index stations by year.




Note: Non-index stations have been sampled regularly since 2008.

the overall trend in both index calculations, the interpretation of the annual 20-mm index does not change when non-index stations are included in the calculation. This suggests that the current index calculation is a good metric for describing annual abundance trends across the Estuary, as it is not heavily influenced by the exclusion or inclusion of north Delta stations.

More information on the 20-mm Survey methods, protocols, prior year indices, and data are available on our webpage: https://www.wildlife.ca.gov/Conservation/Delta/20mm-Survey.

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# Evaluating Potential Impact of Fish Removal at the Salvage Facility as part of the Delta Smelt Resiliency Strategy

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## Introduction

Because of the severe decline of Delta Smelt (*Hypomesus transpacificus*) abundance indices in recent years, the California Natural Resources Agency (CNRA) developed the Delta Smelt Resiliency Strategy document that proposed several actions designed to improve the status of this imperiled species (California Natural Resources Agency 2016). One of the proposed actions in the Delta Smelt Resiliency Strategy is to adjust summer fish salvage operations at the California's State Water Project (SWP) and Central Valley Project (CVP) export facilities. The purpose of this action is to reduce the numbers of predators and competitors for Delta Smelt. The SWP and CVP export facilities, operated by the California Department of Water Resources and U.S. Bureau of Reclamation respectively, divert water from the Sacramento-San Joaquin Delta (Delta) for agricultural and urban uses. In order to minimize impacts on fishes at these pumping facilities, fish collection facilities were constructed at both sites so that entrained fish can be collected and returned into the Delta (hence, fish are "salvaged"). The CNRA (2016) proposed that the California Department of Water Resources and the U.S. Bureau of Reclamation evaluate a potential change to these operations. Specifically, the CNRA suggested that the water agencies should consider the feasibility of not returning salvaged non-native fish back into the Delta during the summer and fall, when few native or sensitive species are present. The removal of these non-native fishes from the Delta is presumed to be beneficial to Delta Smelt because non-native fish species can be competitors and/or predators of Delta Smelt.

Direct removal of competitor or predator species is one tool that may aid the recovery of native species; however, such management action comes with many uncertainties and can often be difficult to implement given regulatory and logistical constraints (Mueller 2005). Even if we assume that predation and competition are both major drivers in the decline of Delta Smelt, effects of non-native species removal may be small or negligible unless a substantial proportion of the problem species can be removed from the system (Beamesderfer 2000). Furthermore, it may be expensive and logistically challenging to isolate non-native fishes from the pool of salvaged fish, particularly if an additional goal of the process is to save native fishes. In this article, we conducted a few exploratory analyses using the SWP and CVP salvage facility datasets in the hope that it would inform the decision making process for a possible fish removal effort. Specifically, we examined the amount of biomass that could potentially be removed through the action. Based on initial discussions with fisheries managers, we assumed that the action might occur during July–September, when federal and State-listed fish species are largely absent from the South Delta. We focused on biomass rather than fish count because we reasoned that biomass would be a more appropriate metric to evaluate the ecosystem impact of fish removal.

## Methods

Fish data collected from the salvage facilities was acquired from the California Department of Fish and Wildlife (http://www.dfg.ca.gov/delta/apps/salvage/). Only data collected between January 1993 and December 2015 was considered for our analysis to minimize bias from past operational and structural changes (Morinaka 2013). A couple of months of data from the CVP salvage facility were removed prior to the analysis: December of 1998 because of the lack of any length measurements and June of 2006 because of an unusually high number of Common Carp, *Cyprinus carpio* (over a million fish counted).

Individual fish length was converted into biomass by using species length-weight equations found in

Schneider et al. (2000), Kimmerer et al. (2005), and Nobriga et al. (2006) per Mahardja et al. (2017). For those species not found in Mahardja et al. (2017), we assigned the most appropriate species length-weight equation from Schneider et al. (2000) and Kimmerer et al. (2005) (Table 1). Because not all fish recorded at the salvage facilities were measured for length, we divided the dataset into different species, facilities (SWP or CVP), and months, and subsequently multiplied the biomass of measured fish with the total fish count/measured fish count ratio. Each month's biomass calculation was then grouped by species status (native vs. non-native) and then averaged across years to assess the impact of summer–fall fish removal on native fishes relative to non-native fishes. We also calculated total biomass adjusted by effort for each month in kilograms per 1,000,000 cubic meters ($m^3$) to see if they vary from the unadjusted total biomass estimates (hereafter referred to as biomass per volume).

With the exception of Striped Bass *Morone saxatilis* (Loboschefsky et al. 2012), there are no total biomass estimates for non-native fish species in the upper San Francisco Estuary. In the absence of comprehensive data on non-native fish biomass, we therefore used the San Francisco Estuary Striped Bass population to provide an indication of how fish removal at salvage facilities might affect the populations of non-native fishes of the upper San Francisco Estuary. We therefore compared our salvage biomass estimates with biomass numbers calculated by Loboschefsky et al. (2012), who quantified the total abundance and biomass of the San Francisco Estuary Striped Bass population between 1969 and 2004. For the years with completely overlapping data between Loboschefsky et al. (2012) and ours (1993–2003), we calculated the total biomass of Striped Bass alone and for all non-native fish species captured in the hypothetical target months (July to September).

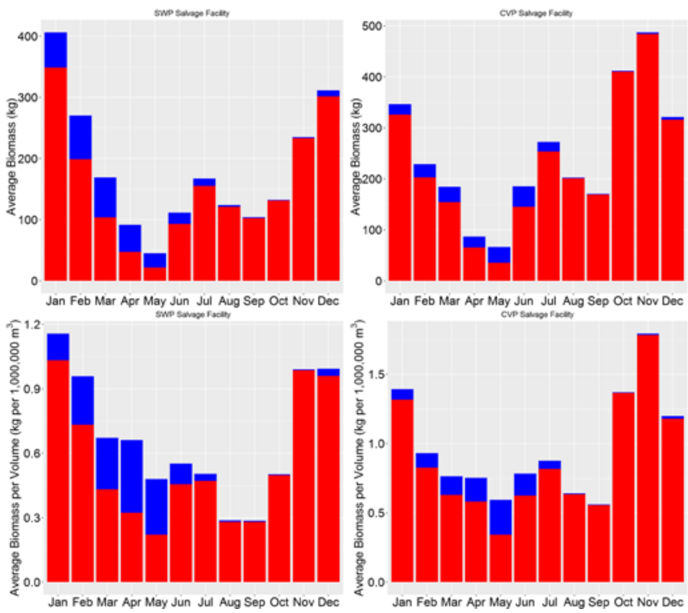
**Table 1 List of length-weight equations used for all species not listed in Mahardja et al. (2017) and their native/non-native status.**

| *Common Name* | *Species* | *Length-Weight Equation Used* | *Native?* |
|---|---|---|---|
| Blue Catfish | *Ictalurus furcatus* | Schneider et al. 2000 (Channel Catfish, *Ictalurus punctatus*) | No |
| California Roach | *Lavinia symmetricus* | Kimmerer et al. 2005 (Sacramento Splittail, *Pogonichthys macrolepidotus*) | Yes |
| Chinook Salmon | *Oncorhynchus tshawytscha* | Kimmerer et al. 2005 (Chinook Salmon) | Yes |
| Green Sturgeon | *Acipenser medirostris* | Schneider et al. 2000 (Lake Sturgeon, *Acipenser fulvescens*) | Yes |
| Lamprey (unknown) | *Lampetra* spp. | Schneider et al. 2000 (*lamprey ammocoete*) | Yes |
| Pacific Herring | *Clupea pallasii* | Kimmerer et al. 2005 (Pacific Herring) | Yes |
| Pacific Lamprey | *Lampetra tridentata* | Schneider et al. 2000 (lamprey ammocoete) | Yes |
| Pumpkinseed | *Lepomis gibbosus* | Schneider et al. 2000 (Pumpkinseed) | No |
| Rainbow Trout / Steelhead | *Oncorhynchus mykiss* | Schneider et al. 2000 (Rainbow Trout) | Yes |
| Riffle Sculpin | *Cottus gulosus* | Kimmerer et al. 2005 (Prickly Sculpin, *Cottus asper*) | Yes |
| Sacramento Perch | *Archoplites interruptus* | Schneider et al. 2000 (Black Crappie, *Percina macrolepida*) | Yes |
| Striped Mullet | *Mugil cephalus* | Kimmerer et al. 2005 (Striped Bass, *Morone saxatilis*) | Yes |
| Surf Smelt | *Hypomesus pretiosus* | Kimmerer et al. 2005 (Delta Smelt, *Hypomesus transpacificus*) | Yes |
| White Sturgeon | *Acipenser transmontanus* | Schneider et al. 2000 (Lake Sturgeon, *Acipenser fulvescens*) | Yes |
| Yellow Bullhead | *Ameiurus natalis* | Schneider et al. 2000 (Bullhead) | No |

## Results

Fish biomass data showed strong seasonal patterns for both facilities (Figure 1). Overall, both CVP and SWP salvage facilities showed similar patterns of higher total biomass and biomass per volume numbers in the late-fall to winter months and lower numbers in the summer and early-fall months. The increased biomass in late-fall and winter months is likely a result of the larger-sized fish being more common during these months (Figure 2). When total biomass for all months are added together, the July to September period encompass 18.2 percent and 21.8 percent for SWP and CVP salvage facilities, respectively (Figure 3). The biomass of Striped Bass at the salvage facilities in the summer and fall months between 1993 and 2003 represents a very small fraction of annual estuary-wide biomass estimates for this predator species (Table 2). Even when the biomass for all non-native fishes during the July–September time frame are considered, these seasonal totals never reached 1 percent of the Loboschefsky et al. (2012) Striped Bass biomass estimates for each of the same years.

**Figure 1 Average biomass and biomass per volume observed at the salvage facilities between 1993 and 2015, grouped by native/non-native(introduced) status.**




Note: The color red represents non-native fish species; the color blue represents native fish species.

## Discussion

In the summer–fall months (July to September), the salvage facilities typically collect less than a quarter of their annual biomass totals. This is because the salvage facilities typically see mostly juvenile fishes in the summer and early-fall months and accrue most of their biomass during the late-fall and winter months when larger-sized fishes are observed (Figure 1, Figure 2). Nonetheless, our results also suggest that the amount of biomass that could be removed during the proposed July–September salvage period is relatively modest.

Given that the 1993–2003 biomass numbers seen at the salvage facilities is but a fraction of the total biomass estimated for the San Francisco Estuary Striped Bass population (Table 2), it appears unlikely that the fish removal action will have a population-level impact for the non-native fish species.

**Figure 2 Boxplot of monthly biomass per fish observed at the salvage facilities between 1993 and 2015.**

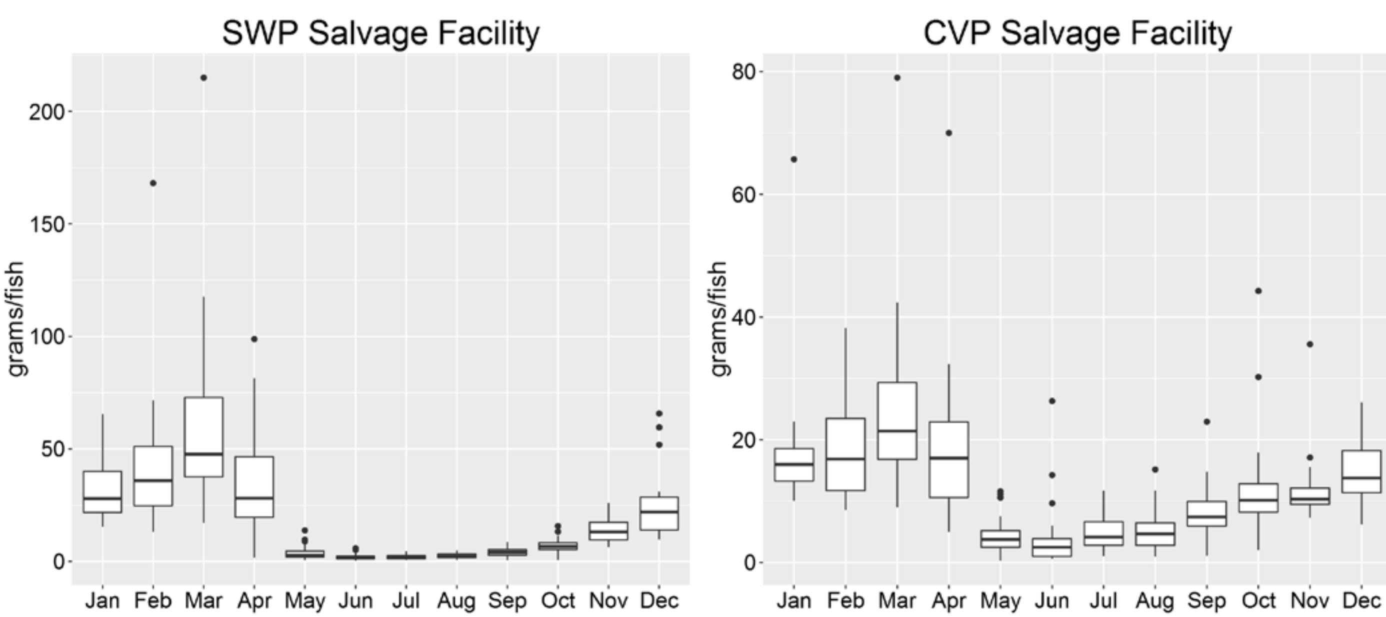


**Figure 3 Percentage of total annual biomass from 1993 to 2015 that comes from the months between July and September.**

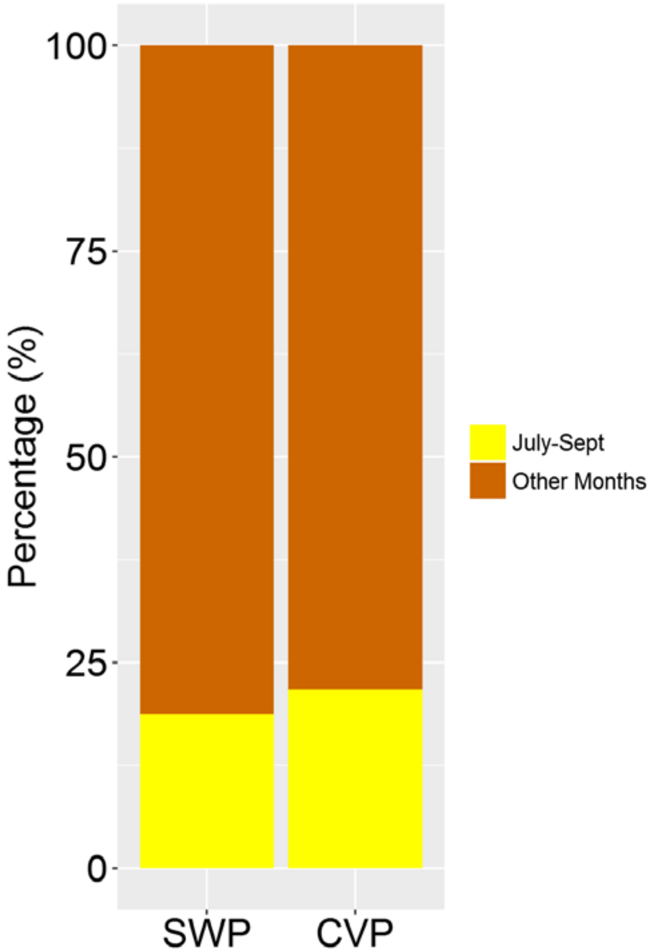



**Table 2 Biomass observed at the salvage facilities compared to the estimated total biomass of the San Francisco Estuary Striped Bass population per Loboschefsky et al. (2012).**

| Year | Loboschefsky et al.'s (2012) Striped Bass total biomass estimates | Biomass of Striped Bass at SWP facility (Jul–Sep) | Biomass of Striped Bass at CVP facility (Jul–Sep) | Biomass of all non-native fishes at SWP facility (Jul–Sep) | Biomass of all non-native fishes at CVP facility (Jul–Sep) |
|---|---|---|---|---|---|
| 1993 | 1,975,864 | 17.3 | 49.1 | 494 | 1,110.5 |
| 1994 | 1,888,764 | 13.3 | 18.3 | 260.7 | 443.8 |
| 1995 | 1,969,953 | 8.7 | 146.1 | 278.7 | 1,616.3 |
| 1996 | 3,483,034 | 15.8 | 21.3 | 377.4 | 743.7 |
| 1997 | 3,922,572 | 9.9 | 13.9 | 213.4 | 502.7 |
| 1998 | 4,094,065 | 6.4 | 41.5 | 289 | 2,116.5 |
| 1999 | 4,243,211 | 25.3 | 16.1 | 873.5 | 827.4 |
| 2000 | 4,703,630 | 25.8 | 15.6 | 923.7 | 555 |
| 2001 | 3,641,749 | 5.8 | 14.3 | 285.6 | 594.4 |
| 2002 | 3,197,359 | 6.2 | 17.5 | 272.2 | 606.3 |
| 2003 | 2,526,521 | 10.0 | 22.5 | 793.6 | 399.1– |

Note: All values are in kilograms (kg).

Nonetheless, we acknowledge that we did not consider any potential local effects of the proposed action and that some localized, beneficial impact on native fishes such as the Delta Smelt remains a possibility. Similarly, it is possible for another non-native fish species with much smaller population size or biomass than the Striped Bass to be impacted by the fish removal effort. We also did not assess the potential of cumulative impact on non-native fishes from several consecutive years of removal at the salvage facilities.

Our hope is that the results of our analyses can help elucidate some of the risks and potential impacts of the CNRA's (2016) proposed fish removal effort.

There is little doubt that predation and competition with non-native fishes contribute to the decline of native fish species of the Delta. Nonetheless, aside from a few studies of predation removal effect on Chinook Salmon survivorship (Cavallo et al. 2012; Demetras et al. 2016; Sabal et al. 2016), there is little information on the potential impact of fish removal in the Delta (Grossman et al. 2016). Additional studies will be required in order to determine the success of the proposed fish removal effort, but such studies are likely to be faced with many challenges given that Delta Smelt have become increasingly rare and difficult to detect in recent years (Interagency

Ecological Program Management Analysis and Synthesis Team 2015; Damon 2016).


## Acknowledgements

We thank all staff members from the various agencies that have worked on the SWP and CVP fish salvage monitoring programs. We thank Erik Loboschefsky for providing data from his study for our Striped Bass biomass comparison. We are also grateful to Brian Schreier, Jerry Morinaka, and Vanessa Tobias for their comments and suggestions that improved this article. The viewpoints expressed in this article are those of the authors and do not necessarily represent the views of the California Department of Water Resources.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# Do Longfin Smelt Spawn in San Francisco Bay Tributaries?

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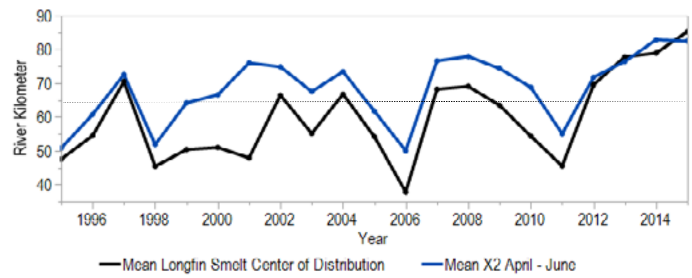
## Introduction

Surveys conducted as part of the Interagency Ecological Program (IEP) and other monitoring programs have shown evidence suggesting Longfin Smelt may utilize tributaries in the North Bay and South Bay as spawning and larval rearing habitat; however, the frequency and magnitude of the contribution of tributary spawning to adult abundance and year-class strength is currently unknown (Baxter 1999). The California Department of Fish and Wildlife (CDFW), as part of the IEP monitoring program, currently samples larval Longfin Smelt (the Smelt Larval Survey) bi-weekly from January through March, and juvenile Longfin Smelt (20-mm Survey) from March through June in the Sacramento-San Joaquin Delta (Delta) and Suisun Bay. The 20-mm survey has few stations in San Pablo Bay, and these are only expanded during wet years, but the Napa River has been sampled more consistently since 2002 as part of expanded monitoring efforts for Longfin Smelt. Catch data from CDFW 20-mm surveys suggests that Longfin Smelt successfully spawn in the Napa River and that larvae and juveniles may be distributed downstream of the fixed stations in San Pablo Bay during wet years (Parker et al 2016) (Figure 1). Consequently, current monitoring programs may underestimate the abundance and spatial distribution of larval and juvenile Longfin Smelt when the Low-Salinity Zone nursery habitat is located in San Pablo Bay.

A more complete understanding of the geographic extent of the population at each life stage, and how various factors may influence abundance, is needed to inform more effective management and protection of the species (Cowin and Bonham 2013). In a broad context, this understanding is critically important

**Figure 1 CDFW 20-mm yearly longfin smelt catch mean center of distribution in river kilometers (black) and mean X2 for April through June for each year (blue).**




Note: For geographical reference, Port Chicago is represented by the dashed line at 64 river km.

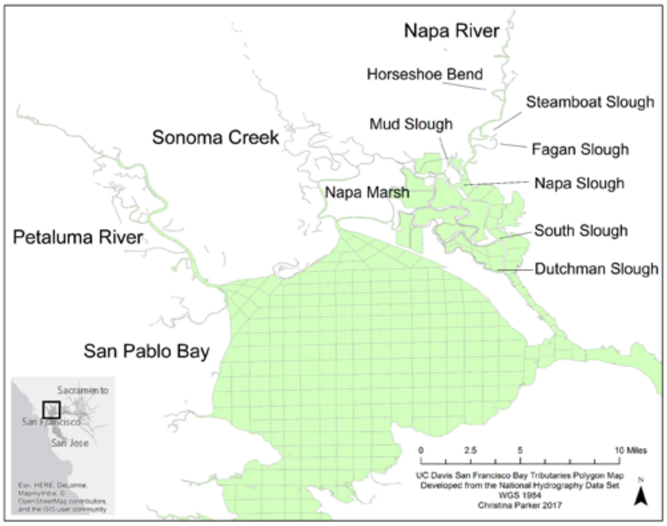
for guiding management actions designed to provide resilience to the population. Furthermore, this information is important for managing freshwater exports in the South Delta and assessing freshwater flow and abundance mechanisms for Longfin Smelt. For example, if Longfin Smelt utilize the Napa River for spawning, offspring would be less susceptible to entrainment in the South Delta and likely more strongly influenced by rearing conditions in the Low-Salinity Zone. Furthermore, flows from smaller tributaries (e.g., the Napa, Sonoma, and Petaluma watersheds) may be important to Longfin Smelt population dynamics. A more complete assessment of the spatial distribution of early life stages could elucidate mechanisms driving recruitment success, particularly during wet years when recruitment success is greater.

To provide a more complete assessment of the spatial distribution and spawning habitats of Longfin Smelt, we sampled tributaries of the San Francisco Bay Estuary, downstream of the legal Delta, to document the relative abundances of adult, larval, and juvenile Longfin Smelt. Surveys were conducted in 2015 and 2016 in both the Northern (Napa River, Sonoma Creek, Petaluma River, and San Pablo Bay) (Figure 2) and Southern (Coyote Creek and Alviso Slough) regions and tributaries of San Francisco Bay (Figure 3).

## Methods

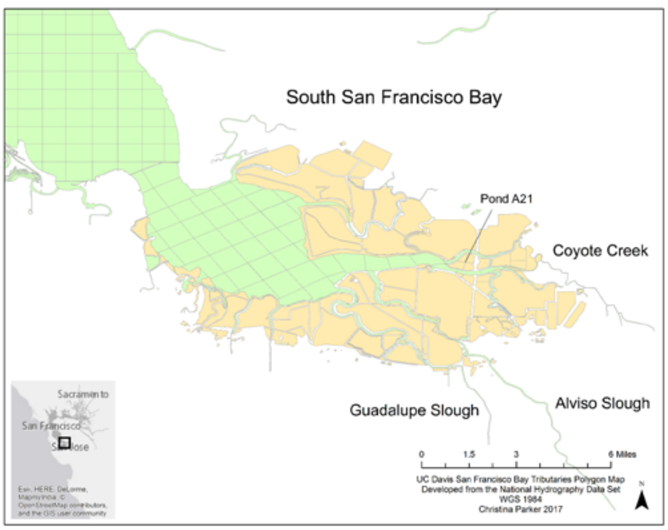
The Hobbs Lab at University of California, Davis (UCD) used CDFW's Smelt Larval Survey (SLS) and

**Figure 2 North San Francisco Bay tributary map of UCD Study area.**




Note: The study area was broken into 1000-meter (approximately) polygons.

**Figure 3 South San Francisco Bay tributary map of UCD Study area.**




Note: The study area was broken into 1000-meter (approximately) polygons.

20-mm survey nets to sample larvae and juveniles in North Bay tributaries. Sample sites were stratified across salinity zones (fresh, 1–3, 4–6, 7–9 and > 10 parts per thousand) to assure coverage of salinity parameters where CDFW previously located Longfin Smelt larvae. We created polygons drawn to 1000 river meters in ArcMap, and when salinity was similar throughout a tributary, we randomly sampled areas using those pre-defined regional polygons (Figure 2), ensuring both spatial and environmental coverage of potential nursery habitats. In 2015, UCD SLS survey began the first week of January and ran through April 2015. The following larval season, UCD SLS survey began the third week of December 2015 and ran through the end of February 2016, while the 20-mm survey was conducted from the first week of March through early June. Note that our 20-mm survey was only conducted in 2016.

### *Water Quality*

Water quality measurements were taken using a YSI 6600 V2 Multi-Parameter Water Quality Sonde deployed at the top and the bottom of the water column. The sonde was programed to measure salinity in parts per thousand (ppt), specific conductance in microSiemens per centimeter (µS/cm), acidity in potential of hydrogen (pH), dissolved oxygen saturation as a percentage (%), dissolved oxygen in milligrams per liter (mg/l), and water clarity in nephelometric turbidity units (NTU). Additionally, Secchi, trawl depth, tide, and tide height were also recorded. During each daily survey, water quality was measured prior to tows, typically from areas adjacent to launch locations. From that measured value we traveled upstream or downstream in search of salinity zones, often requiring stopping in adjacent polygons to measure water quality parameters.

### *Larval and Juvenile Longfin Smelt*

The UCD SLS and 20-mm nets are both conical icthyoplankton nets attached to D-shaped rigid-frames mounted to skis. The smelt larvae sled has a 500-micron mesh net that is 3.35 meters long with a 0.37 square meter mouth area. The 20-mm weighted sled has a 1600-micron mesh net that is 5.1 meters long with a 1.51 square meter mouth area. In addition, we also conducted monthly sampling with a conical plankton net (mysid net) with 250-micron mesh and a 0.2 square meter mouth area attached to a metal sled. All nets terminate in a 1-liter cod-end jar. Each net also has a Clarke-Bumpus (CB) net with 160-micron mesh attached to the top of the frame for zooplankton sampling. All three nets were towed against the prevailing current for 10 minutes in a stepped oblique fashion based on CDFW protocols. Once the tow was complete, the sample was checked for any fish or organisms that could be identified in the field. These were immediately counted, measured and returned to the water. The remaining sample was preserved in 95 percent ethyl alcohol (10 percent formalin in 2015) and returned to the lab for sorting and identification. To assure detection of all Longfin Smelt (LFS), Smelt Larval Survey (SLS) and 20 millimeter survey (20-mm) samples were processed in their entirety without splitting or subsampling. All fish were identified to the lowest possible taxonomic level, usually to the species level, counted, and then 30 randomly chosen individuals of each species were measured in millimeters for total length (TL). Individuals identified as Longfin Smelt in the 2016 surveys were genetically identified using single nucleotide polymorphisms (SNPs) by the Genomic Variation Lab at UCD. Note that this was not done in 2015, as samples were preserved in formalin which is not compatible with methods used by the Genomic Variation Lab.

### *Adult Surveys (Otter Trawl)*

To sample sub adult and adult (fish larger than 38 mm standard length) Longfin Smelt we used an otter trawl with a 1.5 meter by 4.3 meter opening, length of 5.3 meters, and mesh size of 3.5 centimeters in the body and 0.6 centimeters in the cod end. The otter trawl was deployed and towed against the prevailing tide at a speed of approximately 5 kilometers per hour for 10 minutes in sloughs and side channels as well as main channels and shoals. Otter trawl surveys were conducted monthly (September–May for Longfin Smelt), with sites stratified over the same relative locations as with the larval and juvenile surveys. All fish were identified to species in the field, counted, and the first 30 individuals measured for standard length (SL). All Longfin Smelt captured were also measured for standard length, total length, and fork-length, photographed, given a unique serial number and preserved in 95 percent ethyl alcohol. In addition, we conducted up to four tows with the mysid net in bay tributaries during our otter trawl surveys to quantify mysid shrimp and larval fishes in bay tributaries year-round.

## Results

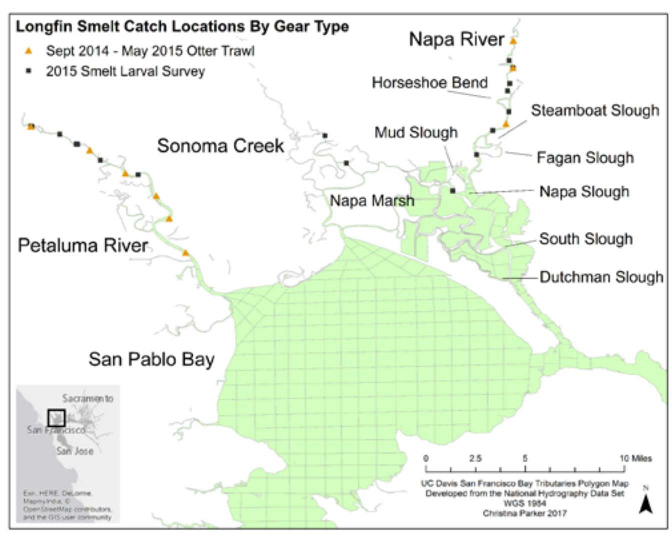
### *Larval Surveys (SLS and Mysid Surveys)*

In 2015, we conducted seven larval cruises from January 3, 2015–April 23, 2015, completing a total of 145 tows in North and South Bay tributaries to the San Francisco Bay Estuary. We caught a total of 34 Longfin Smelt ranging from 4.4 to 12.2 mm TL. Larval Longfin Smelt were found in the Napa River, Petaluma River, and Sonoma Creek, but no Longfin Smelt larvae were found in South Bay tributaries (Table 1, Figure 4).

In 2016, we conducted seven larval cruises from December 16, 2015–February 24, 2016, completing a total of 140 tows in North Bay. We caught a total of 16 larval Longfin Smelt, ranging in size from 5.2 mm 13.9 mm TL. Longfin Smelt were found in the Napa River and the side sloughs of the Napa Marsh, the Petaluma River, and San Pablo Bay, but again no Longfin Smelt larvae were found in South Bay tributaries (Table 1, Figure 5).

In 2015, no Longfin Smelt were found during the monthly mysid net surveys in the North Bay or South Bay tributaries. In 2016, one Longfin Smelt of length 17.1 mm TL was caught in the mysid net in Napa River in Fagan Slough (Figure 5).

**Figure 4 Longfin Smelt catch by gear type for 2014 adult through 2015 juvenile season.**



### *Juvenile Surveys (20-mm Survey & Otter Trawls)*

In March 2015, we captured three juvenile Longfin Smelt (22–28 mm SL) with the otter trawl in the Napa River mainstem below Horseshoe Bend (Figure 4). In 2016, five juvenile Longfin Smelt (22–42 mm SL) were caught in the otter trawl net in the North Bay. Four of the five were caught during the May survey; two in San Pablo Bay, one in South Slough, one in Mud Slough, and one was caught in the April Survey, again in Mud Slough (Table 2).

In 2016, we conducted eight bi-weekly 20-mm cruises from March 1 through June 10, completing a total of 280 tows among the three North Bay tributaries and San Pablo Bay (Table 1). Longfin Smelt were again found in Napa River and side sloughs, Petaluma River, and San Pablo Bay, totaling 38 Longfin Smelt ranging in size from 14.1 to 40 mm TL (Table 1). Several locations on Napa River had Longfin Smelt catch throughout the SLS and 20-mm season in the same polygons (Figure 5).

### *Larval-juvenile Longfin Smelt salinity associations*

Larval Longfin Smelt captured in the SLS surveys were found at salinities ranging from freshwater to 14 ppt, the median for 2015 was 6.0 ppt while the 2016 median was 2.4 ppt. Post-larval to juvenile stage fish in the 20-mm survey were found in freshwater up to 19.1 ppt, and the median was 5.4 ppt (Figure 6). Larvae and juveniles occurred at similar salinities up to 30 mm TL, with one individual at 40 mm occurring in 18 ppt, and one individual at 27.0 mm in 19.05 ppt (Figure 7). The proportion of total catch by salinity zone varied

**Table 1 UCD SLS and 20-mm surveys tows, Longfin Smelt catch, and average total length (TL) for 2015 and 2016 seasons by date and location.**

| *SLS* | | *Alviso* | | | *Napa* | | | *Petaluma* | | | *Sonoma* | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Year* | *Month* | *Tows* | *Catch* | *Avg TL* | *Tows* | *Catch* | *Avg TL* | *Tows* | *Catch* | *Avg TL* | *Tows* | *Catch* | *Avg TL* |
| 2015 | Jan | 15 | 0 | | 11 | 7 | 8.2 | 9 | 7 | 8.2 | 4 | 0 | |
| 2015 | Feb | 16 | 0 | | 11 | 4 | 7.8 | 9 | 6 | 7.6 | 8 | 3 | 9.6 |
| 2015 | Mar | 20 | 0 | | 16 | 5 | 9.2 | 11 | 2 | 10.4 | 12 | 0 | |
| 2015 | April | NA | | | 3 | 0 | | NA | | | NA | | |
| | | 51 | | | 41 | 16 | | 29 | 15 | | 24 | 3 | |

| *SLS* | | *Alviso* | | | *Napa* | | | *Petaluma* | | | *Sonoma* | | | *San Pablo Bay* | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Year* | *Month* | *Tows* | *Catch* | *Avg TL* | *Tows* | *Catch* | *Avg TL* | *Tows* | *Catch* | *Avg TL* | *Tows* | *Catch* | *Avg TL* | *Tows* | *Catch* | *Avg TL* |
| 2015 | Dec | NA | | | 2 | 0 | | 2 | 0 | | NA | | | NA | | |
| 2016 | Jan | 9 | 0 | | 38 | 1 | 5.2 | 24 | 0 | | 6 | 0 | | 6 | 1 | 7.2 |
| 2016 | Feb | 8 | 0 | | 14 | 13 | 11.6 | 12 | 0 | | 10 | 0 | | 26 | 1 | 7.6 |
| | | 17 | | | 54 | 14 | | 38 | 0 | | 16 | 0 | | 32 | 2 | |
| *20-mm* | | | | | | | | | | | | | | | | |
| *Year* | *Month* | | | | | | | | | | | | | | | |
| 2016 | Mar | NA | | | 29 | 3 | 17.1 | 23 | 0 | | 17 | 0 | | 40 | 0 | |
| 2016 | April | NA | | | 21 | 30 | 21.8 | 20 | 1 | 15.1 | 12 | 0 | | 19 | 2 | 35.6 |
| 2016 | May | NA | | | 23 | 1 | 25.0 | 14 | 0 | | 20 | 0 | | 20 | 1 | 27.0 |
| 2016 | June | NA | | | 2 | 0 | | NA | | | NA | | | 20 | 0 | |
| | | | | | 75 | 34 | | 57 | 1 | | 49 | 0 | | 99 | 3 | |

Note: Tows listed as "NA" were not sampled that month.

**Figure 5 Longfin Smelt catch by gear type for 2015 adult through 2016 juvenile season.**

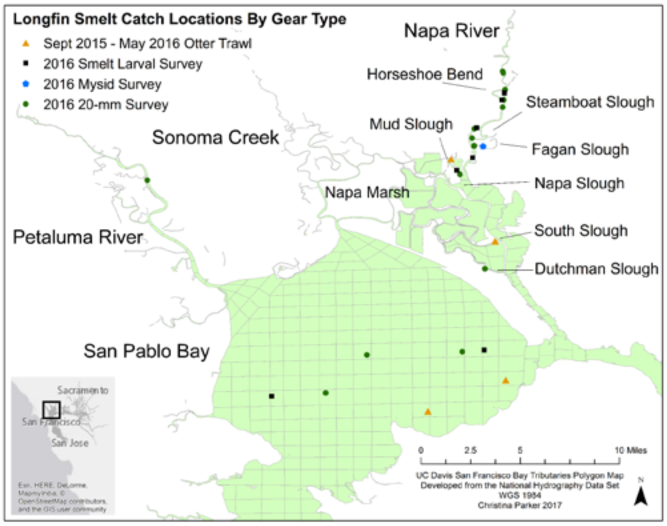
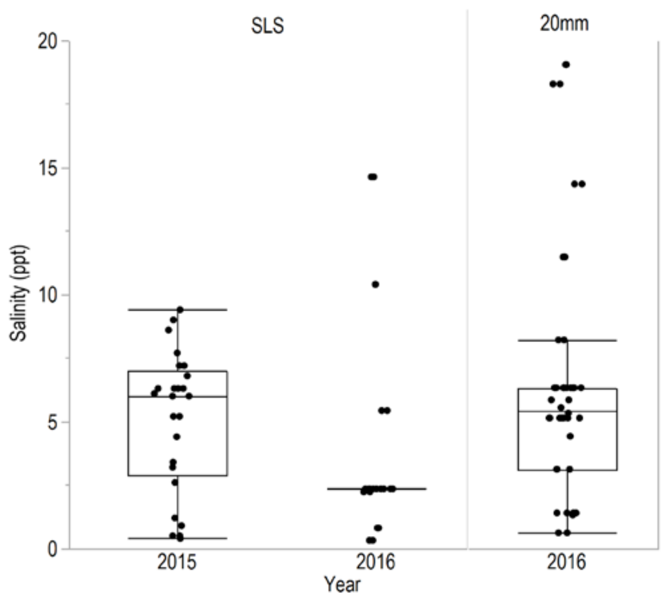


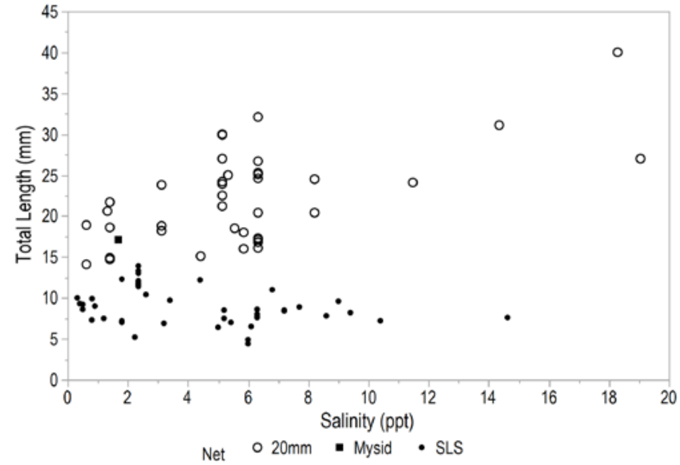

**Figure 6 Box plot of salinity measured for tows with Longfin Smelt in 2015 and 2016 UC Davis SLS Survey and 2016 UC Davis 20-mm Survey.**




Note: Box plots depict the 25–75 percentiles, the bold horizontal line is the median, and dots represent individual fish.

for the SLS and 20-mm Surveys. The SLS survey caught the majority of Longfin Smelt in the 1 to 3 ppt salinity zone, while the 20-mm Survey caught proportionally more fish in the 4 to 6 ppt salinity zone (Figure 8). Fish in the 1 to 3 ppt salinity zone apparently declined or moved to the higher salinity zone between the SLS and 20-mm Survey.

**Figure 7 Relationship between Longfin Smelt total length in millimeter and salinity in parts per thousand for 2016 by net.**




Note: Open circles are 20-mm, black circles are SLS, and the black square is the mysid net.

## *Adult Surveys (Otter Trawl)*

From September 2014 to May 2015, we captured a total of 115 adult Longfin Smelt in South Bay in 209 tows, 79 of which we caught in tidally restored salt ponds along Coyote Creek (Table 2). In a single tow in Pond A21 we caught 31 fish, our largest catch during the study for Longfin Smelt. Fish ranged in length from 50 mm to 113 mm SL, the majority being age 0 fish, with a few individuals age 1+ and one fish 2+. In the North Bay, we caught 13 adult Longfin Smelt, 11 in the Petaluma River and two in the Napa River. In March in Napa River we caught one fish with an SL of 69 mm, as well as three juvenile fish previously mentioned (Table 2). Fish ranged in length from 57 to 85 mm SL and comprised mostly age 0 fish.

In the 2015–2016 survey year, no sub-adult/adult Longfin Smelt were caught in the North Bay, while only 10 sub-adult/adult fish were caught in the Lower South Bay during the survey period (Table 2); however, several individuals were over 100 mm SL, one being a ripe female (Figure 9).

## Discussion

Do Longfin Smelt spawn in tributaries downstream of the legal Delta? Yes. Despite extremely low freshwater outflows from these tributaries during these dry years, adult Longfin Smelt were found in the Petaluma River and Napa River during the spawning season in early 2015. UCD larval surveys in 2015 and 2016 captured larval Longfin Smelt far upstream in the Napa River, Petaluma River, and Sonoma Creek tributaries in low-salinity habitats. Therefore, our data indicate that yes, Longfin Smelt stage and successfully spawn downstream of the Delta; however, given the low numbers, the primary spawning habitat appeared to be the confluence area of the Sacramento and San Joaquin rivers during these dry years. In contrast, preliminary assessments of larval surveys in 2017 suggest larval recruitment in both North Bay and South Bay tributaries during this very wet year, which suggests a potential expansion of suitable spawning habitat bay-wide during wet years.

### *South Bay*

Large numbers of Longfin Smelt, many reaching lengths consistent with reproductive ages and some fish reaching sexual maturity, were found in South San Francisco Bay. Since 2010, we've been monitoring the progress of tidal salt pond restoration

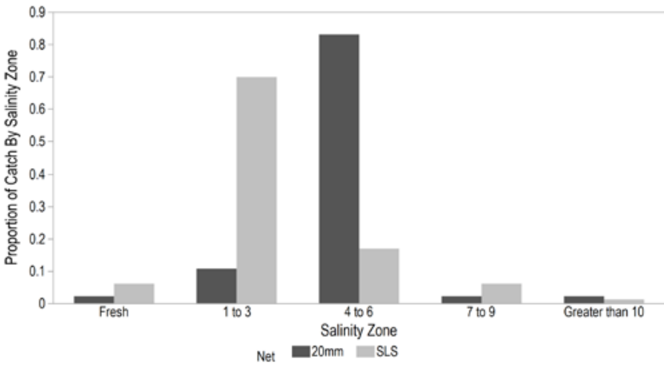
**Table 2 Otter trawl survey tows, Longfin Smelt catch and average standard length (SL) for 2014 to 2016 by date and location.**

| | | *Alviso* | | | *Napa* | | | *Petaluma* | | | *Sonoma* | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ***Year*** | ***Month*** | ***Tows*** | ***Catch*** | ***Avg SL*** | ***Tows*** | ***Catch*** | ***Avg SL*** | ***Tows*** | ***Catch*** | ***Avg SL*** | ***Tows*** | ***Catch*** | ***Avg SL*** |
| 2014 | Sept | 20 | 1 | 52 | NA | | | NA | | | NA | | |
| 2014 | Oct | 17 | 2 | 59 | NA | | | NA | | | NA | | |
| 2014 | Nov | 20 | 15 | 70 | NA | | | NA | | | NA | | |
| 2014 | Dec | 22 | 54 | 81 | NA | | | NA | | | NA | | |
| 2015 | Jan | 27 | 26 | 68 | 4 | 1 | 70 | 7 | 0 | | 2 | 0 | |
| 2015 | Feb | 27 | 15 | 74 | 14 | 0 | | 13 | 5 | 71 | 9 | 0 | |
| 2015 | March | 40 | 2 | 85 | 16 | 4 | 36 | 16 | 6 | 78 | 12 | 0 | |
| 2015 | April | 17 | 0 | | 4 | 0 | | NA | | | NA | | |
| 2015 | May | 19 | 0 | | 10 | 0 | | NA | | | NA | | |
| | | 209 | 115 | | 48 | 5 | | 36 | 11 | | 23 | 0 | |

| | | *Alviso* | | | *Napa* | | | *Petaluma* | | | *Sonoma* | | | *San Pablo Bay* | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ***Year*** | ***Month*** | ***Tows*** | ***Catch*** | ***Avg SL*** | ***Tows*** | ***Catch*** | ***Avg SL*** | ***Tows*** | ***Catch*** | ***Avg SL*** | ***Tows*** | ***Catch*** | ***Avg SL*** | ***Tows*** | ***Catch*** | ***Avg SL*** |
| 2015 | Sept | 21 | 0 | | 9 | 0 | | 8 | 0 | | 8 | 0 | | NA | | |
| 2015 | Oct | 23 | 0 | | 10 | 0 | | 6 | 0 | | 8 | 0 | | NA | | |
| 2015 | Nov | 20 | 0 | | 7 | 0 | | 6 | 0 | | 8 | 0 | | NA | | |
| 2015 | Dec | 20 | 2 | 83 | 8 | 0 | | 8 | 0 | | 8 | 0 | | NA | | |
| 2016 | Jan | 27 | 7 | 98 | 24 | 0 | | 14 | 0 | | 7 | 0 | | 2 | 0 | |
| 2016 | Feb | 29 | 1 | 61 | 10 | 0 | | 7 | 0 | | 4 | 0 | | 8 | 0 | |
| 2016 | March | 20 | 0 | | 7 | 0 | | 8 | 0 | | 7 | 0 | | NA | | |
| 2016 | April | 27 | 0 | | 8 | 1 | 22 | 8 | 0 | | 7 | 0 | | 6 | 0 | |
| 2016 | May | 20 | 0 | | 16 | 2 | 38 | 8 | 0 | | 5 | 0 | | 5 | 2 | 34 |
| | | 207 | 10 | | 99 | 3 | | 73 | 0 | | 62 | 0 | | 21 | 2 | |

Note: Tows listed as "NA" were not sampled that month. The March 2015 Average length in Napa is one Age 0 fish at 69 SL and three juvenile fish at 28, 24, and 23 SL.

**Figure 8 Proportion of each net's catch binned by salinity zone.**



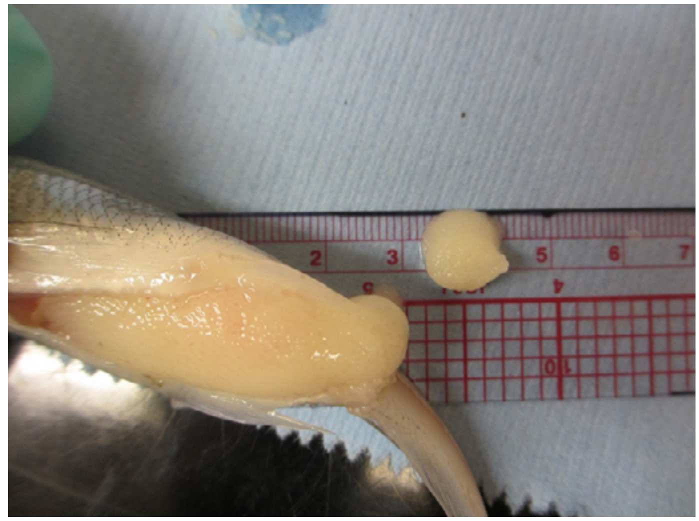

Note: Light gray bars depict the SLS net, dark gray bars depict the 20-mm net.

in the Alviso Marsh, and have been consistently finding Longfin Smelt in similar numbers to those found in 2014–2015, suggesting this area of the estuary may be important for Longfin Smelt. Moreover, a majority of fish captured in the South Bay in 2014–2015 were captured inside these restored salt ponds. From 2010 to 2016, no larval or juvenile Longfin Smelt were found; however, the February and March cruises of 2017 captured over 50 juvenile Longfin Smelt (ranging 20–30 mm TL). Freshwater flows to the Alviso Marsh from the Guadalupe Slough and Coyote Creek are very low in most years, as much of the runoff is captured behind several reservoirs, and what little flows are released are used for groundwater recharge in San Jose. Low-salinity conditions < 10 ppt in the Alviso Marsh were rare during the 2014–2016 period, so larval rearing conditions may be limiting in this area of the estuary. But in early 2017, salinity was less than 1 ppt throughout the Alviso Marsh, so the high flows in 2017 appear to be supporting successful recruitment (J. Hobbs, unpublished data).

### *North Bay*

In the North Bay trawls, larval Longfin Smelt were found at salinities up to 13 ppt, but a large majority of larval life stages were found in 1 to 3 ppt. This was similar to retrospective studies of Longfin Smelt adult otolith chemistry which suggested a large proportion of fish successfully recruiting to spawning stage originated in low salinity habitats (Hobbs et al.

**Figure 9 Ripe Longfin Smelt captured in the Alviso Marsh in January 2016.**



2010). Juvenile life stages caught in this study were found at higher salinity, 4 to 6 ppt, suggesting either fish had higher survival in this salinity zone, or fish moved from the 1 to 3 ppt salinity zone to 4 to 6 ppt during the sampling period. This higher salinity zone is not likely to cause severe osmotic stress as juvenile stages are commonly found up to 20 ppt, and laboratory studies suggest Longfin Smelt are tolerant of high salinities at this life stage (B. Kammerer, University of California Davis, unpublished data). Otoliths from these fish are currently being prepared for otolith microchemistry to determine if fish were indeed moving between salinity habitats during this study.

### *2016–2017 Water Year*

This study is ongoing in the 2016–2017 winter. Fortunately, we are experiencing one of the wettest winters in the last 30 years, and freshwaters flows have been very high, pushing the Low Salinity Zone well into San Pablo and Central Bay. We have conducted four sampling cruises of the SLS survey in the North and South bay tributaries completing almost 300 tows. UCD began sampling with the 20-mm gear the first week in March. Given the long-term trend of increased abundance in wet years, we hypothesize this year will yield much higher catches of larvae and juveniles. If large numbers of juvenile Longfin Smelt are found in San Pablo Bay and its tributaries this spring, this would support the hypothesis that the bulk of the population occurs outside the existing monitoring stations in wet years. This has been a significant limitation in understanding the life history of Longfin Smelt and its habitat requirements for successful recruitment. Preliminary data suggest that catches of larval Longfin Smelt have increased within these extra-Delta tributaries; sampling and processing are currently underway.

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