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Interagency Ecological Program for the San Francisco Estuary

IEP NEWSLETTER

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Interagency Ecological Program

Cooperative Ecological Investigations Since 1970

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 Articles in the IEP newsletter are intended for rapid communication and are not peer reviewed.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

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Article Submission Deadlines for this Calendar Year

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

Above: Melinda Baerwald, Brittany Davis, Cat Pien, and James Newcomb from Department of Water Resources dissecting Delta Smelt. Photo credit: Kelly M. Grow

Cover: Michelle Nelson, Andrew Tran, and Morgan Martinez from Department of Resources collecting water quality data using an EXO 1 sonde. Photo credit: Mike Battey

Of Interest to Managers

This issue of the IEP newsletter features two status and trends reports and two contributed papers covering shifting zooplankton community structure, macroinvertebrate length-weight relationships, beach seine fish sampling results, and the creation of automated seasonal monitoring reports.

1. **Arthur Barros (CDFW)** presents a summary of changes in the prevalence of zooplankton species in the San Francisco Estuary since the IEP Zooplankton Study was initiated in 1972. Many native zooplankton groups have experienced reduced abundance in recent decades, and community composition has shifted to introduced species such as *Limnoithona tetraspina*, *Pseudodiaptomus forbesi*, and *Hypercanthomysis longirostris* dominating the catch-per-unit-effort. Monitoring the abundance and composition of the zooplankton community in the San Francisco Estuary is important in identifying and managing changes in habitat water quality and potential impacts to secondary consumers, such as the declining pelagic fish community.

2. **Christina Burdi (CDFW)** and colleagues, present an examination of preserved fish stomach contents to determine mysid and amphipod length-weight relationships. Results also showed that different preservative types (namely ethanol vs formalin) affected the length-weight equations, making it important to consider preservative type when comparing and interpreting results across study samples. Equations developed in this study can be applied to existing mysid and amphipod length datasets to determine biomass estimates of available prey and to evaluate feeding success for the fishes that feed on them.

3. **Cory Graham and Brian Mahardja (USFWS)** describe inter-annual abundance trends and distributional patterns of juvenile resident fishes within the Delta collected as part of the Delta Juvenile Fish Monitoring Program between 1995 and 2018. Focal species are those that comprise littoral fish community. The abundance indices for Bluegill, Largemouth Bass, Mississippi Silversides, and Redear Sunfish increased overall across the time series likely due to factors such as higher catch per unit effort and submerged aquatic vegetation expansion. The abundance index of Sacramento Pikeminnow was steady but lowest in 2018. The abundance index for Sacramento Sucker peaked in the mid-2000s but has since declined. The abundance index of Longfin Smelt has decreased markedly since 2001 corresponding to the Pelagic Organism Decline with lowest values recorded during the final five years of the time series.

4. **Rosemary Hartman (DWR)** and colleagues, discuss the development of a largely automated IEP Seasonal Monitoring Report. The focus is to establish consistent, repeatable and useful report analysis and data depiction methods for IEP stakeholders that can be applied across all IEP long-term monitoring efforts. The techniques discussed included setting up a collaborative platform for multiple agencies to share code that will enable them to download recent data from online sources, creating standardized graphs, and developing an HTML report that includes built-in ADA compliance features. The automated processes developed for the Seasonal Monitoring Report will help IEP meet its goals of increasing collaboration, communication, uniformity, and timeliness in providing data users short, easy-to-read reports that convey important environmental and ecological trends in the San Francisco Estuary.

5. **Jessica Jimenez (CDFW)** summarizes results from the 2020 Spring Kodiak Trawl (SKT) Survey. CDFW conducts the annual SKT Survey, sampling 40 stations in the upper San Francisco Estuary, to determine relative abundance and distribution of adult Delta Smelt. The 2020 SKT caught just two Delta Smelt, matching the record low set in the 2019 SKT. The SKT normally takes place from January to May each year but CDFW discontinued the 2020 sampling period in late March due to the Covid-19 pandemic.

6. **Brian Jones (CDFW)** summarizes results from the 2020 Smelt Larval Survey (SLS) conducted from January through mid-March. CDFW conducts the annual SLS, sampling 35 stations bi-weekly in the upper San Francisco Estuary, to determine relative abundance and distribution of larval Longfin Smelt. The SLS also collects data on Delta Smelt and other larval fishes. CDFW caught almost 2,800 larval Longfin Smelt in 2020, a fourfold increase from 2019. CDFW began the SLS in 2009 and although there was a significant increase in Longfin Smelt catch in 2020 versus 2019, the overall pattern in catch over the last 6 years (2015-2020) has shown a decrease from the first 6 years (2009-2014) of the survey.

7. **Caitlin Miller and Sarah Perry (DWR)** present a summary of findings from 2018 water quality monitoring efforts in the San Francisco Estuary. These data are collected as part of a long-term monitoring effort by the Environmental Monitoring Program, as dictated by the State Water Project and Central Valley Project. Results breakdown data for 16 water quality analytes, describing any trends or noteworthy takeaways of each analyte. These water quality data, along with past and future years of monitoring, are indicators of ecological health of the Delta, and can be used to inform management or other research activities in the Delta.

8. **Sarah Perry and Betsy Wells (DWR)** summarize the 2019 benthic monitoring conducted by the California Department of Water Resources in the upper San Francisco Estuary, California. The areas monitored include the North Delta, Central Delta, South Delta, Confluence, Suisun Bay, and San Pablo Bay. This year of monitoring revealed a decrease in invasive clam density from the previous year. Densities of other species fluctuated from previous years likely because the wet nature of 2019 decreased salinity in the Estuary. As benthic species respond quickly to changes in physical factors of the system, annual benthic monitoring is vital to understand these physical changes in the Estuary and the implications on the estuarine food web.

9. **Trishelle Tempel and Adam Chorazyczewski (CDFW)** summarize results from the 20-mm Survey during the 2018 and 2019 sampling seasons. The annual 20-mm Survey monitors distribution and relative abundance of larval and juvenile Delta smelt and provides some information on Longfin Smelt due to the partial spatial and temporal overlap of these two species. CDFW had record low Delta Smelt catches in 2018 and 2019 (13 and 16 respectively). The relative distribution of Delta Smelt catch shifted from the confluence of the Sacramento and San Joaquin Rivers in 2018, to the Sacramento River system in 2019. CDFW caught 3,377 Longfin Smelt in 2018 and 8,893 in 2019. The relative distribution of Longfin Smelt catch shifted from the confluence of the Sacramento and San Joaquin Rivers and Carquinez Strait in 2018, to the Napa River and San Pablo Bay in 2019.

Contributed Papers

Zooplankton Trends in the Upper SFE, 1974-2018

Arthur Barros (CDFW)
Arthur.Barros@wildlife.ca.gov

Introduction

Zooplankton are a vital trophic link between aquatic primary producers and higher-level consumers of the San Francisco Estuary (SFE), including other zooplankton, filter-feeding invertebrates, and fishes. As primary consumers of phytoplankton, zooplankton facilitate the flow of carbon into a large and complex food web (Schroeter et al. 2015; Kimmerer et al. 2018). Many fishes, including Striped Bass (*Morone saxatilis*) and Chinook Salmon (*Oncorhynchus tshawytscha*) feed on zooplankton while rearing in the estuary as larvae and juveniles (Goertler et al. 2018; Heubach et al. 1963), while others, including Northern Anchovy (*Engraulis mordax*) and Pacific Herring (*Clupea pallasii*) also feed on zooplankton as adults (Kimmerer 2006; Friedenberg 2009). Zooplankton in the SFE are also a key food source for several endangered and threatened species, notably the Delta Smelt (*Hypomesus transpacificus*) and Longfin Smelt (*Spirinchus thaleichthys*), which feed on zooplankton throughout their lives (Hobbs et al. 2006; Slater and Baxter 2014).

The Zooplankton Study was implemented in 1972 to assess fish food resources in the upper SFE. Mandated by the State Water Resources Control Board's Water Right Decision D-1641, the study is conducted jointly by the California Department of Fish and Wildlife and the California Department of Water Resources under the guidance and management of the Interagency Ecological Program. For nearly 5 decades, this study has monitored the zooplankton community in the region, tracking abundance trends and distributional patterns, detecting and monitoring introduced species, as well as documenting dramatic shifts in community composition. Changes in zooplankton abundance and composition have since been linked to major declines of the pelagic fishes in the upper estuary (Sommer et al. 2007; Winder and Jassby 2011). This report presents zooplankton annual and seasonal abundance indices and trends from 1974 through 2018, as well as distribution patterns in 2018, for the most common copepods, cladocerans, rotifers, and mysids of the upper SFE.

Methods

We have conducted zooplankton sampling since 1974 at a minimum of once a month at 20 fixed stations in the upper SFE (Figure 1). Three gear types are used for each sampling event: a pump with a 43-micron mesh net for micro-zooplankton (rotifers, nauplii, and small cyclopoid copepods); a Clarke-Bumpus (CB) net with a 160-micron mesh for sampling mesozooplankton (cladocerans and most juvenile and adult calanoid copepods); and a mysid net with a 505-micron mesh for sampling mysid shrimp and other macrozooplankton. Both the mysid and CB nets are attached to a sled and towed obliquely from the bottom through the surface for a 10-minute tow. To calculate volume we use a General Oceanics 2030R mechanical flowmeter placed in the mouth of each net so that: *V=(end meter-start meter) *k * a*; where *V* is the volume of water sampled, *k* is a flowmeter correction value, and *a* is the area of the mouth of the net. We also use a Teel Marine 12V utility pump at each station to sample approximately 19.8 gallons from the entire water column, which is filtered through a 43-micron mesh net to concentrate the sample. Samples are preserved in 10% formalin with Rose Bengal dye before being processed in the laboratory for identification and enumeration of organisms using a microscope. More information about the sampling and processing methods can be found in the metadata at ftp://ftp.wildlife.ca.gov/IEP_Zooplankton/.

Abundance indices are calculated for each organism based on the gear type most effective at its capture and reported as the mean catch-per-unit-effort (CPUE). To calculate CPUE we use the number of each organism collected per cubic meter of water sampled, so that: *CPUE=s*V^(-1)*; where *s* is the estimated count of the target organism in the sample. Copepod abundance indices reported here only include adults, as juveniles are not always accurately identified to species. Annual and seasonal abundance indices are calculated using 14 fixed stations sampled consistently since 1974 (Figure 1) and 2 non-fixed stations sampled where bottom specific conductance is between 2 and 6 millisiemens per centimeter (or 1 and 3 psu).

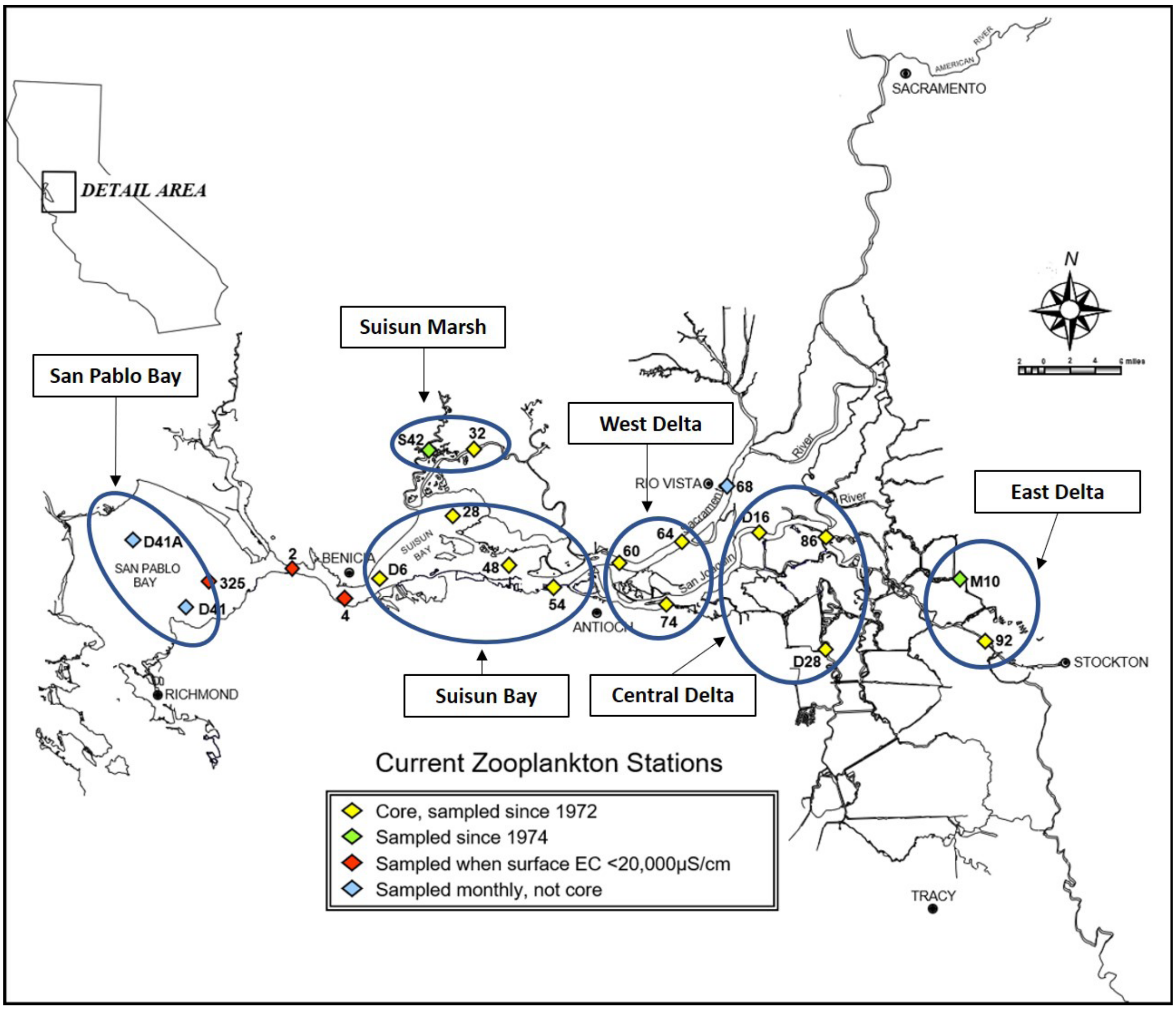

Figure 1: Map of fixed Zooplankton Study stations in the San Francisco Estuary.

To analyze long-term trends (1974 to 2018), I calculated annual abundance indices as the mean CPUE for samples collected from March through November, as winter sampling was inconsistent before 1995. To calculate seasonal abundance indices, I used the mean CPUE for samples collected during each season: winter (previous December to February), spring (March to May), summer (June to August), and fall (September to November). For this paper long-term seasonal trends for winter are only shown for 1995 to present. I described spatial distribution indices for organisms as seasonal mean CPUE by region. SFE regions were defined as San Pablo Bay (stations D41 and D41A), Suisun Bay (stations D6, 28, 54, and 48), Suisun Marsh (stations 32 and S42), West Delta (stations 60, 64, and 74), Central Delta (stations D16, 86, and D28), and the East Delta (92 and M10).

Results and Discussion

Overall abundance of almost all zooplankton in the estuary, especially native species, has dropped dramatically since 1974 (Figure 2). Only the abundance of cyclopoid copepods increased in the estuary in this period, driven by the invasion and spread of *Limnoithona tetraspina*. The overall decrease in zooplankton abundance in the estuary can be attributed to a series of invasions into the estuary, most notably that of the Asian clam *Potamocorbula amurensis* in the mid-1980s (Carlton et al. 1990). The spread of *P. amurensis* throughout the SFE has had disastrous impacts on the planktonic community of the upper estuary due to its high filtration feeding rates on phytoplankton and copepod nauplii (Kimmerer, Gartside, and Orsi 1994). Not only has abundance decreased for most of the zooplankton groups, but this survey has shown that the composition of these zooplankton communities has also shifted dramatically during the period of the Zooplankton Study.

Calanoid copepods

While overall calanoid copepod abundance has declined slightly over the study period, community composition has shifted dramatically (Figure 2A). The copepods *Eurytemora affinis* and *Acartia spp.* dominated the calanoid community when the study began. The non-native *E. affinis* was once the primary prey item of the endangered Delta Smelt, but its abundance has declined to a fraction of what it once

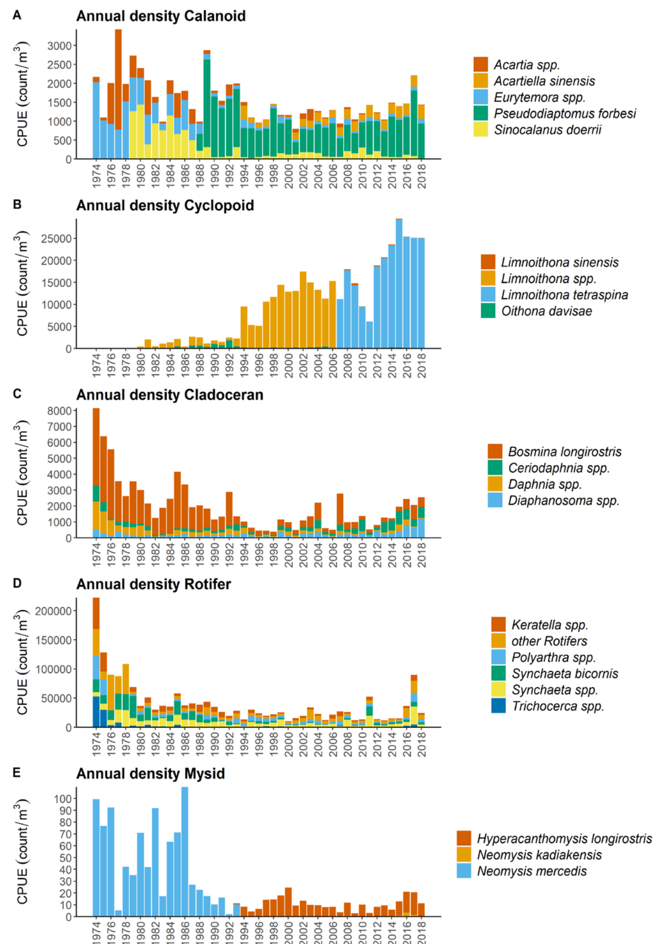

Figure 2: Annual (Mar-Nov) mean zooplankton CPUE for A) Calanoid CPUE in the CB net, B) Cyclopoida CPUE in pump samples, C) Cladocera CPUE in the CB net, D) Rotifer CPUE in pump samples, and E) Mysid CPUE in the mysid net.

was, forcing fish to now prey on recently introduced non-native calanoids (Moyle et al. 1992; Slater and Baxter 2014).

One of the first recorded introduced calanoid copepods was *Sinocalanus doerrii*, a freshwater species native to China that invaded the estuary in 1978 and became the most dominant calanoid species in the SFE for a decade (Orsi et al. 1983). Then in 1987, after the invasion of *P. amurensis*, the calanoid *Pseudodiaptomus forbesi* was introduced to the system, which competed with *E. affinis* and further changed SFE's calanoid community (Orsi and Walter 1991). *P. forbesi* quickly became the numerically dominant calanoid in the upper estuary as other species declined in abundance. Another invasion occurred in 1993, when the predatory calanoid copepod *Acartiella sinensis* quickly became the second most abundant calanoid in the upper SFE, dominating the low-salinity zone (Orsi and Ohtsuka 1999). This invasion is hypothesized to have narrowed the range of *P. forbesi* towards the freshwater zone of the estuary, due to increased predation on *P. forbesi* nauplii by *A. sinensis* (Kayfetz and Kimmerer 2017).

Looking at historical trends, calanoid copepod abundance is highest in the estuary during the summer and fall months, and lower during winter (Figure 3A). While calanoid copepod abundance peaked in the summer of 2017 at a nearly 20 year high, 2018 abundances returned to levels comparable to the previous two decades. However, this followed the near record abundance levels observed in the summer of 2017. The 2017 peak was driven by increases in the abundance of *P. forbesi* during summer (Figures 2A, 3A) in the Suisun Marsh region (Hennessy 2018). This 2017 peak corresponded with record precipitation levels and Delta outflows, which caused the low salinity zone to extend throughout Suisun Marsh region well into the warm summer months. This contrasts with 2018, a lower outflow year with lower *P. forbesi* abundance and a distribution shifted eastward into the Delta. *E. affinis*, once the most abundant copepod in the SFE, peaked in abundance in the spring of 2018 in Suisun Marsh region, with occurrences also further upstream in the Delta than the prior high outflow year 2017 (Hennessy 2018). The correlation between summer outflows and zooplankton abundances and distribution has also been observed amongst rotifers in 2017, and mysid species before the invasion of *P. amurensis* (Siegfried et al. 1979; Cloern et al. 1983).

In 2018 predatory *A. sinensis* densities were highest in the summer and fall in the Suisun Marsh and West Delta regions, similar to the prior year (Figure 5A). In fall 2018, *A. sinensis* was the most abundant calanoid in Suisun and the West Delta, where it co-occurred with high densities of one of its prey species *Limnoithona tetraspina* (Figure 5B). *Acartia* spp. was the only native calanoid copepod commonly found in 2018, mostly restricted to the higher-salinity San Pablo Bay region during the winter.

Cyclopoid copepods

While calanoid abundance declined and the community composition dramatically changed, the abundance of cyclopoid copepods has increased dramatically during the period of study (Figure 2B). The native *Oithona* and *Acanthocyclops* species of cyclopoid copepods were at low abundances when the study began, but with the introduction of *Limnoithona sinensis* in the early 1980s, and the later identification of the invasive *Limnoithona tetraspina* in 1993, cyclopoid indices have increased exponentially (Ferrari and Orsi, 1984; Orsi and Ohtsuka, 1999). Abundance indices for the two species of *Limnoithona* were combined from 1980 through 2006 as *Limnoithona* spp., then in 2007 they were identified and enumerated as *L. sinensis* and *L. tetraspina*.

Since the early 1990s, *Limnoithona* spp. abundance has been higher than calanoid copepod abundance, and the small *L. tetraspina* has become the most common copepod in the upper SFE. This increase in *L. tetraspina* abundance is likely due to a decline of Northern Anchovy in the upper SFE and subsequent decreased predation (Kimmerer 2006), as well as the cyclopoid's small size, high growth rate, and motionless behavior, making it very difficult for visual feeders to capture (Bouley and Kimmerer 2006; Greene et al. 2011). These characteristics may make it more able to escape predation in a region where visual predation is most dominant among fish (Kimmerer 2006). The introduction of *L. tetraspina* is also linked to the reduction in the distribution of *P. forbesi* in the low-salinity zone of the SFE, as high *L. tetraspina* densities may have fed and sustained larger populations of the predatory *A. sinensis*, which also preys on *P. forbesi* nauplii (Kayfetz and Kimmerer 2017).

Seasonally, *L tetraspina* peaks in summer and fall (Figure 3B), with lower abundance in winter and spring, and in 2018 *L. tetraspina* abundance was the highest observed for all copepods. As in prior years, this cyclopoid was most abundant in the low-salinity zone of the estuary in Suisun Marsh and the West Delta regions, with lower abundances during winter and spring, before its population increased and peaked in summer and fall (Figure 5B). *Oithona davisae*, a native cyclopoid, was the most abundant cyclopoid in the higher-salinity San Pablo Bay region throughout the year, with peaks in abundance also in summer and fall (Figure 5B).

Copepod Carbon

The total copepod community abundance (both calanoid and cyclopoid species) has

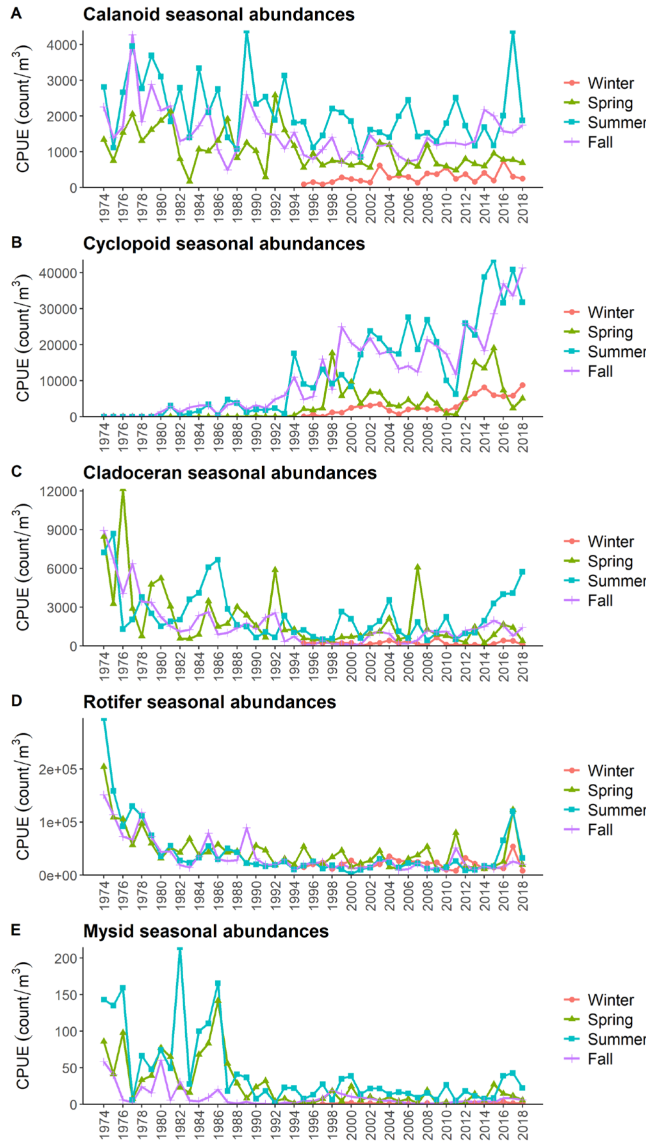

Figure 3: Seasonal mean zooplankton CPUE. Spring, summer, and fall are reported for 1974-2018, winter is reported for 1995-2018. A) Calanoid CPUE in the CB net. B) Cyclopoida CPUE in pump samples. C) Cladocera CPUE in the CB net. D) Rotifer CPUE in pump samples. E) Mysid CPUE in the mysid net.

increased by roughly an order of magnitude over the study period, despite the apparent decline in calanoids. This increase was driven by the introduction and spread of the cyclopoid *L. tetraspina* (Figure 4A). While the number of copepods in the SFE has increased, the total amount of carbon biomass has stayed relatively the same (Figure 4B). The composition of copepod carbon biomass has shifted from being dominated by the larger calanoid copepods, preferred food sources for many fish species in the SFE, to being more and more composed of the smaller *L. tetraspina*, which Delta Smelt select against as prey (Slater and Baxter 2014). This change could represent a detrimental shift in the abundance of carbon biomass available to visually feeding fish in the SFE (Bouley and Kimmerer 2006).

Cladocerans

The cladoceran community of the upper SFE is composed of *Bosmina, Daphnia, Ceriodaphnia,* and *Diaphanosoma* species, whose populations have also significantly declined since the onset of the study (Figure 2C). These cladocerans tend to be herbivorous, feeding primarily on phytoplankton, and abundances were negatively impacted by the invasion of the clam *P. amurensis* (Baxter et al. 2008; Kratina and Winder 2015). Cladocerans make up a significant portion of the diets of Delta Smelt, juvenile Chinook Salmon, and young-of-the-year Striped Bass throughout

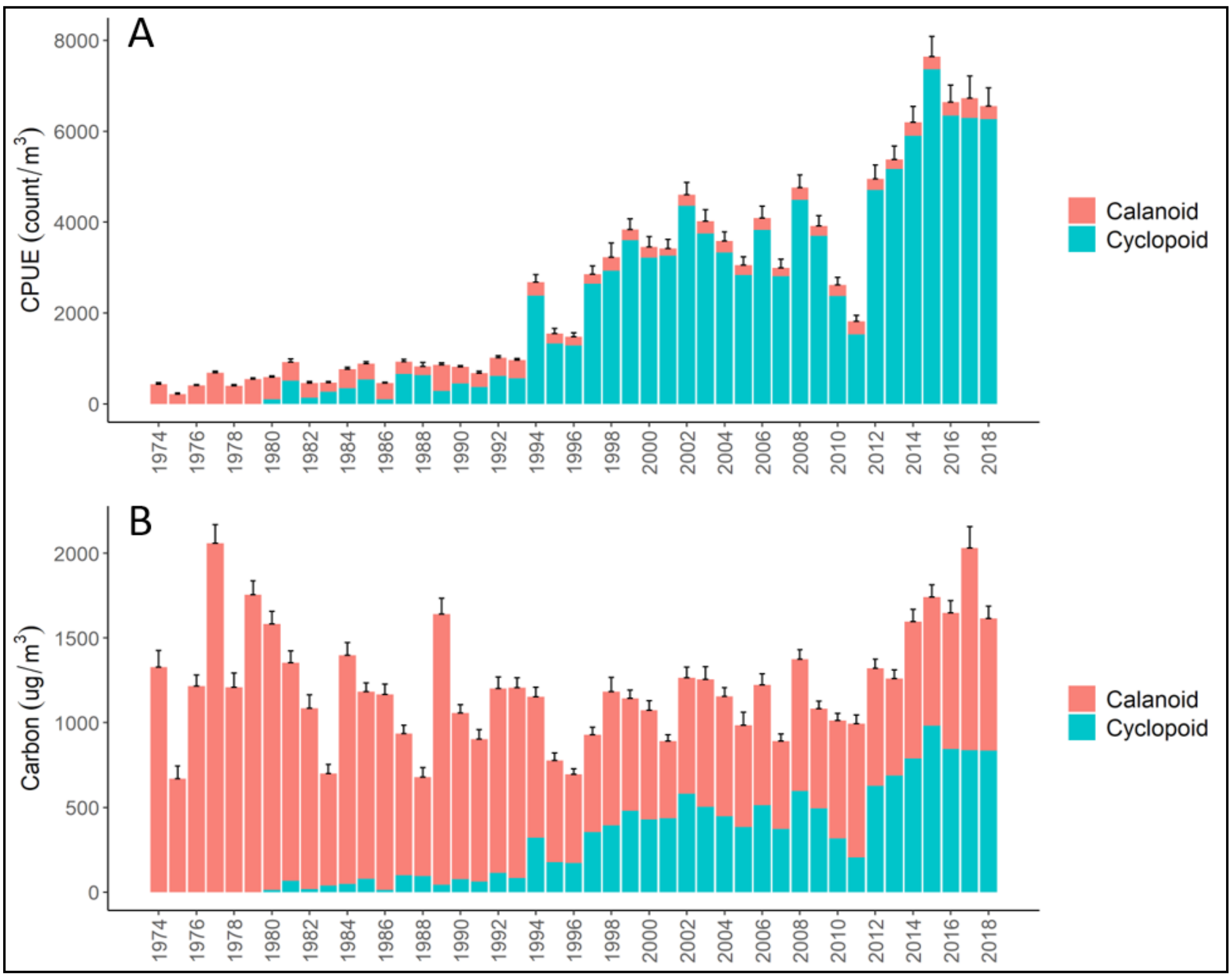

Figure 4: A) Annual (Mar-Nov) Calanoid and Cyclopoid CPUE from CB and pump samples. B) Annual (Mar-Nov) Calanoid and Cyclopoid CPUE as carbon biomass.

the upper SFE (Heubach et al. 1963; Slater and Baxter 2014; Goertler et al. 2018).

While cladoceran abundance has declined overall, in recent years summer abundance has been increasing. For example, in 2018, summer cladoceran abundance was the highest observed since the *P. amurensis* invasion (Figure 3C). This increase in abundances during recent years is yet unexplained, and further research and analysis will be required. In 2017 some cladocerans, namely *Bosmina*, were found down-river in Suisun Marsh and the West Delta regions, while in 2018 the highest densities of cladocerans were found in the East Delta, with trace concentrations found in other regions of the SFE, and abundance peaked in summer (Figure 5C). This difference in distributions across the estuary is likely due to the high variation in outflow between the two years.

Rotifers

Rotifers are the most abundant zooplankton in the SFE, although long-term sampling shows a dramatic decrease in their annual abundance since the beginning of this study (Figure 2D). Interestingly, the decline of rotifer abundance beginning in the late 1970s preceded the invasion of *P. amurensis* in the estuary (Cloern and Jassby 2012). The most abundant rotifer species sampled in the SFE include: *Polyarthra, Synchaeta,* and *Keratella* genera.

The 2018 rotifer abundance was lower than in 2017 and distributions also differed between the two years. In 2017, rotifer abundances were double those in 2018, and *Synchaeta* peaked in Suisun Marsh in 2017, as opposed to in San Pablo Bay in 2018 (Figure 2D, Hennessy 2018). This high rotifer abundance and shift in distribution in 2017 was likely due to the record high outflows. Spatial and temporal differences were discernable between *Synchaeta* and other rotifers, wherein *Synchaeta* had the highest densities in San Pablo

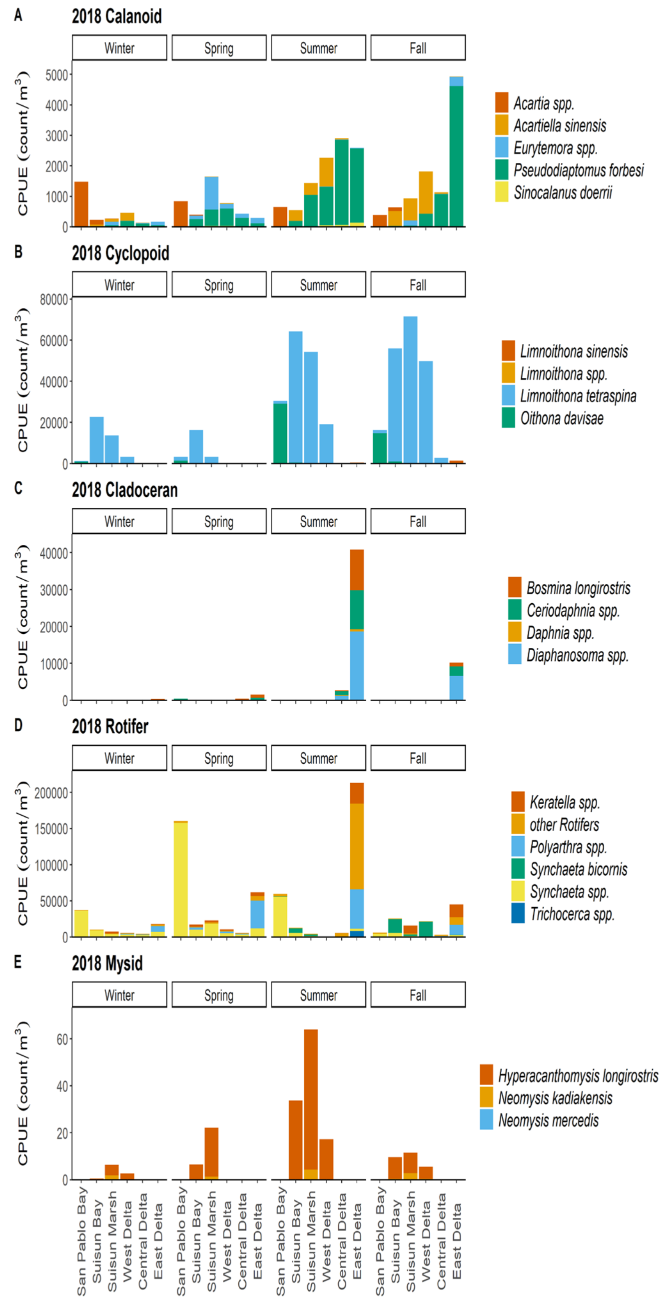

Figure 5: Seasonal mean zooplankton CPUE for 2018 by region for A) Calanoid CPUE in the CB net, B) Cyclopoida CPUE in pump samples, C) Cladocera CPUE in the CB net, D) Rotifer CPUE in pump samples, and E) Mysid CPUE in the mysid net.

Bay during the spring, and other rotifers like *Keratella* and *Polyarthra* were most abundant in the East Delta in summer (Figure 5D, Winder and Jassby 2011).

Mysids

Mysid abundances declined noticeably since the 1970s. The mysid community also shifted from being composed almost entirely of the native *Neomysis mercedis*, to being dominated by the non-native *Hyperacanthomysis longirostris* (formerly *Acanthomysis bowmani*) (Figure 2E). The first significant decline in *N. mercedis* occurred during the 1976-1977 drought, likely caused by food limitation from an absence of diatoms due to very low river discharges (Siegfried et al. 1979; Cloern et al. 1983). The populations of *N. mercedis* rebounded after the years of drought and stayed at high densities in the Suisun Bay region of the upper estuary until the introduction of *P. amurensis* in the mid-1980s, after which their numbers crashed.

In 1993 the introduced *H. longirostris* was first detected by this study, shortly after the decline of *N. mercedis*, and it quickly became the most common mysid in the system. However, overall mysid abundances have not returned to their pre-clam invasion levels (Modlin and Orsi 1997, Figure 2E). Mysids have always peaked in the spring and summer months, fluctuating with the higher productivity in the estuary during those seasons (Figure 3E). Historically mysids have been of critical importance in the diets of many fish species in the SFE including Delta Smelt, Longfin Smelt, Striped Bass, and Chinook Salmon (Moyle et al. 1992; Feyrer et al. 2003; CDFG 2009; Goertler et al. 2018). However, the decline of mysids in the upper estuary has resulted in a significant decrease in their presence in the diets of fishes of the region (Feyrer et al. 2003).

The general decline in mysid abundance continued in 2018, even though 2017 saw an increase in mysid abundances (Figure 2E), and the distribution and timing of peaks has stayed similar over the last two decades (Figure 5E; Hennessy 2018). *Hyperacanthomysis longirostris* was again the most common mysid in the estuary during all seasons, while abundances of the once common native *Neomysis mercedis* continued to be almost imperceptible in the region. This has been the overall trend in the estuary's mysid communities since 1994. As in prior years, mysids in 2018 were most abundant during the summer, and highest concentrations occurred in the low-salinity zone of West Delta, Suisun Bay and Marsh regions.

Conclusion

In 2018 the Zooplankton Study recorded abundances of calanoids, cladocerans, rotifers, and mysids at lower densities comparable to other recent years and consistent with the downward historic trends in the estuary. Calanoid and cyclopoid copepod abundance peaked in fall, whereas cladocerans, rotifers, and mysids peaked in summer. The small, abundant *Limnoithona tetraspina* was again the most abundant copepod in the SFE. This multi-decade study has enabled researchers and managers to track the shifts in zooplankton abundances and community composition across the estuary for nearly 5 decades. The Zooplankton Study has documented the introduction and dominance of new species, including *Pseudodiaptomus forbesi, Limnoithona tetraspina,* and *Hypercanthomysis longirostris*, as well as the community's response to the invasive clam *Potamocorbula amurensis*. Understanding the zooplankton community dynamics and how they have fundamentally changed trophic interactions is critical to assessing water quality and food resources for fish and conservation strategies in the SFE.

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Mysid and Amphipod Length-Weight Relationships in the San Francisco Estuary

Christina E. Burdi*, Steven B. Slater, Tricia L. Bippus, and Jessica A. Jimenez (IEP, CDFW)

*Corresponding Author:
Christina.Burdi@wildlife.ca.gov

Introduction

Macrozooplankton such as mysids and amphipods are important prey to many fishes in the San Francisco Estuary (SFE; Feyrer et al. 2003; Bryant and Arnold 2007; Slater and Baxter 2014; Slater et al. 2019). Habitat restoration and augmented flow actions to enhance nutrient inputs in the SFE are directed to help produce prey for fish to address food limitation. Examination of prey use by fish as a response to actions often includes a measure of stomach fullness or estimates of available prey biomass. Mass of individual prey is difficult to determine, and sometimes not possible, and so length-weight relationships are applied. Currently there is limited information on the length-weight relationships of the mysid and amphipod species found in this region (See: Chigbu and Sibley 1996 for *Neomysis mercedis* in Lake Washington). The length-weight equations of commonly found mysid and amphipod species in the stomachs of pelagic fishes of the SFE are given here.

Fish stomachs that were preserved in both ethanol and formalin were used in this study. The type of preservative used for fish or invertebrate samples often depends on the intended use of the specimen collected. Ethanol is typically used in cases where DNA or otolith studies are planned. However, ethanol can cause samples to become brittle or desiccated, therefore formalin is often used when needing to retain the form of small structures or delicate organisms for morphological analysis (Markel 1984; Krogmann and Holstein 2010; Hughes and Ahyong 2016). The influence of preservative on the equations reported here is also described in brief.

Methods

The mysid and amphipod length-weight equations reported here were calculated by the California Department of Fish and Wildlife (CDFW) Fish Diet and Condition Study (“Diet Study”) (https://wildlife.ca.gov/Conservation/Delta/Special-Studies) (Slater and Baxter 2014; Hammock et al. 2017; Slater et al. 2019). The Diet Study identifies and enumerates gut contents of Delta Smelt (*Hypomesus transpacificus*), Longfin Smelt (*Spirinchus thaleichthys*), Striped Bass (*Morone saxatilis*), American Shad (*Alosa sapidissima*) and Threadfin Shad (*Dorosoma petenense*), and other young fishes in the SFE. Gut contents are identified to the lowest possible taxon. Larger prey items, such as mysids and amphipods are measured, weighed, sexed, and categorized by life stage when specimens are intact and not digested.

Individual mysids and amphipods were taken from the stomachs of fish preserved in 10% formalin or 95% ethanol collected by various Interagency Ecological Program (IEP) Long Term Monitoring Surveys during years 2011-2019. Additional amphipod measurements were taken from macrozooplankton samples collected by the IEP Zooplankton Study (https://wildlife.ca.gov/Conservation/Delta/Zooplankton-Study) and preserved in 10% formalin. Amphipod (Figure 1A) and mysid (Figure 1B) body lengths (± 0.1 mm) were measured from the base of the telson to the tip of the rostrum using a dissecting microscope. Individuals were blotted dry and total wet weight (± 0.0001 g) was measured using a Mettler Toledo XS205DU analytical balance.

Samples of mysids and amphipods taken from fish guts varied in level of digestion, size, and completeness. Size of the organism can limit the ability of accurate weights based on the sensitivity of the scale used. Digestion can affect the level of identification, as well as the accuracy of measurements based on if an organism is fully intact or not. Due to this, not all specimens found in fish guts were fully intact or large enough to provide accurate measurements of both length and weight. For example, prey length of an amphipod missing antennae could be accurately obtained, however, an accurate weight could not. In this instance, the organism would only have a length measurement and therefore would not be used in this analysis. Only specimens where both length and weight measurements could be taken were used to generate equations. Another consideration is the influence of preservation effects on lengths and weights of samples (Howmiller 1972; Mills et al. 1982). Ethanol can cause desiccation that results in shrinkage of length and loss of weight, whereas formalin can cause an increase in weight and reduction in length. We report only intact specimens and preservation separately and did not have equal sample sizes in all cases. Individuals that were sexed and identified by life stage were combined to increase sample size used in these equations. Higher taxonomic classifications for amphipods are described when species identification was not possible, or there was a small sample size of an identified species.

Scatterplots were used to present the length and weight data. Length-weight equations were generated as power functions in Excel (2016) with W=aLb, where W is the weight of the individual (g), L is the body length (mm), a is a constant, and b is an exponent (Culver et al. 1985). All weights are wet weights. Equations are separated by the preservative in which the organisms were stored in. The maximum and minimum of the observed lengths are given, in addition to the number of specimens used to calculate the equations. The preservative length-weight relationships were used to determine weights at 1 mm intervals for the range of lengths measured to determine average percent difference for a few of the taxa. Percent difference calculated as ((Abs (ethanol - formalin)) / ((ethanol + formalin) / 2)) * 100.

Analysis of covariance (ANCOVA) (SYSTAT 13, GLM procedure) was conducted on log10 transformed length and weight data to determine if length-weight

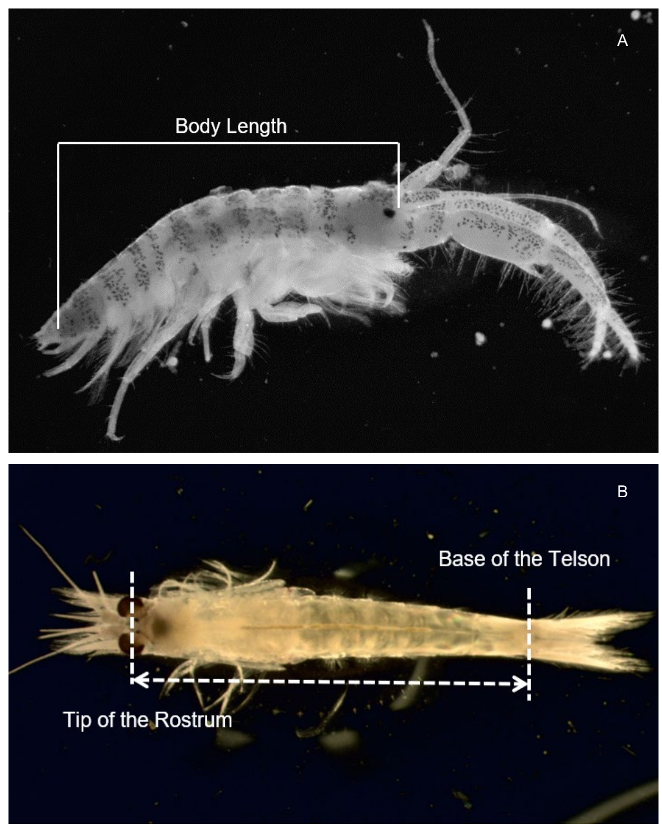

Figure 1. Diagram of length measurements (mm). Amphipods (A) and mysids (B) were measured from the base of the telson to the tip of the rostrum using a dissecting microscope. Amphipod species pictured is *Americorophium spinicorne* and the mysid species is *Hyperacanthomysis longirostris*.

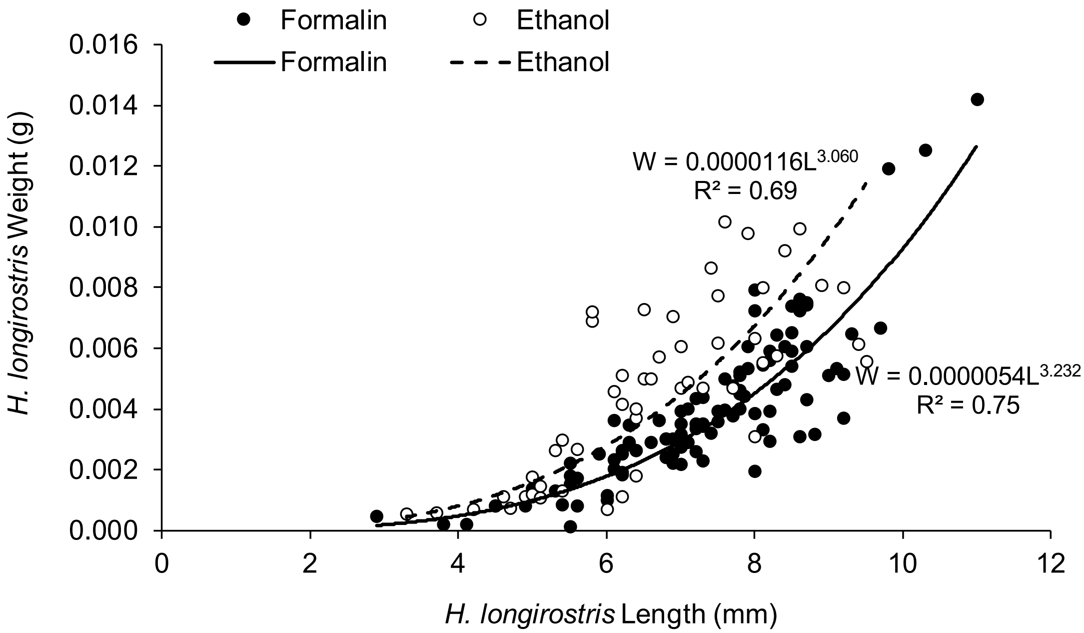

Figure 2. Scatterplot of the length-weight relationship of *Hyperacanthomysis longirostris* preserved in ethanol (n= 50; W= 0.0000116L3.060) and formalin (n= 107; W =0.0000054L3.232). Slope of the length-weight relationships did not significantly differ between preservatives ($F_{1, 166}$= 3.34, p= 0.07), but the intercepts were significantly different ($F_{1,167}$= 25.25, p<< 0.001).

relationships significantly differed among preservatives using the following formula: log10 (W) = log10 a + b × log10 (L), where W is weight (g), L is body length (mm), a is the y-axis intercept, and b is the slope of the line (Culver et al. 1985). ANCOVAs were used to test for a significant ($\alpha < 0.05$) difference among slopes with the interaction term preservative*loglength, and among intercepts without the interaction term, of the linear regressions (Zar 1999) for the mysid *Hyperacanthomysis longirostris*, as well as amphipods classified under the order Amphipoda, family Gammaridae or Corophiidae, and species with individuals preserved in both ethanol and formalin.

Results

A total of 4,513 fish guts were dissected, with 2,569 mysids and 7,002 amphipods identified. Due to the variable condition and size of prey, measurements of both length and weight were obtained for 107 mysids and 966 amphipods. Mysid lengths ranged from 2.9 to 11.0 mm and weights from 0.0001 to 0.0100 g (Table 1). Amphipod lengths ranged from 1.9 to 10.2 mm and weights from 0.0001 to 0.0190 g (Table 1). It is possible that amphipods <2 mm are too small to be accurately weighed, which would explain the absence of smaller individuals in these equations, despite their importance in fish diets (Slater et al. 2019).

Length-weight relationships were generated for one mysid species (*Hyperacanthomysis longirostris*, Figure 2) and 8 species of amphipods (*Americorophium spinicorne*: Figure 3; *A. stimpsoni*: Figure 4; *Gammarus daiberi*: Figure 5; *Sinocorophium alienense*, *Crangonyx* spp. and *Hyalella* spp.: Figure 6; *Ampelisca abdita* and *Monocorophium* spp.: Figure 7). Note, some amphipods were not identified to species, or had a small sample size at the species

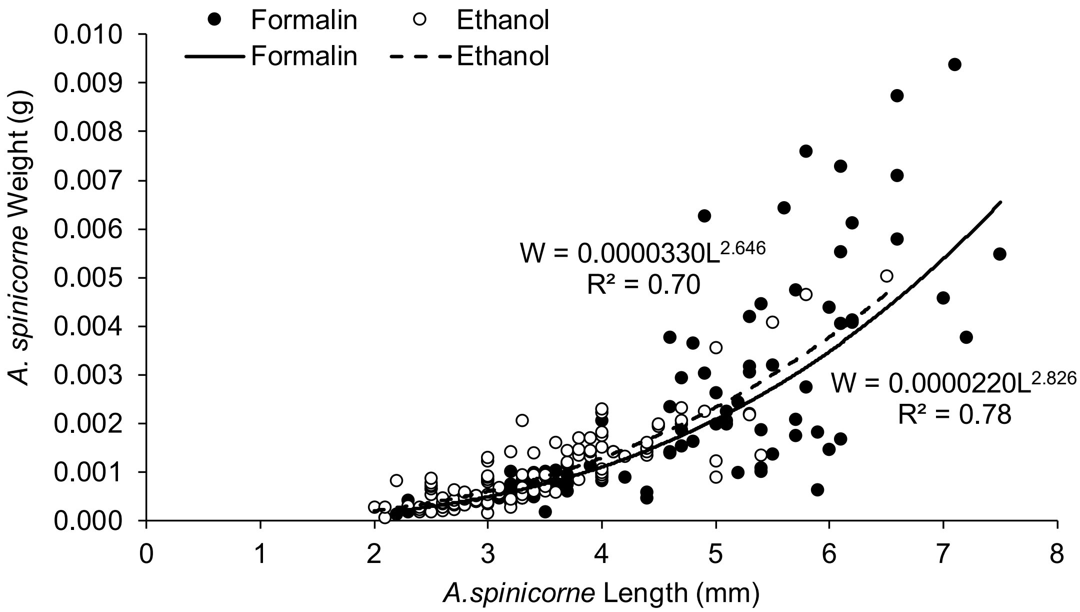

Figure 3. Scatterplot of the length-weight relationship of *Americorophium spinicorne* preserved in ethanol (n= 108; W= $0.0000330L^{2.646}$) and formalin (n= 113; W= $0.0000220L^{2.826}$). The intercepts of the length-weight relationships were significantly different ($F_{1, 218}$=6.69, p<0.01), but not the slopes ($F_{1,217}$= 0.65, p=0.42).

level, so higher level classifications of order or family were used. The length-weight equation for order Amphipoda (Figure 8) includes all amphipods identified to lower classification levels and those categorized as Unidentified ("Unid") Amphipod. Length-weight relationships at the family level of Corophiidae (Figure 9) or Gammaridae (Figure 10) includes amphipods identified to genus or species, as well as those classified as Unid Corophium or Unid Gammarus. The difference in weight derived from slopes of the preservatives for the general range of measurements was 44.5% for *H. longirostris*, 18.5% for Amphipoda, 24.1% for Gammaridae, 38.9% for G. daiberi, 11.3% for Corophiidae, and 15.0% and 13.1% for *A. spinicorne* and *stimpsoni*, respectively (Table 1).

The ANCOVA results (Table 2) showed no significant difference between the slopes of the length-weight relationships for *H. longirostris* (ethanol, n=50; formalin, n=107; $F_{1, 166}$= 3.34, p= 0.07), order Amphipoda (ethanol, n=367; formalin, n=599; $F_{1, 962}$= 3.77, p=0.05), amphipods in the family Corophiidae (ethanol, n=156; formalin, n=292; $F_{1, 444}$= 1.44, p=0.23), *A. spinicorne* (ethanol, n=108; formalin, n=113; $F_{1,217}$= 0.65, p=0.42), and *G. daiberi* (ethanol, n=84; formalin, n=106; $F_{1, 186}$= 0.08, p=0.78) preserved in ethanol and formalin. However, the intercepts of the length-weight relationships were significantly different, with ethanol being heavier at length than formalin (*H. longirostris*: $F_{1,167}$= 25.25, p<< 0.001; Amphipoda: $F_{1, 963}$= 21.92, p<<0.001; Corophiidae: $F_{1, 445}$= 12.94, p<<0.001; *A. spinicorne*: $F_{1, 218}$=6.69, p<0.01, *G. daiberi*: $F_{1,187}$= 57.20, p<<0.001). Amphipods in the family Gammaridae preserved in ethanol (n=209) were significantly ($F_{1,512}$=19.51, p<0.001) heavier at length than those in formalin (n=307). The

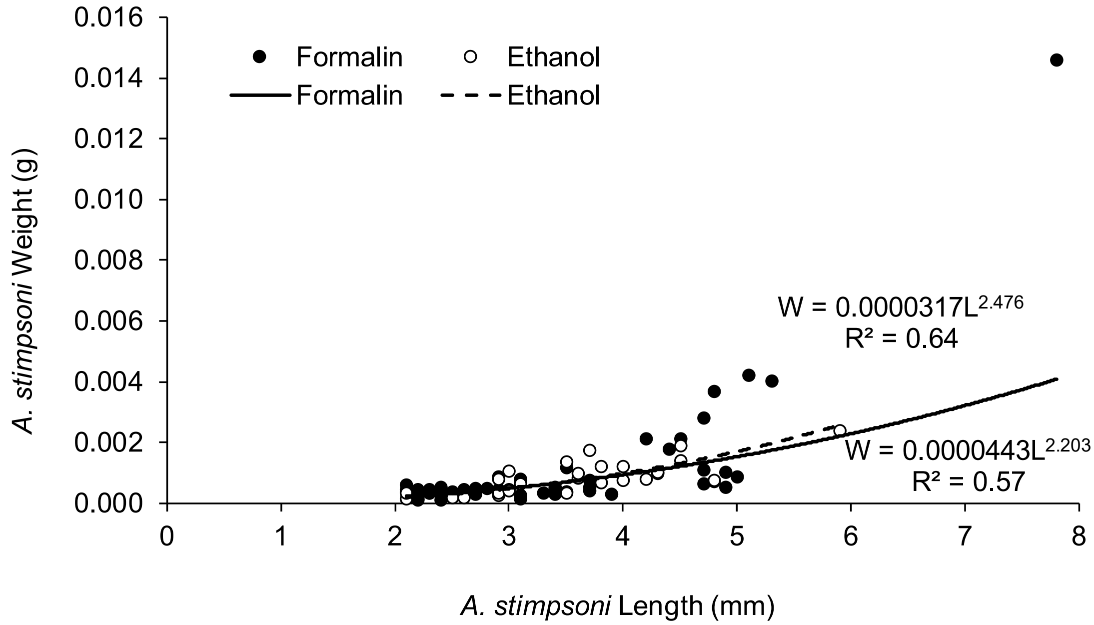

Figure 4. Scatterplot of the length-weight relationship of *Americorophium stimpsoni* preserved in ethanol (n= 25; W= $0.0000317L^{2.476}$) and formalin (n= 57; W =$0.0000443L^{2.203}$). There was no significant difference between the slopes ($F_{1, 78}$=0.27, p=0.60) or the intercepts ($F_{1,79}$= $1.70x10^{-6}$, p=0.99).

length-weight relationships of *A. stimpsoni* preserved in ethanol (n=25) and formalin (n=57) showed no significant difference between the slopes ($F_{1, 78}$=0.27, p=0.60) or the intercepts ($F_{1,79}$= $1.70x10^{-6}$, p=0.99).

Conclusion

This effort captured novel length-weight relationships of multiple macroinvertebrates in the SFE. The measures included a wide range of size, life stage, and sex of mysids and amphipods. Additional effort is needed for smaller size classes of both amphipods (<1.9 mm) and mysids (<2.9 mm). Organisms preserved in ethanol had a higher mass at length than those preserved in formalin. This pattern is inconsistent with previous studies where ethanol preserved invertebrates had increased weight loss compared those in formalin (Howmiller 1979, DiStefano et al. 1994, Mährlein et al. 2016). Weight loss could have occurred for both ethanol and formalin preserved specimens, with less loss occurring with ethanol preserved specimens as found by Wetzel et al. (2005). However, the amount of weight loss could be time dependent, and Mills et al. (1982) found that amphipods preserved in ethanol increased in weight during the first two months, and then slowly decreased. Therefore, our results could have been influenced by preservation time and future efforts should consider time in preservative between the two treatments. Despite the difference in pattern to other studies, our results still reiterated the influence preservative has on invertebrate lengths and weights and the importance of considering preservative when utilizing these equations. Combining measurements of male and female individuals in sexually dimorphic species may contribute to variability in length-weight relationships. For instance, the body lengths of female amphipods are typically smaller than males, however gravid females would likely have a larger weight at that size. In addition, Corophium antennae size differs

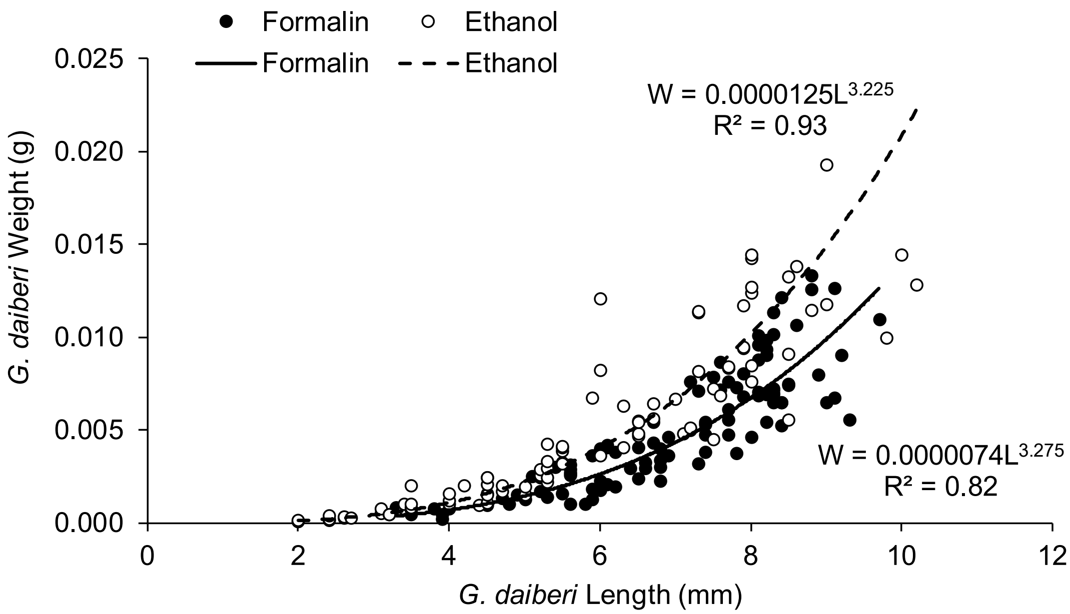

Figure 5. Scatterplot of the length-weight relationship of *Gammarus daiberi* preserved in ethanol (n= 84; W= 0.0000125L$^{3.225}$) and formalin (n= 107; W= 0.0000074L$^{3.275}$). There was a significant difference between the intercepts ($F_{1,187}$= 57.20, p<<0.001), but not the slopes ($F_{1, 186}$= 0.08, p=0.78).

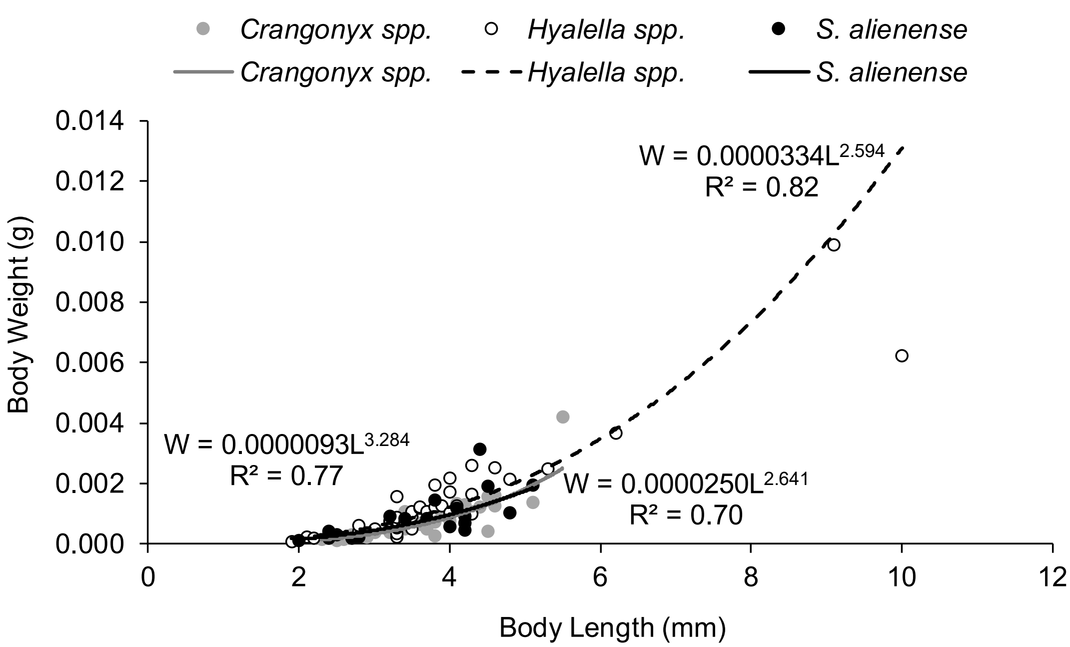

Figure 6. Scatterplot of the length-weight relationship of *Sinocorophium alienense* (n= 19; W= 0.0000250L$^{2.641}$), *Crangonyx* spp. (n= 37; W= 0.0000093L$^{3.284}$) and *Hyalella* spp. (n= 39; W= 0.0000334L$^{2.594}$). All were preserved in ethanol.

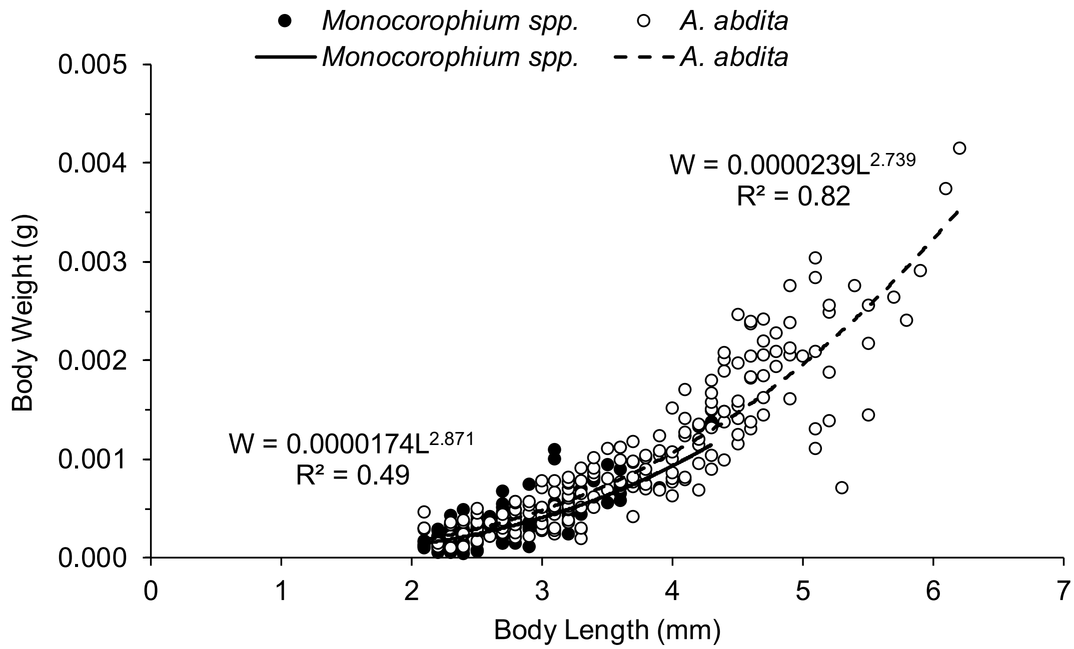

Figure 7. Scatterplot of the length-weight relationship of *Ampelisca abdita* (n= 196; W= $0.0000239L^{2.739}$) and *Monocorophium* spp. (n= 109; W= $0.0000174L^{2.871}$). Both were preserved in formalin.

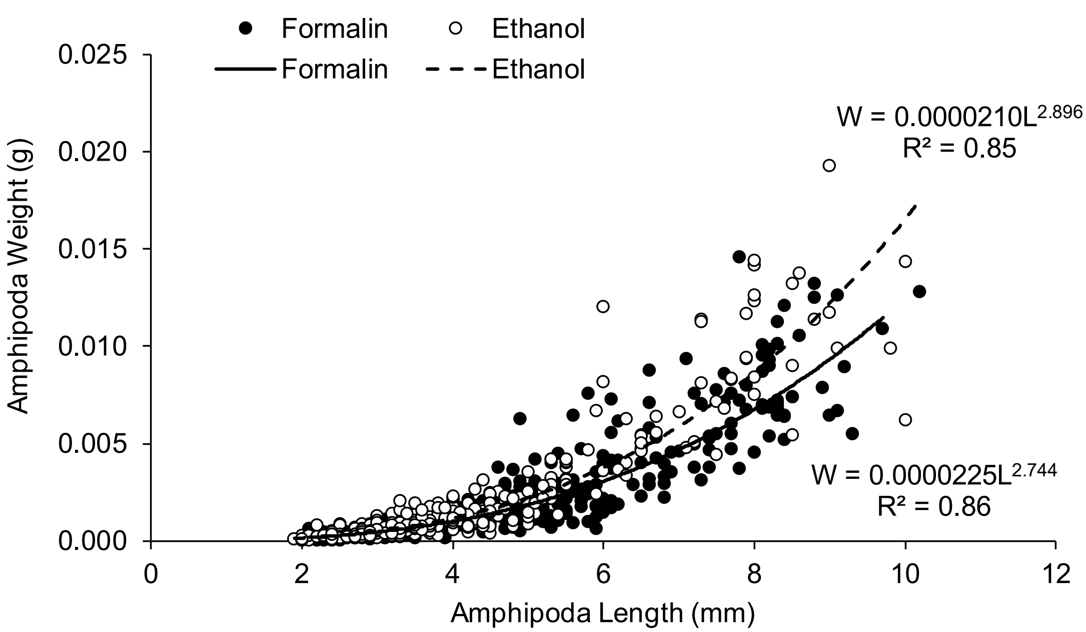

Figure 8. Scatterplot of the length-weight relationship of all amphipods (order Amphipoda) preserved in ethanol (n= 367; W= $0.0000210L^{2.896}$) and formalin (n= 599; W= $0.0000225L^{2.744}$). The intercepts of the length-weight relationships were significantly different ($F_{1, 963}$= 21.92, p<<0.001), but not the slopes ($F_{1, 962}$= 3.77, p=0.05). $F_{1, 963}$= 17.08, p< 0.001).

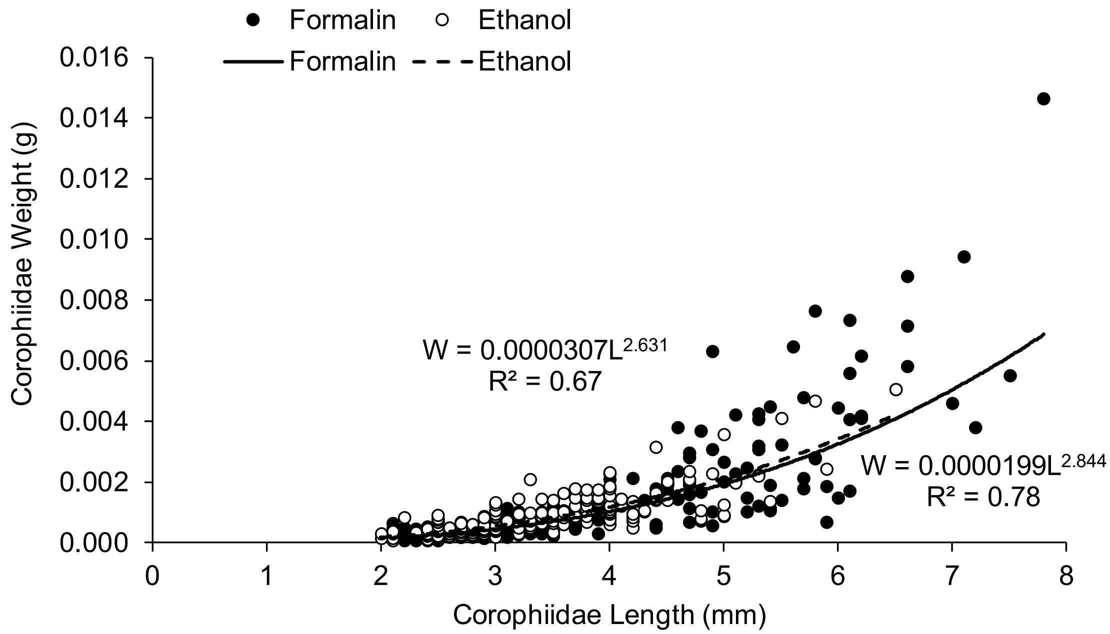

Figure 9. Scatterplot of the length-weight relationship of amphipods in the family Corophiidae preserved in ethanol (n= 156; W= $0.0000307L^{2.631}$) and formalin (n= 292; W= $0.0000199L^{2.844}$). There was not a significant difference between the length-weight relationship slopes ($F_{1,444}$= 1.44, p=0.23), but there was between the intercepts ($F_{1,445}$= 12.94, p<<0.001).

among sexes with males having larger physical structures than females of similar body length, thus greater overall mass. Differences in length-weight relationships in sexually dimorphic species of mysids and amphipods need to be examined further. Application of these equations to length data could provide biomass estimates of available prey in the environment for higher trophic levels, as well as to examine stomach fullness of zooplanktivorous fish to evaluate feeding success.

We acknowledge that the samples here were from the stomachs of young fish and some amount of digestion, thus lowered mass is possible, but we believe it to be minor if negligible in most cases as the delicate structures of the invertebrates (e.g. antennae) were intact and bodies whole. Future evaluations of length-weight relationships could target species directly, smaller life stages, and sex differences of macrozooplankton.

Acknowledgements

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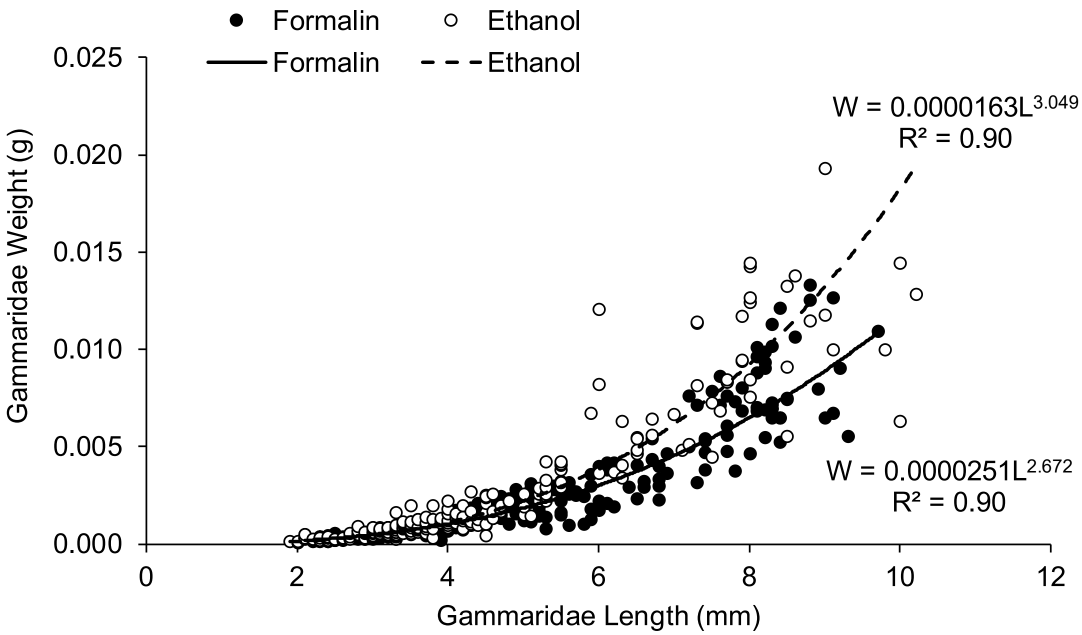

Figure 10. Scatterplot of the length-weight relationship of amphipods in the family Gammaridae preserved in ethanol (n= 209; W= $0.0000163L^{3.049}$) and formalin (n= 307; W= $0.0000251L^{2.672}$). There was a significant difference between preservatives ($F_{1,512}$=19.51, p<0.001).

Table 1: Length-weight relationships for mysids and amphipods. Equations are separated by preservative and taxonomic classification. Equations are in a W=aLb format, where W is the weight (g), L is the length (mm), a is a constant and b is an exponent. All weights are wet weights. N is the number of individuals used to calculate the equations. The average percent difference of estimated weights based on the equations are also given for taxa preserved in both ethanol and formalin.

Taxonomic Name	Difference between Preservatives (%)	Preservative	N	Min Length (mm)	Max Length (mm)	a	b	R^2
Hyperacanthomysis longirostris	44.5	Ethanol	50	3.3	9.5	0.0000116	3.060	0.69
		Formalin	107	2.9	11.0	0.0000054	3.232	0.75
Amphipoda	18.5	Ethanol	367	1.9	10.2	0.0000210	2.896	0.85
		Formalin	599	2.1	9.7	0.0000225	2.744	0.86
Gammaridae	24.1	Ethanol	209	1.9	10.2	0.0000163	3.049	0.90
		Formalin	307	2.1	9.7	0.0000251	2.672	0.90
Gammarus daiberi	38.9	Ethanol	84	2.0	10.2	0.0000120	3.225	0.93
		Formalin	106	3.3	9.7	0.0000074	3.275	0.82
Crangonyx spp.		Ethanol	37	2.3	5.5	0.0000093	3.284	0.77
Hyalella spp.		Ethanol	39	1.9	10.0	0.0000334	2.594	0.82
Ampelisca abdita		Formalin	196	2.1	6.2	0.0000239	2.739	0.82
Corophiidae	11.3	Ethanol	156	2.0	6.5	0.0000307	2.631	0.67
		Formalin	292	2.1	7.8	0.0000199	2.844	0.78
Americorophium spinicorne	15.0	Ethanol	108	2.0	6.5	0.0000330	2.646	0.70
		Formalin	113	2.1	7.5	0.0000220	2.826	0.78
Americorophium stimpsoni	13.1	Ethanol	25	2.1	5.9	0.0000317	2.476	0.64
		Formalin	57	2.2	7.8	0.0000443	2.203	0.57
Sinocorophium alienese		Ethanol	19	2.0	5.1	0.0000250	2.641	0.70
Monocorophium spp.		Formalin	109	2.1	4.3	0.0000174	2.871	0.49

Table 2. The Analysis of Covariance (ANCOVA; SYSTAT 13) results for comparisons of the same taxon in both ethanol and formalin. The taxonomic group, whether the test was on the slope or the intercept, the degrees of freedom (df), F statistic and p-value from the ANCOVA are given. All groups except for the family Gammaridae and *A. stimpsoni* showed significant differences between the intercepts, but not the slopes with ethanol being heavier at length. There was no significant difference between preservatives for *A. stimpsoni*. Gammaridae individuals in ethanol had a significantly higher length- weight relationship slope than those in formalin.

Taxonomic Group	ANCOVA	df (between groups, within groups)	F- Statistic	p Value
Hyperacanthomysis longirostris	Slope	1, 166	3.34	0.07
	Intercept	1, 167	25.25	<<0.001
Amphipoda	Slope	1, 962	3.77	0.05
	Intercept	1, 963	21.92	<<0.001
Corophiidae	Slope	1, 444	1.44	0.23
	Intercept	1, 445	12.94	<<0.001
Gammaridae	Slope	1, 512	19.51	<0.001
Americorophium spinicorne	Slope	1, 217	0.65	0.42
	Intercept	1, 218	6.69	<0.01
Americorophium stimpsoni	Slope	1, 78	0.27	0.06
	Intercept	1, 79	1.70×10^{-6}	0.99
Gammarus daiberi	Slope	1, 186	0.08	0.78
	Intercept	1, 187	57.20	<<0.001

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2018 Delta Juvenile Fish Monitoring Program Resident Fishes Status and Trends

Cory Graham* and Brian Mahardja (USFWS)

*Corresponding Author:
cory_graham@fws.gov

Introduction

The Delta Juvenile Fish Monitoring Program (DJFMP) of the United States Fish and Wildlife Service has monitored juvenile Chinook Salmon (*Oncorhynchus tshawytscha*) within the Sacramento-San Joaquin Delta (Delta) since the mid-1970s. The original purpose of DJFMP was to evaluate the impact of water operations in the Delta on the survival, distribution and outmigration timing of juvenile Chinook Salmon. However, with the growing recognition of importance of other members of the fish community in shaping ecosystem health and resilience, the objectives of DJFMP were expanded in the early 2000s to include documenting the abundance and distribution of the Delta juvenile fish community.

The purpose of this report is to describe inter-annual abundance trends and distributional patterns of juvenile resident fishes within the Delta. Because DJFMP is currently the only long-term nearshore monitoring program in the Delta, special focus will be paid to the littoral fish community such as Bluegill (*Lepomis macrochirus*), Largemouth Bass (*Micropterus salmoides*), Mississippi Silversides (*Menidia audens*), Redear Sunfish (*Lepomis microlophus*), Sacramento Pikeminnow (*Ptychocheilus grandis*), and Sacramento Sucker (*Catostomus occidentalis*). Abundance trends of Longfin Smelt (*Spirinchus thaleichthys*) will also be presented in this report due the species' listing under the California Endangered Species Act (CESA). This article covers data collected from 1995 to 2018. The complete DJFMP dataset, including environmental data not included in this report, and a description of sampling procedures are available at DJFMP's Environmental Data Initiative Data Portal (IEP et al. 2019).

Methods

Species

The analyses in this report were limited to 7 species. For centrarchids, Bluegill, Largemouth Bass, and Redear Sunfish were selected due to their high catch numbers in our sampling areas (Table 1) and their ability to cause long-term changes to the local food web (Mittelbach et al. 1995). Mississippi Silversides were included due to their high biomass in littoral habitats and their potential predation on Delta Smelt (*Hypomesus transpacificus*; Baerwald et al. 2012, Schreier et al. 2016). Relative abundance trends were also examined for Sacramento Pikeminnow and Sacramento Sucker because they are understudied native species with uncertain status and trends. Sacramento Splittail (*Pogonichthys macrolepidotus*) were not included because their abundance trends for 2018 have already been reported (White et al. 2019). Longfin Smelt were presented in this report due to their decline in abundance following the Pelagic Organism Decline (POD; Sommer et al. 2007) and their threatened status under CESA.

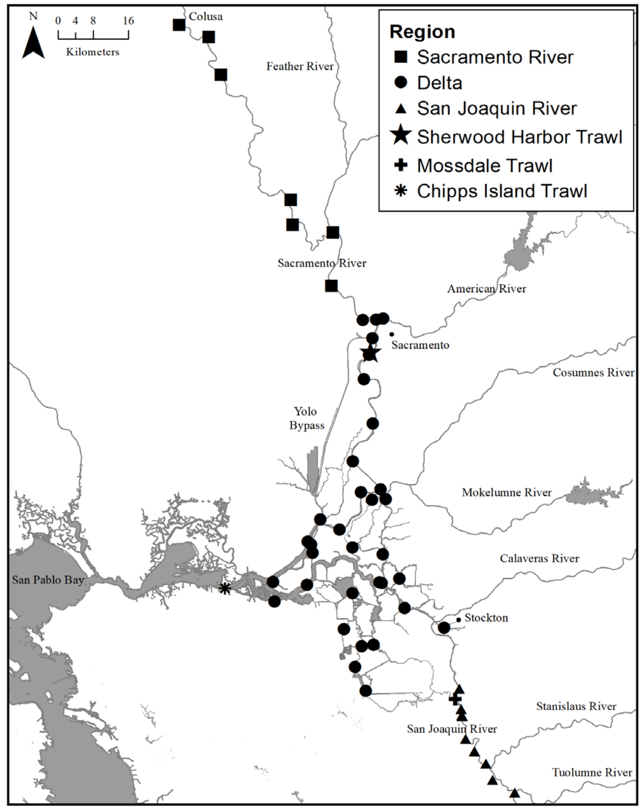
Beach Seines

Beach seines were used by DJFMP to quantify the spatial distribution of fishes occurring in unobstructed nearshore habitats (i.e., beaches and boat ramps) throughout the Delta. Currently, this is the only long-term monitoring program surveying littoral habitats in the Delta, which makes the data valuable for a more holistic understanding of fish community changes (Nobriga et al. 2005) and documenting the expansion of non-native fishes in nearshore habitats (Moyle and Bennett 2008).

In general, beach seine sampling was conducted weekly at sites located throughout the Delta using a 15.2 x 1.3 m net with 3 mm2 mesh. Beach seine sites were stratified into 3 geographic regions (Figure 1), which were composed of subareas, following the designations that the California Department of Fish and Wildlife (CDFW) uses to estimate age-0 Splittail abundance indices (White et al. 2019). These regions were adopted for this report because DJFMP's seine runs were designed for sampling convenience and do not account for large-scale habitat characteristics. Because year round sampling started in 1995, prior samples were excluded. Beach seine samples collected from Liberty Island were also excluded from this report due to inconsistent sampling resulting from submerged aquatic vegetation (SAV) incursion into the sites.

The beach seine dataset was used to generate abundance indices for Bluegill, Largemouth Bass, Mississippi Silversides, Redear Sunfish, Sacramento Pikeminnow, and Sacramento Sucker. Longfin Smelt are rarely caught using beach seines; therefore, their index was not created using this dataset. Because beach seines are most efficient at capturing fish during early life stages and length-at-age estimates were not available for the species in this report, it was assumed that the majority of catch was represented by age-0 fish.

Figure 1. Beach seine and trawl sites sampled during the 1995-2018 field seasons. Beach seines were grouped by region (i.e., Sacramento River, Delta, San Joaquin River).



Surface Trawls

Surface trawls were used to examine the relative abundance of fishes migrating into (i.e., Sherwood Harbor, Mossdale) and out of (i.e., Chipps Island) the Delta. Chipps Island was sampled using a mid-water (MWTR) trawl. In contrast, Mossdale was sampled using a Kodiak (KDTR) trawl. Mossdale was sampled by CDFW in April through June following similar methodologies. Finally, Sherwood Harbor was sampled using a combination of KDTR (October through March) and MWTR (April through September).

In general, a total of ten 20-minute tows were attempted three times per week at each sampling location. In 2018, Chipps Island and Sherwood Harbor were sampled 5-7 times per week between January and May for Chipps Island and January and March for Sherwood Harbor. Additional sampling at these locations was part of a project intended to estimate gear efficiencies and produce absolute abundance estimates of juvenile Chinook Salmon.

Surface trawl data were used to create abundance indices for Longfin Smelt. Abundance indices for Bluegill, Largemouth Bass, Mississippi Silversides, Redear Sunfish, Sacramento Pikeminnow, and Sacramento

Sucker were not estimated using trawl data because of the greater number of sub-adults and adults caught by surface trawls and generally lower catch numbers relative to beach seines (Table 2).

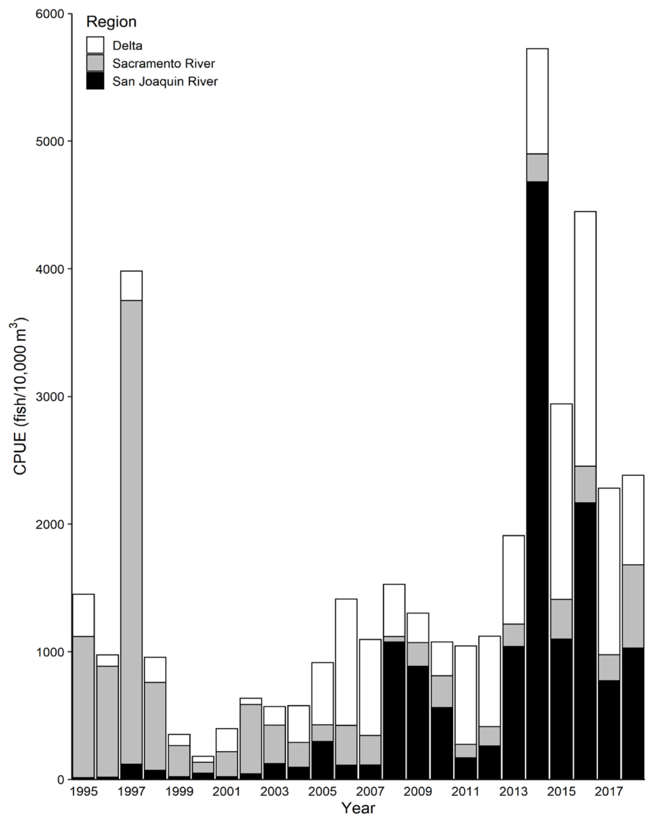
Fish Processing

For both beach seines and surface trawls, all fish ≥ 25 mm fork length (FL) were identified to species and measured to the nearest 1 mm with the exception of Sacramento Sucker, which were identified at fork lengths ≥ 20 mm. For large catches of non-listed species, a subsample of 30 individuals was measured for FL and the rest were counted but not measured (referred to as a plus count). For listed species, 50 individuals were measured before plus counting. All unidentifiable fish above the size threshold were brought back to the laboratory where their species was determined using a dichotomous key and microscope.

Abundance Indices

For beach seines, annual abundance indices were estimated by averaging CPUE (catch/m3 * 10,000) by station, subarea, month, year, and region. Mean CPUEs for each region (i.e., Sacramento River, Delta, San Joaquin River) were summed to create the Delta-wide index. For surface trawls, CPUE was also calculated by dividing catch by volume and multiplying by 10,000. The abundance indices were then estimated by averaging by date, station, month, and year. For both gear types, samples with compromised gear deployment and/or those without volume estimates were excluded from the estimates. Further, for surface trawls, outlier volume samples from the period covered in this article (1995-2018) were excluded from the estimates by removing points that fell outside of box plot whiskers (R Core Team 2019; function: boxplot.stats; package: grDevices).

Figure 2. Time series of abundance index estimates for Bluegill.



Results and Discussion

Bluegill

Bluegill are native to the eastern and southern United States, however, after their introduction to California in the early 1900s, they have become one of the most widely distributed and abundant warm water species in the state (Moyle 2002). Their wide distribution and high abundance within the Delta may result from their ability to survive and reproduce under a wide variety of environmental conditions and habitat types. Bluegill are tolerant of high temperatures and low dissolved O2, and are often found in association with rooted aquatic vegetation, which provides foraging opportunities and refugia from predators. While they exhibit a wide geographical range, they have limited local ranges throughout their lifespan. They are opportunistic foragers and may feed on variety of aquatic and terrestrial invertebrates, fish larvae, and algae and aquatic plants. Their wide distribution, high abundance, and opportunistic foraging strategy may limit the production of native species directly through predation on their larvae and indirectly through changes to the littoral food web. Introduced sunfishes such as Bluegill have been implicated as a primary driver of the extirpation of the Sacramento Perch (Archoplites interruptus) from the Central Valley of California (Moyle 2002).

In general, the abundance index for Bluegill has increased across the time series, with the increase resulting from higher CPUEs in San Joaquin River and the Delta regions (Figure 2). In contrast, CPUE in the Sacramento River Region has declined following highs in the mid- to late-1990s. The increase in Bluegill abundance may be related to SAV expansion within the Delta. The total area of SAV within the Delta increased from 2004 to 2014 (Ustin et al. 2016), which coincided with an 893 percent increase in the Bluegill abundance index. However, the index declined 58 percent from 2014 to 2018 indicating that the abundance of this species may be influenced by factors other than SAV extent.

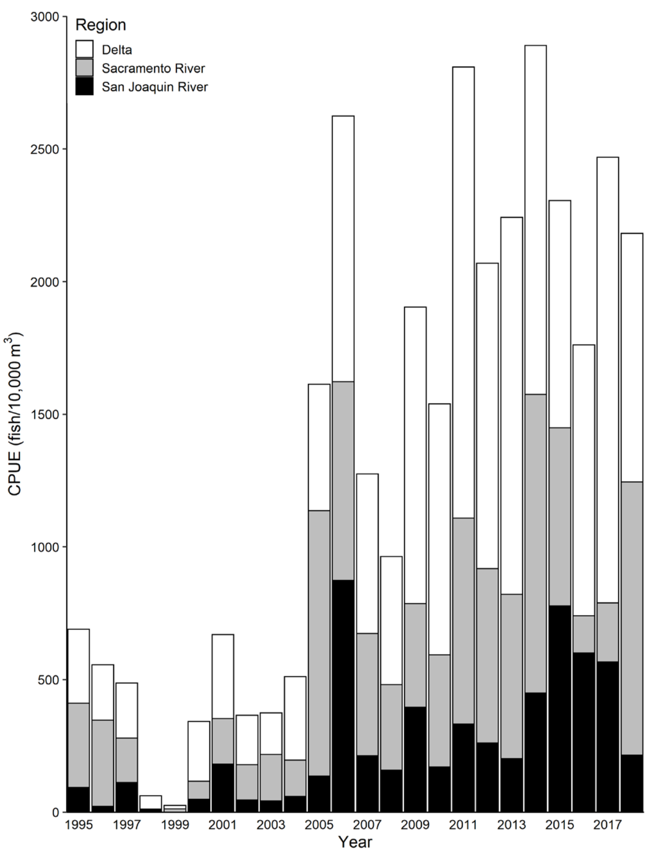


Figure 3. Time series of abundance index estimates for Largemouth Bass.

Largemouth Bass

Largemouth Bass are native to eastern North America and were introduced to California in the 1890s (Moyle 2002). While they have been present in the Delta for over a century, their abundance within the system seems to have increased concurrently with the proliferation of the invasive weed Egeria densa (Brown and Michniuk 2007, Conrad et al. 2016, Mahardja et al. 2017). Their large gape size and flexible foraging behaviors have allowed Largemouth Bass to become an apex predator in nearshore areas of the Delta. Although Largemouth Bass are often found in association with non-native species and may have lower spatial overlap with native fish species than other predators, they can be effective predators of native fish in the Delta under certain circumstances (Nobriga and Feyrer 2007). Therefore, there is concern that increases in abundance and distribution of this species may further imperil a variety of native fishes within the Delta.

There was a marked increase in the abundance index of Largemouth Bass in 2005, which was sustained for the remainder of the time series (Figure 3). Similar to Bluegill, the increase in Largemouth Bass abundance coincided with SAV expansion within the Delta. The 2018 abundance index was 2,181 which was the seventh highest recorded value and was 8,529 percent higher than the minimum recorded value in 1999. While CPUE was higher in all three regions following 2005, the largest increases in CPUE occurred in the Delta and Sacramento regions. The Sacramento River is an

Table 1. Total individuals caught using beach seines during calendar year 2018. Counts were grouped by species and region.

Fish Species	Delta	Sacramento River	San Joaquin River
Bluefin Killifish *Lucania goodei*	1	0	0
Bluegill *Lepomis macrochirus*	259	87	379
Black Bullhead *Ameiurus melas*	1	0	0
Black Crappie *Pomoxis nigromaculatus*	6	146	6
Brown Bullhead *Ameiurus nebulosus*	1	0	0
Common Carp *Cyprinus carpio*	1	50	1
Channel Catfish *Ictalurus punctatus*	0	0	17
Fathead Minnow *Pimephales promelas*	32	110	0
Goldfish *Carassius auratus*	3	3	0
Green Sunfish *Lepomis cyanellus*	0	1	0
Golden Shiner *Notemigonus crysoleucas*	363	241	153
Hitch *Lavinia exilicauda*	0	11	0
Hardhead *Mylopharodon conocephalus*	1	16	0
Largemouth Bass *Micropterus salmoides*	435	165	66
Bigscale Logperch *Percina macrolepida*	25	211	69
Western Mosquitofish *Gambusia affinis*	258	421	519
Mississippi Silverside *Menidia audens*	59514	3579	16559
Prickly Sculpin *Cottus asper*	90	2	10
Pacific Staghorn Sculpin *Leptocottus armatus*	3	0	0
Redear Sunfish *Lepomis microlophus*	472	136	82
Rainwater Killifish *Lucania parva*	640	2	4
Red Shiner *Cyprinella lutrensis*	1717	2395	4914
Sacramento Pikeminnow *Ptychocheilus grandis*	216	174	3
Sacramento Sucker *Catostomus occidentalis*	1837	2147	494
Sacramento Blackfish *Orthodon microlepidotus*	0	2	1
Shimofuri Goby *Tridentiger bifasciatus*	65	0	2
Smallmouth Bass *Micropterus dolomieu*	2	12	0
Spotted Bass *Micropterus punctulatus*	40	42	4
Splittail *Pogonichthys macrolepidotus*	879	179	113
Striped Bass *Morone saxatilis*	29	0	42
Threadfin Shad *Dorosoma petenense*	1671	2331	2459
Tule Perch *Hysterocarpus traskii*	135	3	0
Threespine Stickleback *Gasterosteus aculeatus*	5	0	0
Warmouth *Lepomis gulosus*	1	0	0
Wakasagi *Hypomesus nipponensis*	12	1	0
White Catfish *Ameiurus catus*	3	0	0
White Crappie *Pomoxis annularis*	0	18	0
Yellowfin Goby *Acanthogobius flavimanus*	60	0	0

important source of native fish production in the Delta (Brown and May 2006), therefore, high abundance of Largemouth Bass in this region may increase predation pressure on a variety of native fishes.

Mississippi Silversides

Since becoming established in the Delta in the mid-1970s, Mississippi Silversides have become one of the most prolific species in the system (Moyle 2002). They can tolerate a wide variety of environmental conditions, but are often found in shallow nearshore areas where they shoal in high numbers. While their impacts on native populations are not well understood, they may reduce them directly via larval predation (Schreier et al. 2016) and/or indirectly through competition for limited food resources (i.e., zooplankton; Moyle 2002)

With few exceptions, the abundance index for Mississippi Silversides has progressively increased throughout the time series with the majority of the increase being driven by higher CPUEs in the Delta and San Joaquin River regions (Figure 4). In contrast, there have been negligible increases in CPUE in the Sacramento River Region. In 2018, the abundance index was 302,978 which was the highest recorded index and was 146 percent higher than the index in 2017. The increase in the abundance index from 2017 to 2018 likely reflects the high recruitment success of Mississippi Silversides during years with low flow (Mahardja et al. 2016). Both the abundance index and the catch in all three regions for Mississippi Silversides were the highest of any species in this report (Table 1).

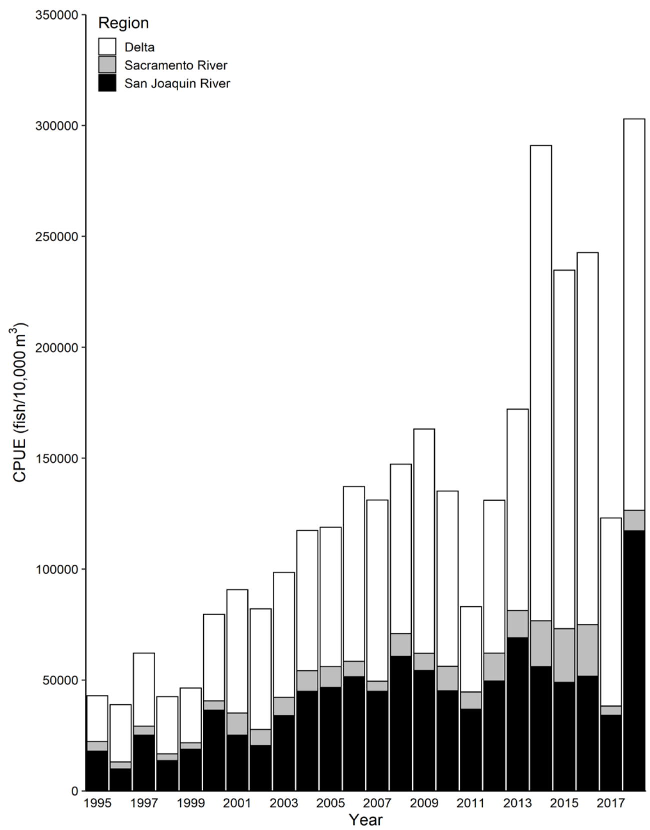


Figure 4. Time series of abundance index estimates for Mississippi Silversides.

Redear Sunfish

Redear Sunfish are native to the southeastern United States and were first identified in California in the early 1950s (Moyle 2002). While Redear Sunfish are found in a variety of freshwater habitats, they prefer deep water in lakes, ponds, and reservoirs where they forage on benthic invertebrates and aquatic plants. Their growth and reproductive success are positively related to water clarity due to high turbidity limiting plant growth. Their abundance has increased significantly over the past few decades similar to Largemouth Bass and Bluegill (Brown and Michniuk 2007), which is likely due to their association with SAV (Young et al. 2018).

The abundance index for Redear Sunfish has increased across the time series with this increase being most apparent starting in 2011 (Figure 5). When considering region, the largest increase in CPUE occurred in the Delta; however, CPUE was also higher in the Sacramento and San Joaquin regions relative to the beginning of the time series. The large increase in CPUE in the Delta and the San Joaquin River may result from the proliferation of SAV in these regions (Ta et

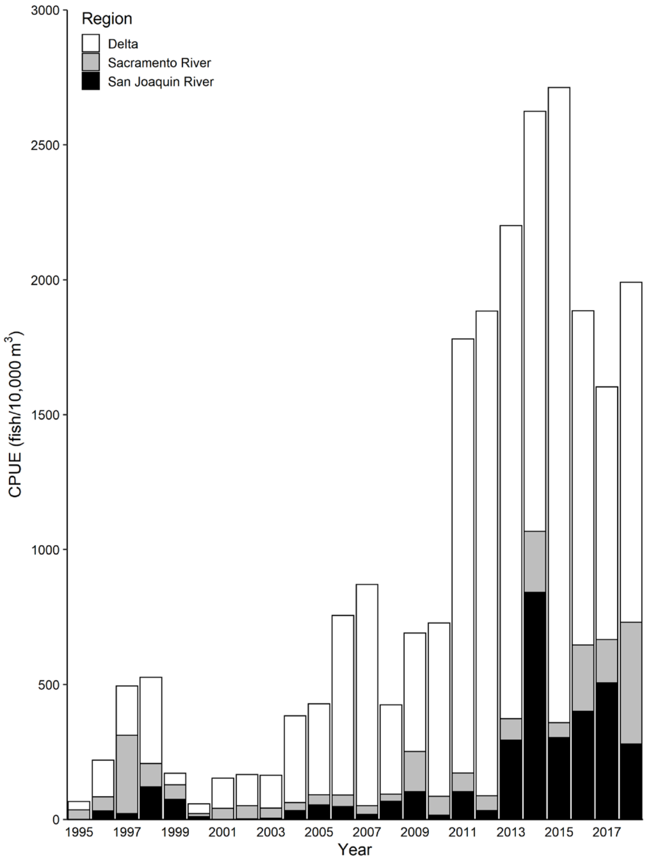


Figure 5. Time series of abundance index estimates for Redear Sunfish.

al. 2017) and its potential contribution to the decline of turbidity within the Delta (Hestir et al. 2016). The highest index values for this species occurred 2014 and 2015, which were classified as critically dry water years in the Sacramento River (CDWR 2018). The index declined during the wet water year of 2017, however, it was still greater than pre-drought levels. While the index value of 1,990 in 2018 was lower than the maximum recorded index value of 2,713 in 2014, it was the fourth highest recorded index and was 24 percent higher than the index in 2017.

Sacramento Pikeminnow

Sacramento Pikeminnow is a large, long-lived cyprinid species that is endemic to California (Moyle 2002). They are highly migratory and spawn in major tributaries of the Delta in March through May. After hatching, juveniles disperse downstream where they rear in backwater habitats. The Delta is thought to be an important rearing ground for age-1+ fish with flow levels determining how many rear in the region (Nobriga et al. 2006). Overall, the production of Sacramento Pikeminnow is higher in the Sacramento River relative to the San Joaquin River where there is negligible production except in years with high flow (Brown and Michniuk 2007). Sacramento Pikeminnow are opportunistic feeders that may forage on a variety of prey types throughout the water column, however, they display an ontogenetic shift and feed on a higher proportion of fish as they grow. Prior to the introduction of Striped Bass (*Morone saxatilis*) and Largemouth Bass, they were apex predators in the Delta.

In general, the abundance index for Sacramento Pikeminnow has remained steady across the study period (Figure 6). However, the index value of 1,445 in 2018 was the lowest recorded in the time series and was 37 percent lower than 2017 and 88 percent lower than the maximum recorded index in 2008. Because Sacramento Pikeminnow are widely distributed on the Sacramento River and may rear for multiple years in their natal tributaries (Moyle 2002), it is not possible to attribute the decline in the 2018 index to low overall abundance or to a shift in the distribution of the species. When considering the spatial coverage sampled for this report, there have not been dramatic changes in the regional distribution of Sacramento Pikeminnow. Catch of this species continued to be highest in the Sacramento River Region and lowest in the San Joaquin Region. Because Sacramento Pikeminnow cannot complete their life cycle within the Delta, negligible catches of this species in the San Joaquin River (Table 1; Figure 6) suggest there is low reproductive success within the tributaries of this region.

Table 2. Total individuals caught using trawls during calendar year 2018. Counts were grouped by species and trawl site.

Fish Species	Chipps Island	Mossdale	Sherwood Harbor
Bluegill *Lepomis macrochirus*	3	3820	22
Black Bullhead *Ameiurus melas*	0	1	1
Black Crappie *Pomoxis nigromaculatus*	1	10	12
Common Carp *Cyprinus carpio*	0	12	6
Channel Catfish *Ictalurus punctatus*	1	697	6
Delta Smelt *Hypomesus transpacificus*	1	0	0
Fathead Minnow *Pimephales promelas*	0	0	2
Goldfish *Carassius auratus*	0	13	1
Green Sunfish *Lepomis cyanellus*	1	0	3
Golden Shiner *Notemigonus crysoleucas*	2	247	22
Jacksmelt *Atherinopsis californiensis*	3	0	0
Longfin Smelt *Spirinchus thaleichthys*	197	0	0
Largemouth Bass *Micropterus salmoides*	1	22	2
Bigscale Logperch *Percina macrolepida*	0	3	1
Western Mosquitofish *Gambusia affinis*	0	0	2
Mississippi Silverside *Menidia audens*	1	8742	340
Northern Anchovy *Engraulis mordax*	1798	0	0
Pacific Herring *Clupea pallasii*	54	0	0
Pacific Lamprey *Lampetra tridentata*	2	8	9
Pacific Staghorn Sculpin *Leptocottus armatus*	3	0	0
Redear Sunfish *Lepomis microlophus*	1	89	8
Rainwater Killifish *Lucania parva*	0	3	0
Red Shiner *Cyprinella lutrensis*	0	103	0
Sacramento Pikeminnow *Ptychocheilus grandis*	0	0	22
Sacramento Sucker *Catostomus occidentalis*	0	6	0
Sacramento Blackfish *Orthodon microlepidotus*	0	3	0
Shokihaze Goby *Tridentiger barbatus*	5	0	0
Shimofuri Goby *Tridentiger bifasciatus*	7	1	0
Spotted Bass *Micropterus punctulatus*	1	1	0
Splittail *Pogonichthys macrolepidotus*	61	214	2
Striped Bass *Morone saxatilis*	1516	591	4
Starry Flounder *Platichthys stellatus*	21	0	0
Threadfin Shad *Dorosoma petenense*	1594	4295	122
Tule Perch *Hysterocarpus traskii*	2	1	1
Threespine Stickleback *Gasterosteus aculeatus*	0	0	1
Warmouth *Lepomis gulosus*	0	0	1
Wakasagi *Hypomesus nipponensis*	0	2	2
White Catfish *Ameiurus catus*	0	134	6
White Crappie *Pomoxis annularis*	1	6	2

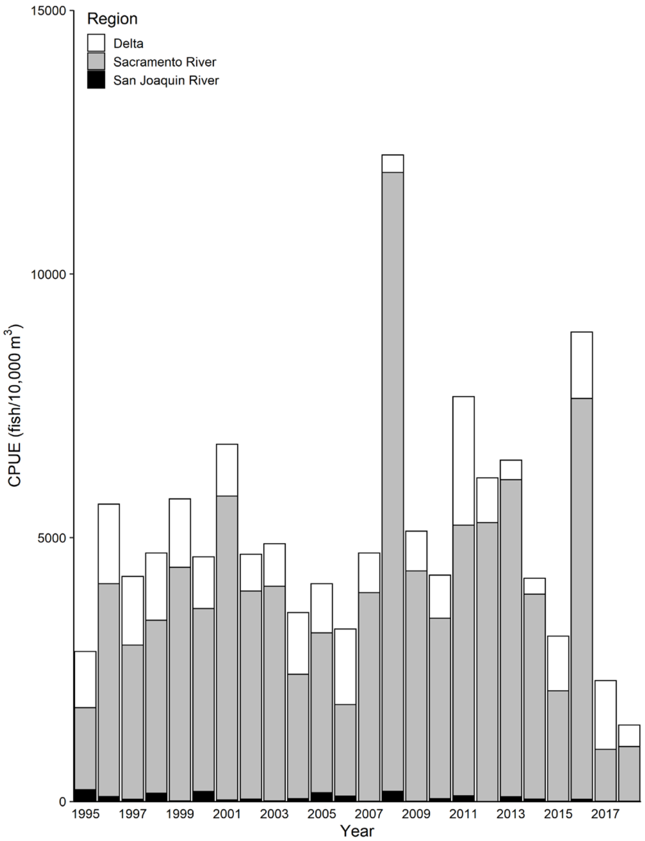


Figure 6. Time series of abundance index estimates for Sacramento Pikeminnow.

Sacramento Sucker

Sacramento Sucker is a long-lived catostomid species that is native to the Delta (Moyle 2002). They may inhabit a variety of freshwater habitats but are most abundant in cool streams and rivers with low turbidity. In general, Sacramento Sucker migrate into major tributaries where they spawn on riffles between February and June. Their recruitment success is thought to be highest when high flows increase spawning and rearing habitat and provide refugia from predators. After emerging, larvae are flushed downstream to areas (i.e., warm shallows, flooded vegetation) where they may rear for multiple years before migrating into the Delta. Due to their ability to tolerate a variety of environmental conditions and their high recruitment success when conditions are favorable, they are one of the few native species that maintained relatively high numbers within the highly modified Delta.

The abundance index for Sacramento Sucker peaked in the mid-2000s before declining to late-1990s and early-2000s values at the end of the time series (Figure 7). While previous research suggests that the reproductive success of this species is highest during wet years (Moyle 2002), the top five abundance index values all occurred during below normal to critically dry water years (CDWR 2018). Because this species is migratory and may rear in tributaries for multiple years before entering the Delta, the high abundance index values during dry years may reflect distributional changes and not recruitment success. Throughout the majority of the time series, CPUEs were highest in the Sacramento followed by the Delta and the San Joaquin regions. In 2018, the abundance

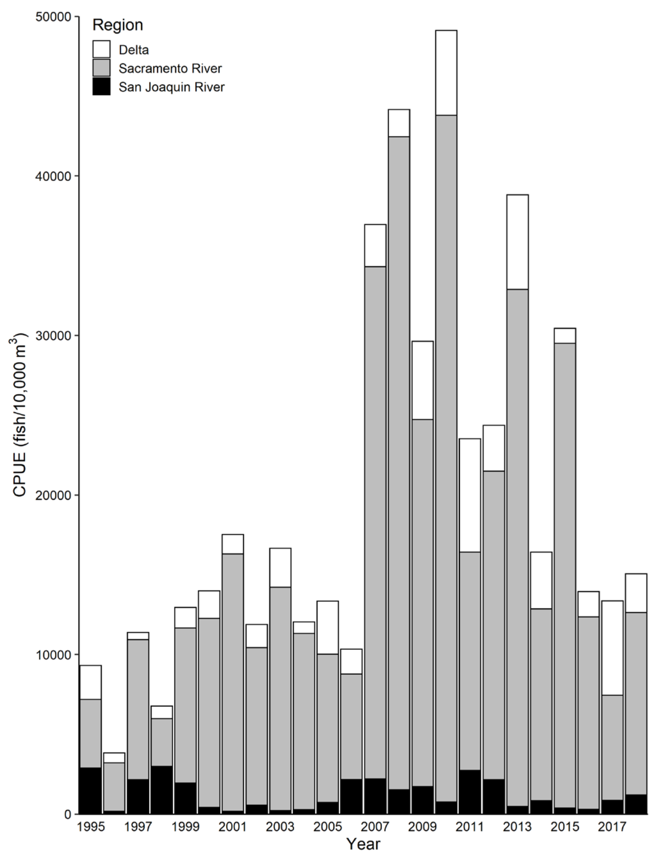


Figure 7. Time series of abundance index estimates for Sacramento Sucker.

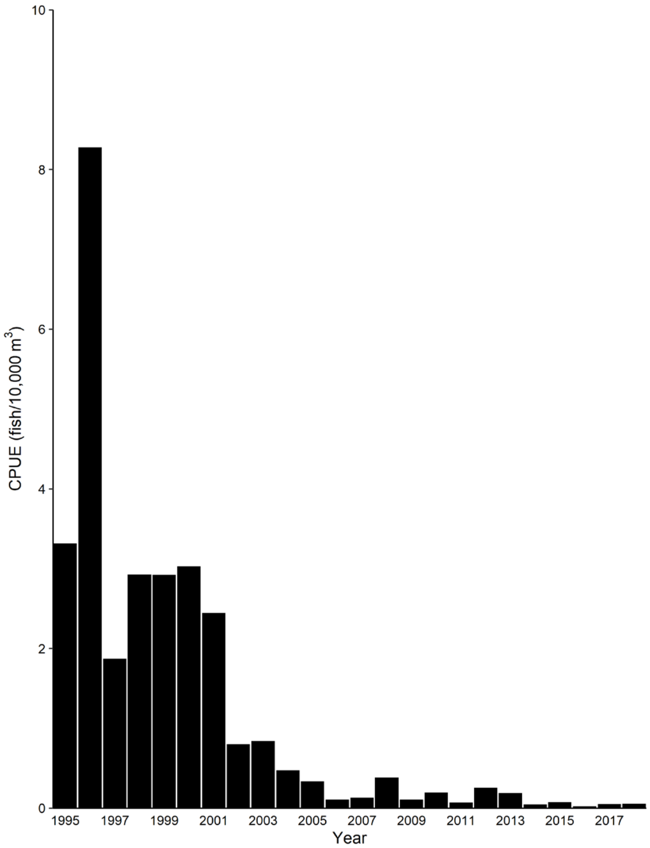


Figure 8. Time series of abundance index estimates for Longfin Smelt at Chipps Island.

index was 15,058 which was 69 percent lower than the maximum value observed in 2010. While the abundance index has declined following highs recorded in the mid-2000s, Sacramento Sucker were one of the most frequently caught species in the Delta and Sacramento River regions, and was the most frequently caught native fish species in all three beach seining regions in 2018 (Table 1).

Longfin Smelt are endemic to the West Coast of North America with the San Francisco Estuary (SFE) representing the southern extent of their distribution (Moyle 2002). Within the SFE, they rear in the coastal marine waters for 1-2 years before migrating upstream to spawn in tidally influenced freshwater habitats. At one time, Longfin Smelt were among the most abundant fish species in the SFE with their recruitment success being positively related to flow during their early life history (Rosenfield and Baxter 2007, Nobriga and Rosenfield 2016). However, following the POD in the mid-2000s, their abundance declined precipitously which led to them being listed as threatened under the CESA in 2009 (Sommer et al. 2007).

Due to low catches at Mossdale and Sherwood Harbor trawl sites (Table 2), results are only presented for Chipps Island (Figure 8). There has been a dramatic decline in the abundance index of Longfin Smelt since the start of the time series, which is consistent with the findings of CDFW's Fall Midwater Trawl Survey (Contreras et al. 2011). Further, this decline is highlighted by the drop in the abundance index starting after 2001, which corresponded to the POD (Sommer et al. 2007). Even with the wet water year of 2017, the index continues to decline with the five lowest index values being recorded during the final five years of the time series. While the index increased 8 percent from 2017 to 2018, it is far below the mean value prior to the POD and 99 percent below the maximum recorded index in 1996.

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An Online Seasonal Monitoring Report for Major Interagency Ecological Program Surveys

Rosemary Hartman* (DWR), Nick Rasmussen (DWR), Lara Mitchell (USFWS), Michael Koohafkan (DWR), David Bosworth (DWR), JohnFranco Saraceno (DWR), Jason DuBois (CDFW), Sam Bashevkin (DSP), and Louise Conrad (DSP)

*Corresponding Author:
Rosemary.Hartman@water.ca.gov

Introduction

Long-term ecological surveys are a core function of the Interagency Ecological Program (IEP). Translating these survey data into graphical, easy-to-interpret reports is an important part of communicating Program results. The IEP Synthesis team has been producing a series of concise graphical reports that highlight the breadth and longevity of major IEP surveys. Previously, these reports were in the form of static PDFs, shared via listservs and a document repository (Hartman et al. In Press; Rasmussen and Conrad 2018). We have begun to automate the production and updating of these reports to reduce the effort required to produce them over the long term and to assure that they are released on a quarterly basis. Furthermore, we want the reports to be publicly available on the IEP website, which requires that they be compliant with the Americans with Disabilities Act (ADA). Therefore, the reports must be automated in a way that complies with these regulations.

The goal is to provide reports that reach agency managers and directors, IEP stakeholders, and potential academic, private, or non-governmental collaborators. We hope that these reports will facilitate improved communication of IEP efforts to a broad community. Also, we believe the tools and techniques employed in streamlining the production of the Seasonal Monitoring Reports could be applied to many other IEP reports, particularly those that consist of routine updates on monitoring programs.

Methods

The automated reports are generated quarterly by adding an additional season of data to the previous report. Each report shows data for a given season. The development of the Fall and Winter reports has been described in IEP Newsletter Volume 32 No1 (Rasmussen and Conrad 2018), and Volume 34 No1 (Hartman et al. In Press). In this article, we describe development of the Spring and Summer reports (Appendix A and B) and process that was used to automate the compilation of all four reports into an online resource (https://interagencyecologicalprogram.github.io/Status-and-Trends/).

The Spring Report (Appendix A) covers March-May and displays trends in:

- Average Spring Delta Outflow (DWR's Dayflow model),
- Water quality (DWR-CDFW Environmental Monitoring Program [EMP]; IEP 2020a),
- The planktonic food web (EMP),
- Longfin Smelt, *Spirinchus thaleichthys*, and Delta Smelt, *Hypomesus transpacificus* (CDFW 20-mm survey),
- Adult Spring-Run Salmon, *Oncorhynchus tshawytscha*, (CDFW Grand Tab),
- Juvenile Sacramento Splittail, Pogonichthys macrolepidotus, (DWR Yolo Bypass Fish Monitoring Program; IEP 2018)
- Juvenile Chinook Salmon (USFWS Chipps Island Trawl; IEP 2020b).

In the first five sections, the full duration of all surveys is shown, from 1967-2018. The last section shows recent fisheries data (2004-2018) to demonstrate trends since the Pelagic Organism Decline. Each page includes a brief narrative for context produced by the report team after the graphs are updated. Full details on data processing are provided in the metadata.

The Summer Report (Appendix B) covers June-August and displays trends in:

- Average Summer Delta Outflow (DWR's Dayflow model),
- Water quality (EMP; IEP2020a),
- Pacific Anchovy, Engraulis mordax, (CDFW Bay Study),
- Delta Smelt, (CDFW Summer Townet),
- Sacramento Pikeminnow, Ptychocheilus grandis (USFWS Beach Seine; IEP 2020b),
- Aquatic weeds (UC Davis Center for Spatial Technologies and Remote Sensing [CSTARS]),
- The toxic algae Microcystis (EMP and Summer Townet).

In the first five sections, the full duration of all surveys is shown, from 1967-2018. The last section shows recent data (2004-2018) to demonstrate trends since the Pelagic Organism Decline and issues that have only become a problem in recent years (aquatic weeds and Microcystis). Each page includes a brief narrative for context. Full details on data processing and interpretation are provided in the metadata.

We chose these data sets and format after extensive conversations with the IEP Science Management Team, Coordinators Team, Stakeholders, and other managers. We also communicated with the principal investigators for most of the surveys to ensure our interpretation of their data is not misleading.

The Spring and Summer reports were then combined with the Fall and Winter reports (updated since their last publication to include data from 2018). To automate the creation of the report, and allow for routine updating, we followed these basic steps:

1. Set up a collaboration platform to share and save code across multiple agencies.
2. Wrote code to download the most recent data from online repositories.
3. Created standardized graphs with uniform date range, labels, and themes.
4. Developed narratives (updated as needed) in an HTML report combining all the graphs, with built-in ADA compliance features (such as alternative text for graphics).
5. Published the report in a location where synthesis team members can control updates.

Collaboration platform

To quickly share code and track report versions, we utilized the IEP GitHub site, setting up a repository for Seasonal Monitoring Report code (https://github.com/InteragencyEcologicalProgram/Status-and-Trends). GitHub is a platform for collaboratively building software that allows for code review, version control, package construction, workflow development, and web page creation. As of 5/5/2020, six IEP scientists have contributed 286 updates to the repository.

All data access, manipulation, and graphing scripts were conducted with R version 3.6.3 (R Foundation for Statistical Computing 2020, https://www.r-project.org/). Early development experimented with using Python (https://www.python.org/) and Docker (https://www.docker.com/) for data access, with graphing and manipulation conducted in

R. However, we switched to R for the entire project life cycle because R is more widely used by IEP scientists and we wanted a system that could be updated by a wide range of staff members.

Downloading data

Most of the data sets featured in the Seasonal Monitoring Report are currently available online, across multiple platforms and in various formats (Table 1). Some datasets are only available upon request to the Principal Investigator. For all datasets that are available online, we developed a series of functions in R to automatically download the data from the online repository and reformat the data, when necessary, for easier graphing. Datasets that were made available as Access databases were queried so that the relevant data were compiled into a single data table. Datasets that are only available upon request were obtained from the PI and stored on a DWR SharePoint site for later access.

Creating Graphs

The purpose of the graphs in these reports is to show large scale, long term patterns. Therefore, we summarized the data by geographic region and season. For data sets collected throughout the Bay-Delta ecosystem, we generally calculated means for three regions: San Pablo Bay, Suisun Marsh and Bay, and the Delta. As an exception, fish data were not summarized by region because many of them can move freely throughout the ecosystem. For data sets collected throughout the year, such as water temperature, we calculated the mean for each season separately. For data sets that are season-specific, we included the entire sampling period, even if it did not overlap exactly with our season definition (for example, the 20mm Survey index includes data from March-July, whereas the spring season is defined as March-May). We also calculated the mean across the entire period of record for each data set to highlight differences from average values. These data manipulations were all recorded in R script files and stored in the GitHub repository. For more details, also see the metadata document, which is published with the reports (see link below).

- Spring = March to May,
- Summer = June to August,
- Fall = September to November, and
- Winter = December to February, with January and February included with December of the previous year

In order to standardize the look of the report, and facilitate comparison between seasons and data sets, we kept the x-axis the same for all graphs in the first five sections of each seasonal report (1967-present). The last section of each seasonal report was standardized as the last 14 years. The y-axes were standardized so that each metric had the same y-axis across all seasons. Each graph also has a dashed red line indicating the mean over the entire course of the study.

The specifications for these axes, as well as the axis labels, line type, colors, graph size, label size, mean line, and other graphical specifications were written as a series of functions that could be applied to all plots in the report, using the “theme” functionality in the R package ggplot2 (Wickham et al. 2020). These functions, along with functions for downloading data, were deployed as a package to facilitate their reuse in future reports (smonitr; https://github.com/InteragencyEcologicalProgram/smonitr). As of 5/5/2020, this package had four contributors and 46 updates.

Creating the report

To create the report, we used RMarkdown (Allaire et al. 2020) and Bookdown (Xie 2020a) to arrange the graphs and accompanying narrative in an easy-tonavigate electronic book. RMarkdown is a lightweight markup language that allows integration of R code chunks with plain-text syntax to create HTML documents. In combination with the R packages Bookdown and knitr (Xie 2020b), RMarkdown can be used to create automated reports that include tags, heading styles, graphics, a navigation panel, alternative text for figures, and other features needed for ADA compliant HTML documents.

All the graphs within the report can be automatically updated by running the original code with updated data. We also included some brief background information about each panel, and a brief interpretive sentence below each graph that puts the most recent year into context of the long-term average. These interpretive sentences must be updated manually after the graphs are updated, but we are looking into ways to make this process more automated as well.

Publishing the report

The IEP Seasonal Monitoring report is currently published via GitHub Pages, at: https://interagencyecologicalprogram.github.io/Status-and-Trends/ GitHub pages is a free service provided by our GitHub account that makes HTML files in a GitHub repository available as a website. When the RMarkdown files that create the report are updated, these updates can be "pushed" to the website in a matter of minutes. This is linked on the IEP website under the "Summaries at a Glance" tab.

Discussion

The Seasonal Monitoring Report is an example of how automated report creation can increase IEP's transparency and relevancy. IEP has been criticized in the past for not making data and reports available in a timely manner. For example, the 2019 Delta Independent Science Board's review of IEP recommended that IEP: "develop uniform procedures with associated instructions for reporting", "develop dynamic tools to facilitate and support enhanced communication within IEP, among member agencies, and with stakeholders" and "increase collaboration among IEP and other entities to foster synthesis" (Delta Independent Science Board et al. 2019). Producing short, easy-to-read reports such as this one can help address many of these needs at once, with a relatively small investment of staff time needed for maintenance. Web-based tools such as GitHub and SharePoint can greatly facilitate collaborative projects across agencies, reducing the need for collaborators to be co-located or meet face-to-face. Online data availability, reproducible code, version control, and reporting tools such as RMarkdown made producing automated reports easy and fast. While the time invested in creating the first version of each seasonal report was significant, updating the report a year later took only a few minutes.

A few parts of this report, and the process to create the report could use improvement. All the data included in the report should be made available online along with their metadata and quality assurance standards. While IEP makes much of their data available on departmental web sites, some data is still only available upon request to the Principle Investigators. Publishing data in open-access formats (like a csv, not proprietary Excel or Access files) on a dedicated data repository with complete metadata and versioning (such as the Environmental Data Initiative; https://environmentaldatainitiative.org/) will allow greater reproducibility in creating automated reports. The IEP Data Utilization Work Group has been developing resources to assist PI's with publishing their data to help overcome this problem.

There can be greater automation of the interpretive sentences below the graphs. Currently, the interpretation is somewhat subjective. To remove any subjectivity, the interpretation can instead display a statistic such as the percent difference from the long-term average. This can be incorporated in future iterations of the report.

Graphs should have capabilities to zoom in and out so a viewer can see details more clearly.

We received a wide variety of feedback on the report. Overall, the feedback has been extremely positive, though no one format for the data will satisfy all users. The report had multiple iterations and reviews through various scientific and management teams. There was some disagreement about which data to display and the format of the report, so the result is a compromise. However, this concise, visual report is designed to be a first look at the data. We hope it will highlight data and trends that inspire researchers to look at IEP datasets more deeply and pull together new synthesis projects to apply IEP data to management questions.

Acknowledgements

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2020 Spring Kodiak Trawl Summary

Jessica Jimenez* and Adam Chorazyczewski (CDFW)

*Corresponding Author:
Jessica.Jimenez@wildlife.ca.gov

The California Department of Fish and Wildlife (CDFW) conducts the Spring Kodiak Trawl Survey (SKT) annually to determine the distribution and relative abundance of adult Delta Smelt (*Hypomesus transpacificus*), which are endemic to the San Francisco Estuary (SFE), and are listed under the California and United States Endangered Species Acts. The SKT also monitors the gonadal maturation of Delta Smelt, which can indicate when and where spawning is likely to be occurring. The SKT is routinely conducted from January to May but was expanded into December starting in 2014 to increase coverage during drought years and allow for equipment comparisons with another CDFW survey, the Fall Midwater Trawl. The SKT conducts one survey each month, which consists of sampling 40 stations throughout the upper SFE (Figure 1). Each station is sampled using a standard Kodiak Trawl with a total length of 65' and an expanded mouth opening of 25' by 6'. The net is composed of variable mesh sizes ranging from 2" at the mouth to ¼" at the cod end and has a weighted foot rope and a head rope with floats to allow the trawl to fish the top 6' of the water column. Each sample is collected by towing the net between two boats at the water's surface for 10 minutes. At each station, crews measure the electrical conductivity, temperature, and turbidity of the surface water, along with the water depth, Secchi depth, and tidal direction.

The 2020 SKT season conducted surveys from December 2019 through March 2020.

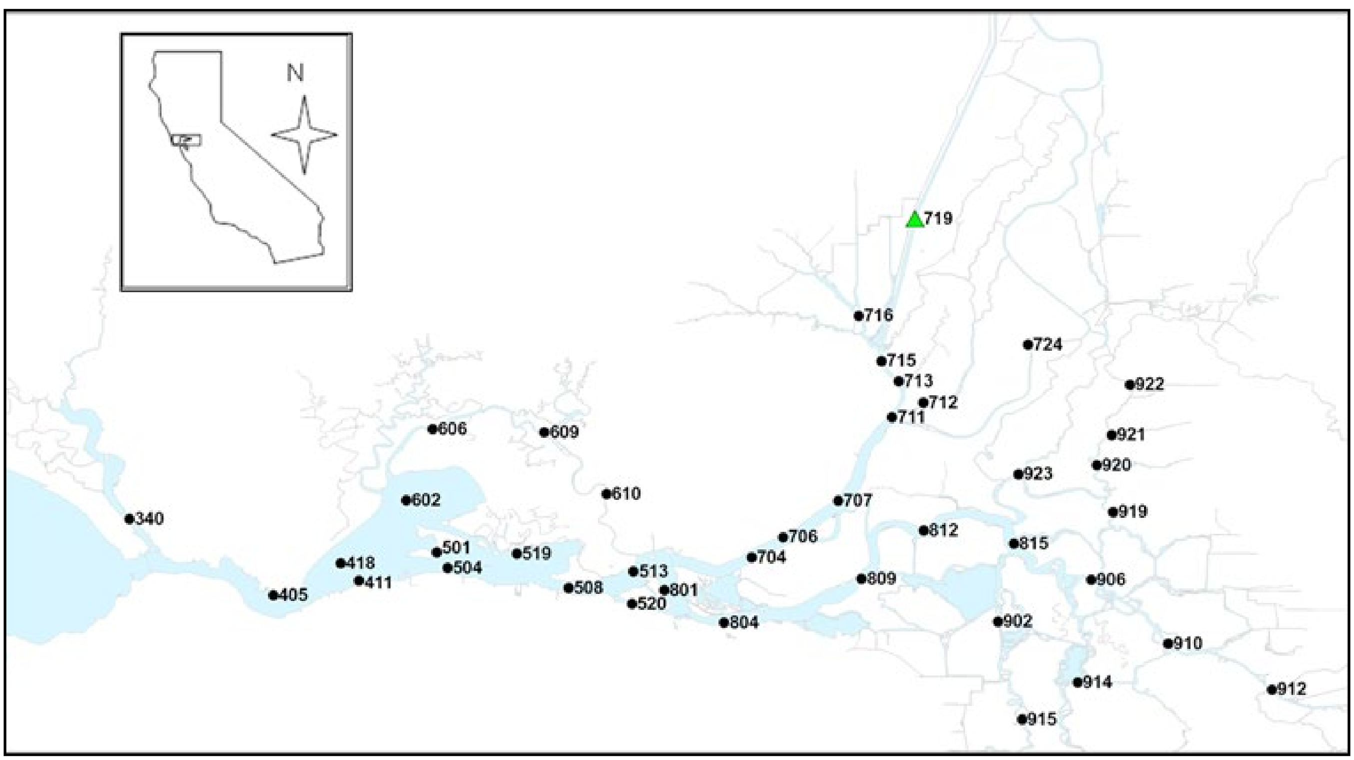


Figure 1. Geographical map of the Spring Kodiak Trawl station locations sampled by the California Department of Fish and Wildlife in the San Francisco Estuary. Black dots represent stations that have been sampled since the survey's inception and the green triangle represents a station added in 2005.

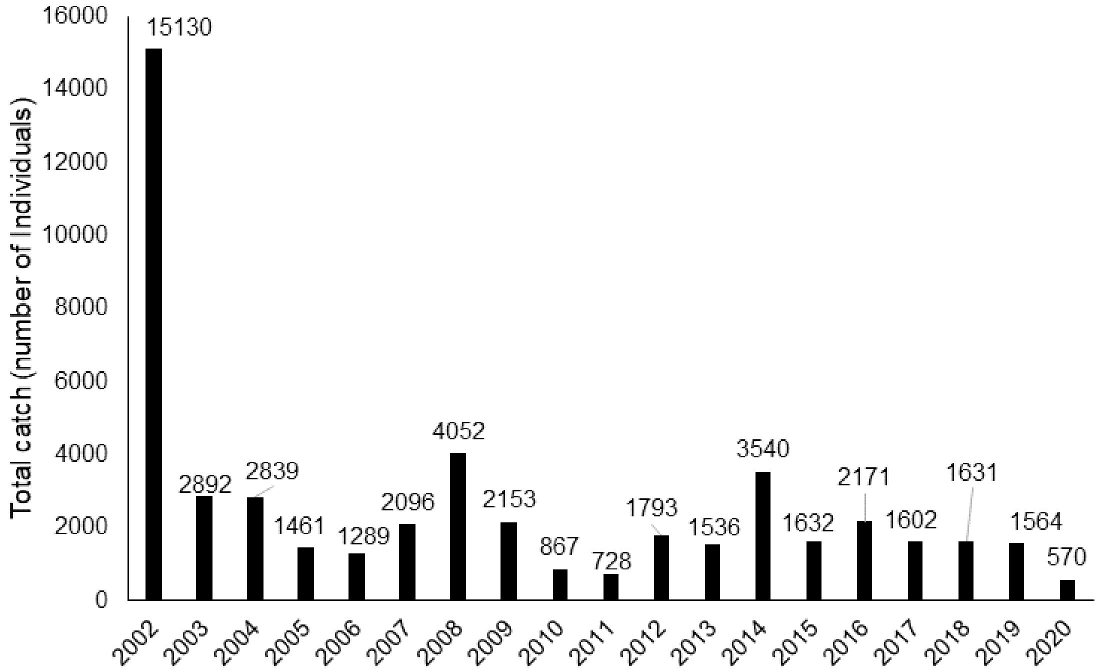


Figure 2. Total annual organism catch for surveys conducted between January and March for the California Department of Fish and Wildlife's Spring Kodiak Trawl. Catch from supplemental surveys is not included.

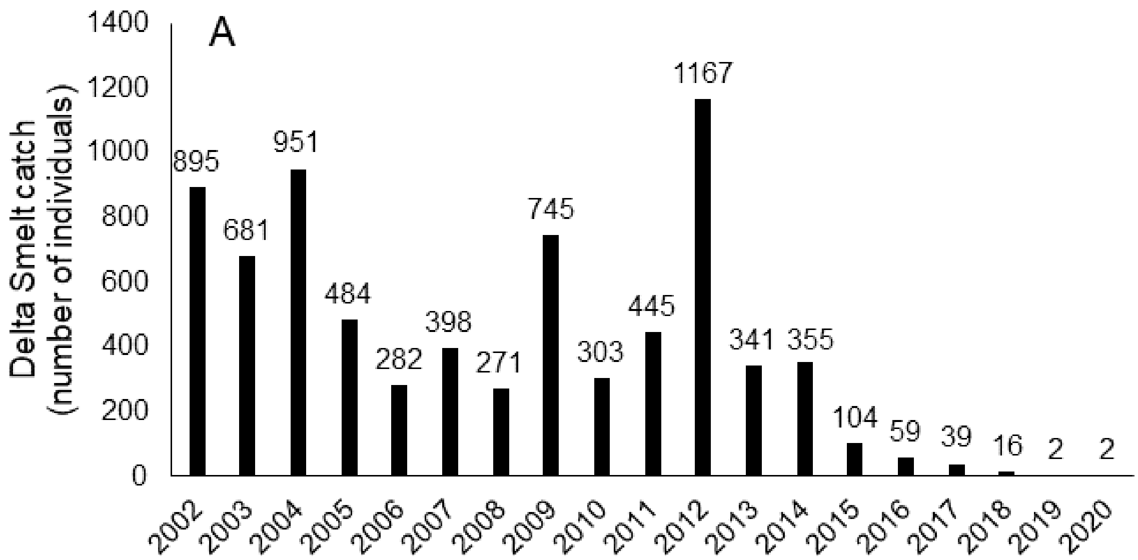
Surveys number 1 and 2 sampled all stations. The Mokelumne River stations (920, 921, 922, and 923) were not sampled during survey 3 due to boat issues. Due to the COVID-19 pandemic, the 2020 SKT season was discontinued on March 23rd. Surveys completed between January and March collected a record low catch of 570 organisms representing 25 species (Figure2). Threadfin Shad (*Dorosoma petenense*) (35%), American Shad (*Alosa sapidissima*) (25%), and Inland Silversides (*Menidia beryllina*) (14%) were the most abundant species, together comprising about 74% of the total catch (Table 1). The majority of the fish caught in the December survey consisted of Threadfin Shad (49%) and American Shad (45%) (Table 2).

Only two Delta Smelt were caught, mirroring the historic low seen in 2019 (Figure 3A). Both Delta Smelt were collected in the lower portion of the Sacramento River. One near-ripe female with a fork length of 56 mm was caught in January at station 704 and one ripe female with a fork length of 65 mm was caught in February at station 707. This suggests that spawning may have begun in February, which is corroborated by the first larval Delta Smelt observation occurring in mid-March, during the CDFW Smelt Larva

Table 1. Organism catch for all stations sampled between January 2020 and March 2020 for California Department of Fish and Wildlife's Spring Kodiak Trawl.

Common Name	Total Catch (Number of Individuals)	Pecent
Threadfin Shad	197	34.56%
American Shad	144	25.26%
Inland Silverside	81	14.21%
Crangon Shrimp	30	5.26%
Striped Bass Age 0	22	3.86%
Pacific Herring	16	2.81%
Palaemon Shrimp	12	2.11%
Steelhead	11	1.93%
Siberian Prawn	8	1.40%
Threespine Stickleback	8	1.40%
Splittail	7	1.23%
Longfin Smelt	6	1.05%
Northern Anchovy	6	1.05%
Chinook Salmon	5	0.88%
Bluegill	3	0.53%
Hitch	3	0.53%
Delta Smelt	2	0.35%
Golden Shiner	2	0.35%
Largemouth Bass	1	0.18%
Pacific Lamprey	1	0.18%
Rainwater Killifish	1	0.18%
Spotted Bass	1	0.18%
Starry Flounder	1	0.18%
Topsmelt	1	0.18%
Yellowfin Goby	1	0.18%
No Catch	0	0.00%

Study (Jones 2020). Since 2015, there has been a dramatic decrease in annual SKT Delta Smelt catch across the SFE. From 2002 through 2014, annual Delta Smelt catch in the SFE ranged from 271 to 1,167 and from 2015 through 2020, annual Delta Smelt catch ranged from 2 to 104 (Figure 3A). Historically, the Sacramento Deep Water Shipping Channel (SDWSC) had reliably high Delta Smelt catches, though catch has decreased in recent years. From 2005 through 2014, annual Delta Smelt catch in the SDWSC ranged from 106 to 459 and from 2015 through 2020, annual Delta Smelt catch ranged from 0 to 45 (Figure 3B). This shift in catch reflects the overall decline in Delta



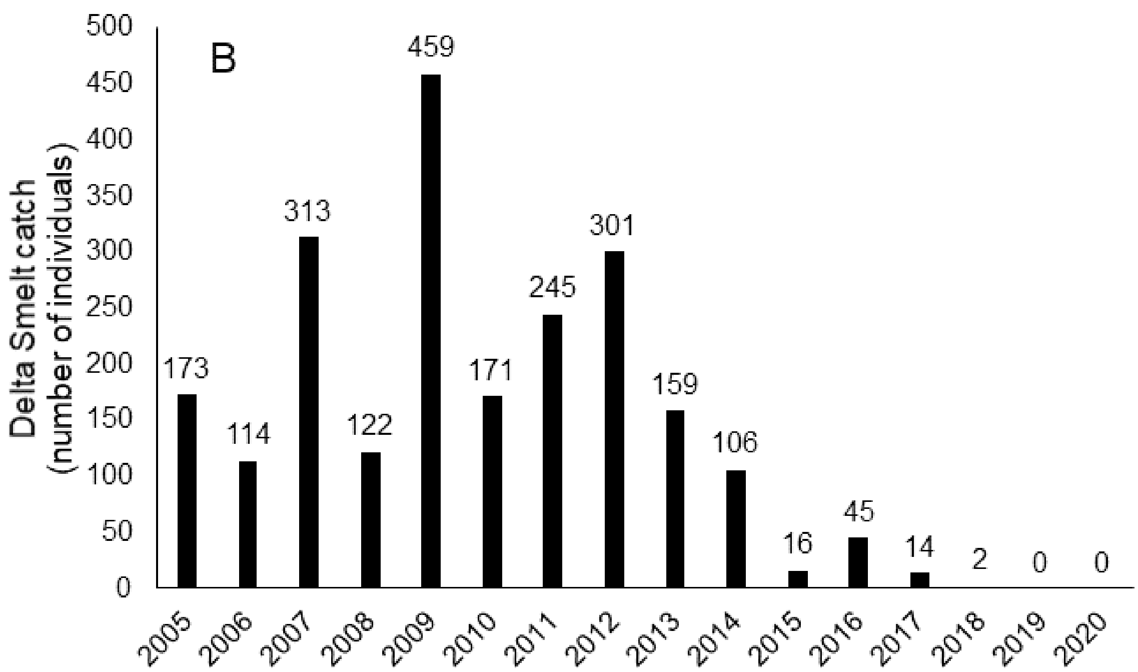


Figure 3. A) Annual Delta Smelt catch at all stations for the California Department of Fish and Wildlife's Spring Kodiak Trawl. Catch from supplemental surveys, including December sampling, is not included. B) Annual Delta Smelt catch in the Sacramento River Deep Water Shipping Channel for the California Department of Fish and Wildlife's Spring Kodiak Trawl. Catch from supplemental surveys, including December sampling, is not included.

Smelt catch within the SFE.

Six Longfin Smelt (*Spirinchus thaleichthys*), were caught between January and March (Figure 4A). Longfin Smelt which is listed as a threatened species under the California Endangered Species Act, comprised 1% of total catch this year (Table 1), similar to previous years (Figure 4B). Eight Longfin Smelt were collected between

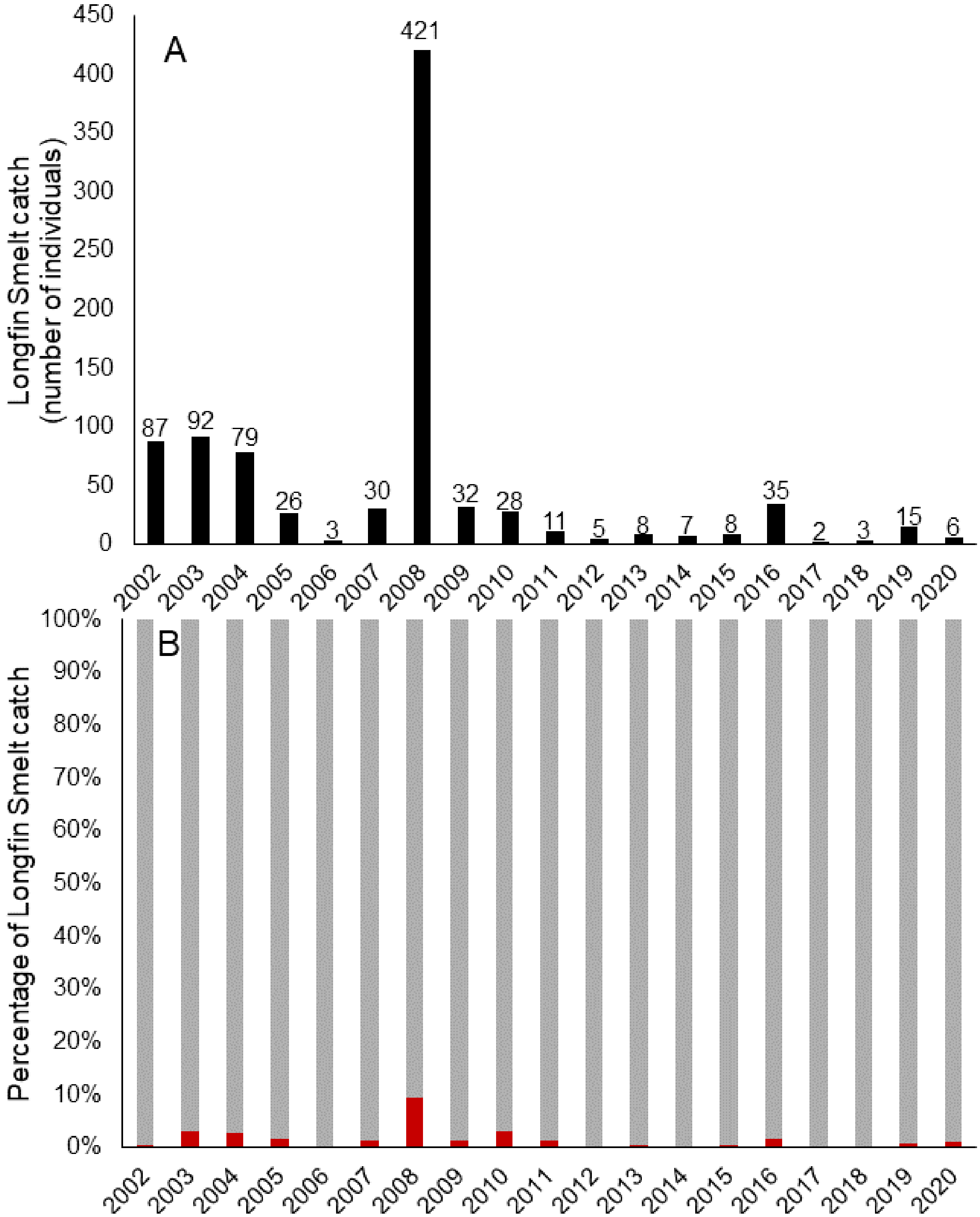


Figure 4. A) Annual Longfin Smelt catch between January and March at all stations for the California Department of Fish and Wildlife's Spring Kodiak Trawl. B) Percentage of Longfin Smelt catch between January and March at all stations for the California Department of Fish and Wildlife's Spring Kodiak Trawl.

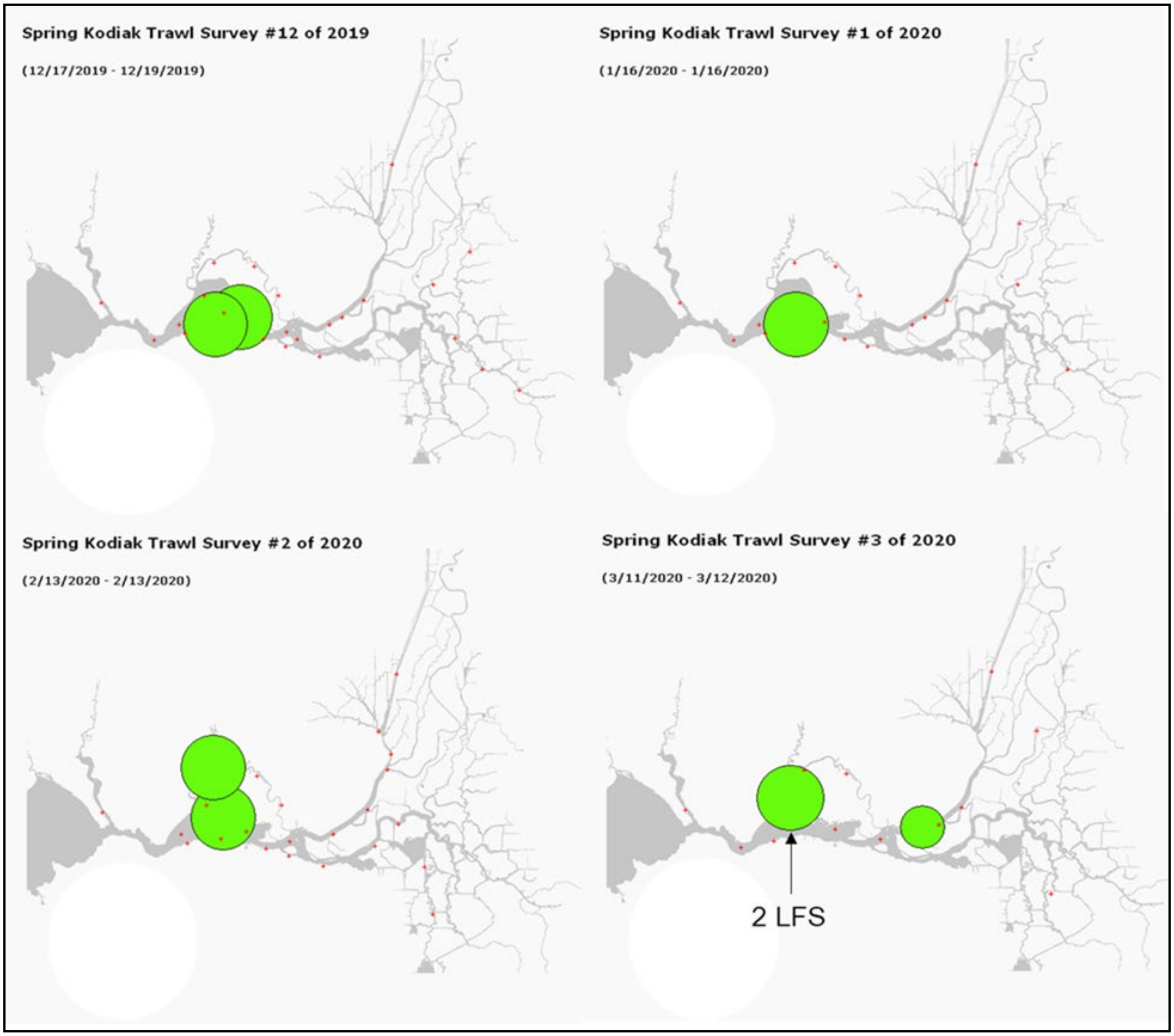


Figure 5. Geographic bubble plot of Longfin Smelt catch from December 2019 through March 2020 from the California Department of Fish and Wildlife's Spring Kodiak Trawl. Each bubble is equal to one individual, unless otherwise denoted.

December 2019 and March 2020 at stations located between Grizzly Bay and the lower Sacramento River, including Montezuma Slough (Figure 5).

Data from the SKT is reported in near real-time to the Smelt Monitoring Team, the Salmon Monitoring Team, and the Data Assessment Team to help inform adaptive management decisions. SKT catch summaries are publicly available through the SKT webpage , typically within a week of sampling efforts. The webpage provides catch distribution maps for all species collected, along with information on Delta Smelt gender and reproductive maturity, and Chinook Salmon adipose fin status and race information based on length-at-date and coded wire tag (CWT) results.

The 2021 Spring Kodiak Trawl is scheduled to begin in December 2020 and run through May 2021. Data and metadata

Table 2. Total organism catch for all stations sampled December 2019 for California Department of Fish and Wildlife's Spring Kodiak Trawl.

Common Name	Total Catch (Number of Individuals)	Percent
Threadfin Shad	773	48.89%
American Shad	717	45.35%
Golden Shiner	32	2.02%
Inland Silverside	15	0.95%
Northern Anchovy	11	0.70%
Chinook Salmon	8	0.51%
Striped Bass Age 0	7	0.44%
Wakasagi	6	0.38%
Splittail	5	0.32%
Steelhead	3	0.19%
Bluegill	2	0.13%
Longfin Smelt	2	0.13%

are available through the SKT File Transfer Protocol (FTP) website .

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2020 Smelt Larva Survey Summary

Brian Jones* and Adam Chorazyczewski (CDFW)

*Corresponding Author:
Brian.Jones@Wildlife.ca.gov

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

The SLS began in 2009, and each year six bi-weekly surveys are conducted from January through mid-March. This period is when Longfin Smelt larvae are most likely to be present in the survey area. Each survey consists of 35 stations (Figure 1). At each station, an oblique tow is conducted using a rigid-framed, plankton-style net with 500-micron Nitrex mesh. All samples are preserved in 10% buffered formalin dyed with rose Bengal for later identification and enumeration in the laboratory. Presence or absence of a yolk sac or oil globule is noted for larval osmerids, including Longfin Smelt.

The 2020 SLS Survey ran from January 6th through March 16th. All stations were sampled except during Survey 2, when heavy fog prevented sampling in the north Delta (Stations 711, 716, 723). A total of 16,001 fish representing 15 taxa were collected (Table 1). Each year four species have comprised over 98% of the total SLS catch: Prickly Sculpin (*Cottus asper*), Yellowfin Goby (*Acanthogobius flavimanus*), Pacific Herring (*Clupea pallasii*), and Longfin Smelt. This trend continued in 2020, with those four species totaling 99.78% of the total catch (Figure 2).

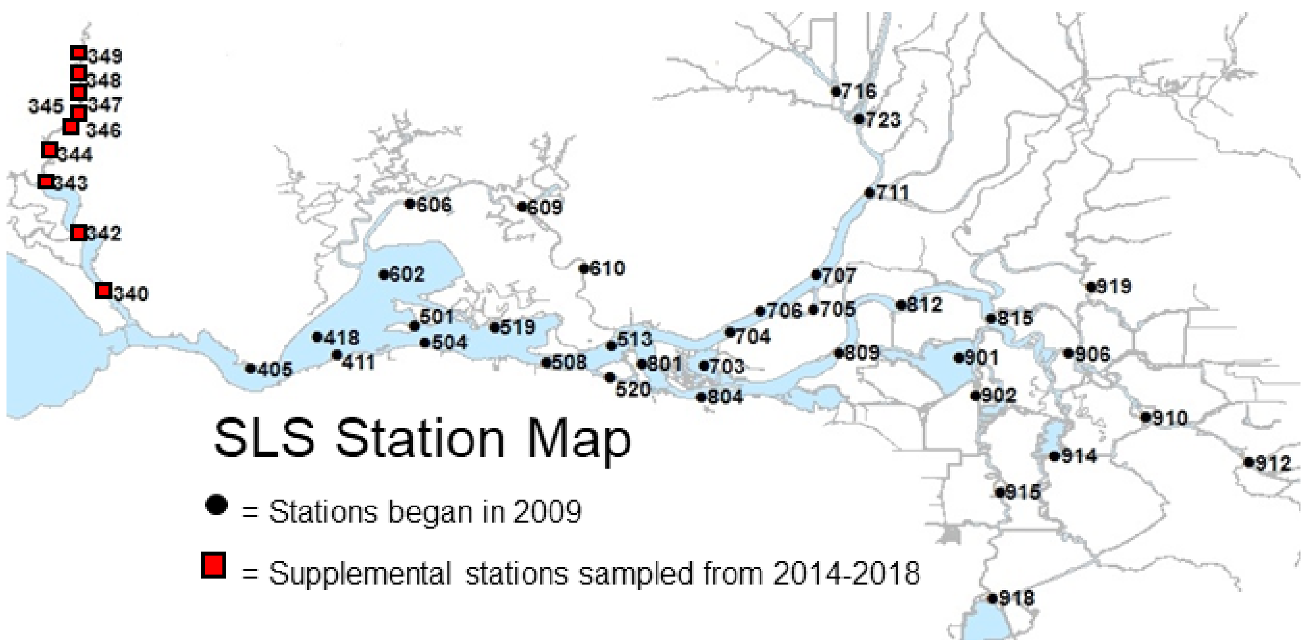

Figure 1. Geographical map of the Smelt Larva Survey station locations sampled by the California Department of Fish and Wildlife.

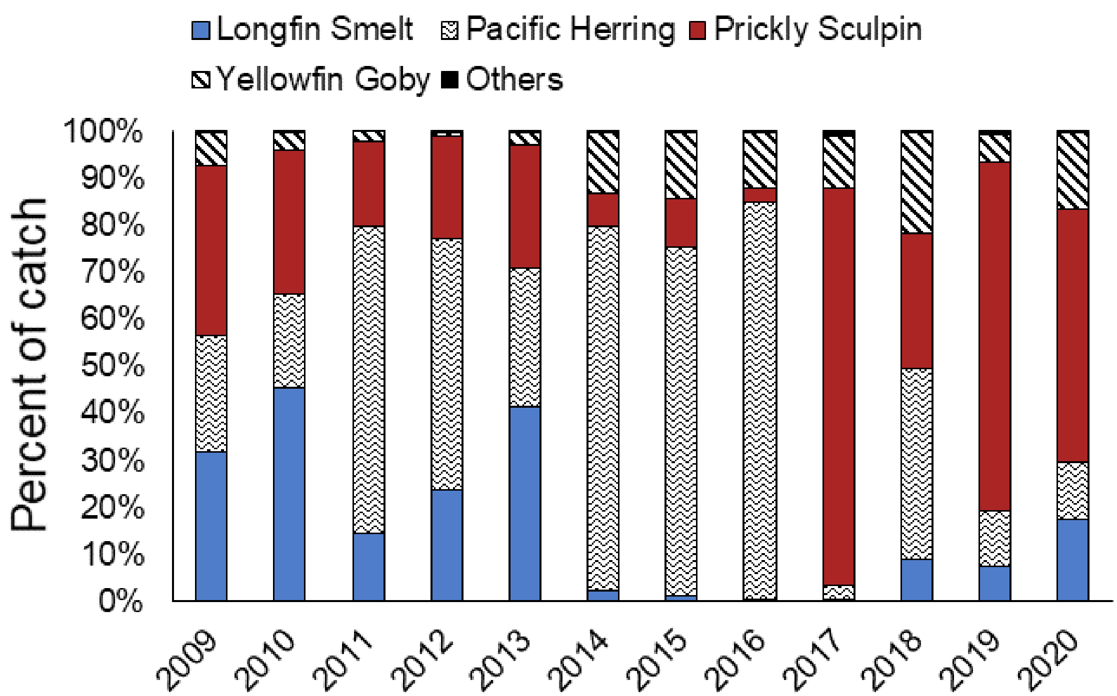

Figure 2. Annual species composition from the California Department of Fish and Wildlife Smelt Larva Survey.

A total of 2,788 Longfin Smelt were collected in 2020, four times as many as last year's catch (n=561) (Figure 3). Despite the increased catches in 2018 and 2020, the past six years (2015-2020) have seen much lower catches than the first six years of the survey (2009-2014) (Figures 2 and 3). From 2009-2014, annual Longfin Smelt catch ranged from 5,631 to 22,727 (average: 12,428) and contributed between 2.45% and 45.38% of total annual catch (average: 26.51%). From 2015-2020, annual Longfin Smelt catch ranged from 79 to 2,788 (average: 1,196) and contributed between 0.57% and 17.42% of total annual catch (average: 6.05%).

Longfin Smelt were first collected in early January, during Survey 1. They were observed during each of the six surveys, with the highest catch during Survey 3 (2/3/2020 – 2/5/2020) (Figure 4). Yolk sac larvae were collected during Surveys 2 through 6, which indicates that hatching occurred throughout the survey season (Figure 4). The presence of yolk sac larvae in all 3 survey regions indicates hatching events occurred throughout the delta system (Figure 5) with the highest concentration of events located downstream and at the junction of the Sacramento and San Joaquin Rivers.

Young of the year Delta Smelt were collected in March, near or west of Chipps Island (n=19, Figure 6). This timing suggests that spawning likely began in early March. Catch was higher in 2020 than in 2019, which may be the result of increased rainfall in 2019. However, catch was far lower than catches seen in 2012 and 2013 (Figure 7). The fall and winter of 2011 and 2012 appear to have provided favorable spawning conditions for Delta Smelt, resulting in a more productive start to the spawning season (IEP MAST, 2015). A similar response was not observed in 2020.

For additional information of SLS methods, sampling deign, and prior year summary reports, see our online bibliography: http://www.dfg.ca.gov/delta/data/sls/bibliography.asp. For CPUE values, and data

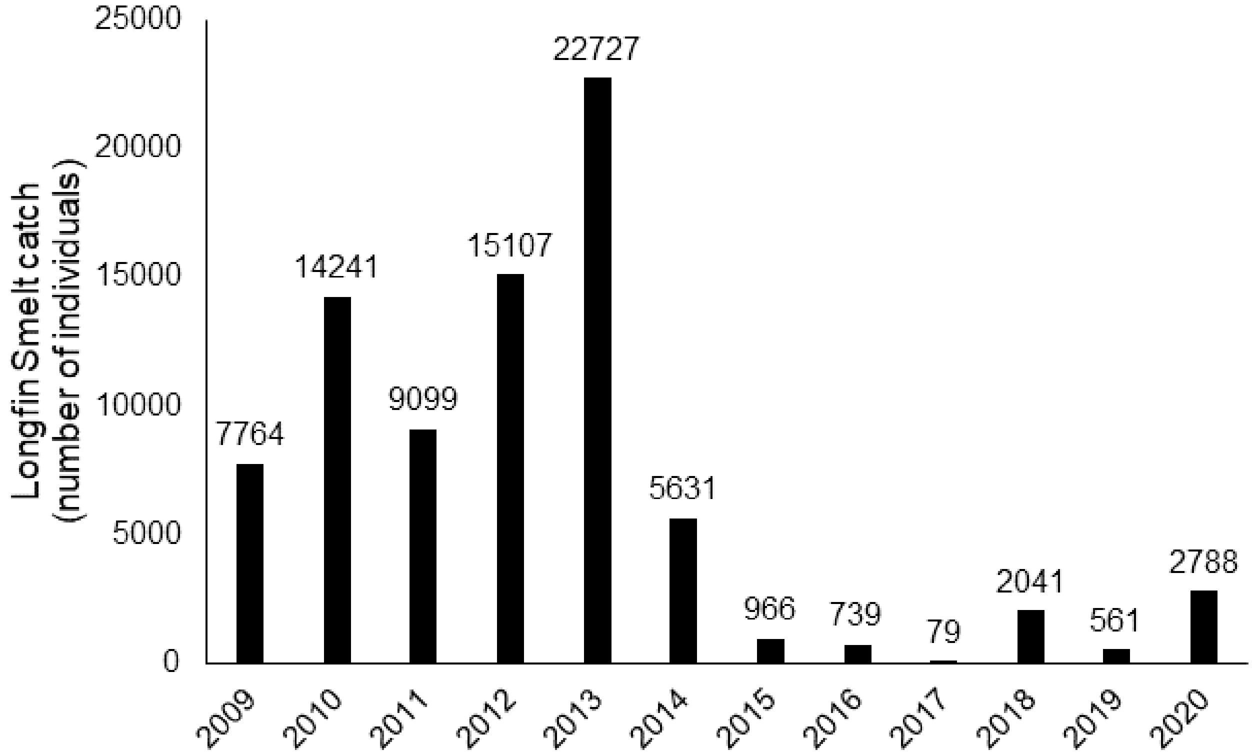

Figure 3. Annual Longfin Smelt catch from the California Department of Fish and Wildlife Smelt Larva Survey.

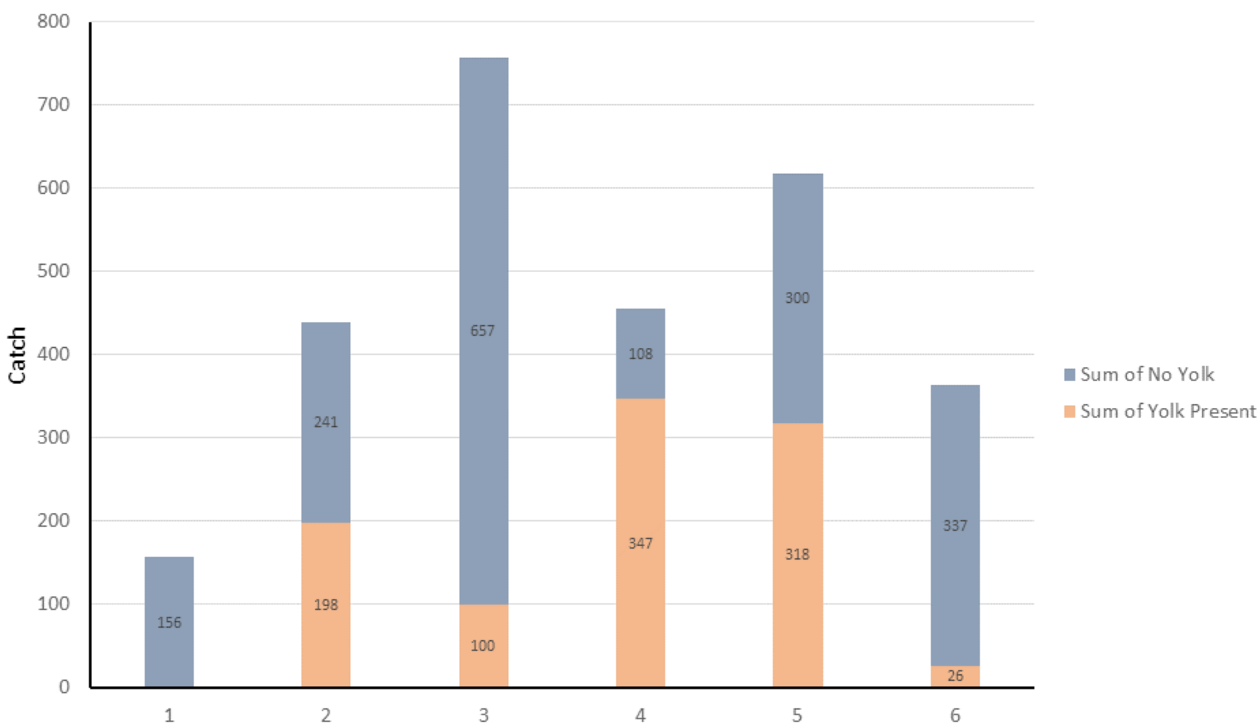

Figure 4. 2020 Longfin Smelt catch by survey in relation to presence or absence of yolk sac from the California Department of Fish and Wildlife Smelt Larva Survey.

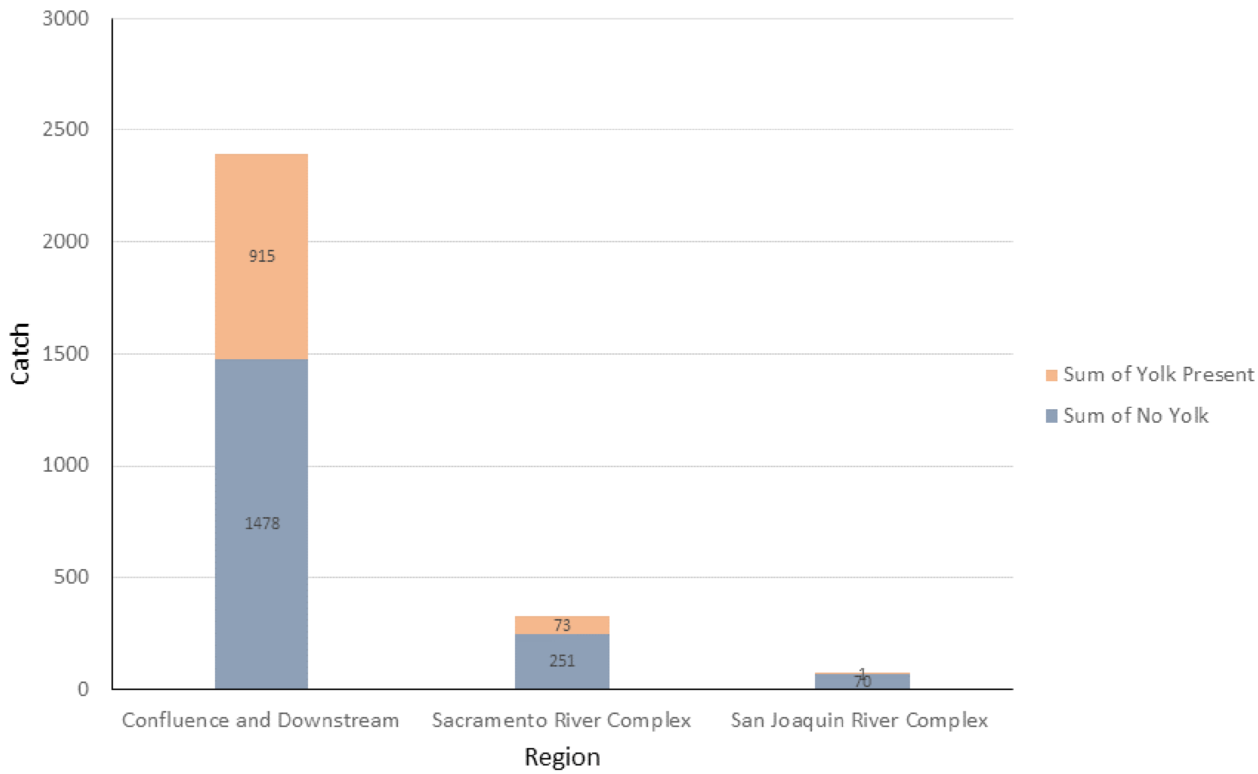

Figure 5. 2020 Longfin Smelt catch by region in relation to presence or absence of yolk sac from the California Department of Fish and Wildlife Smelt Larva Survey.

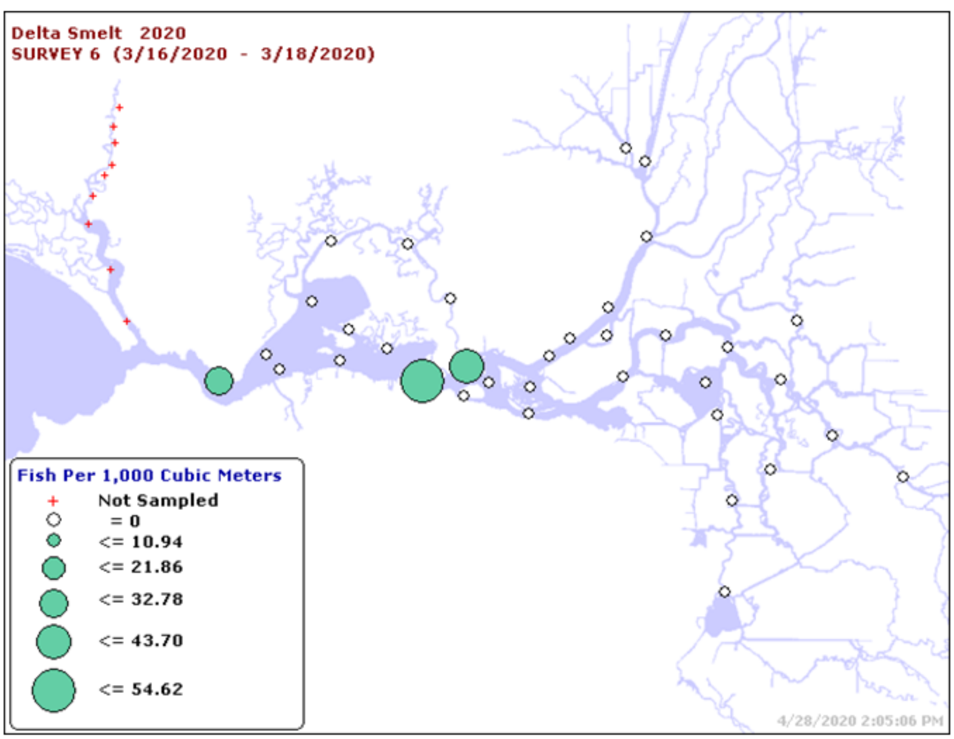

Figure 6. Geographical bubble plot of the distribution of catch per unit effort of Delta Smelt for Survey 6 of the 2020 California Department of Fish and Wildlife Smelt Larva Survey (SLS). Taken from the SLS webpage: https://www.wildlife.ca.gov/Conservation/Delta/Smelt-Larva-Survey

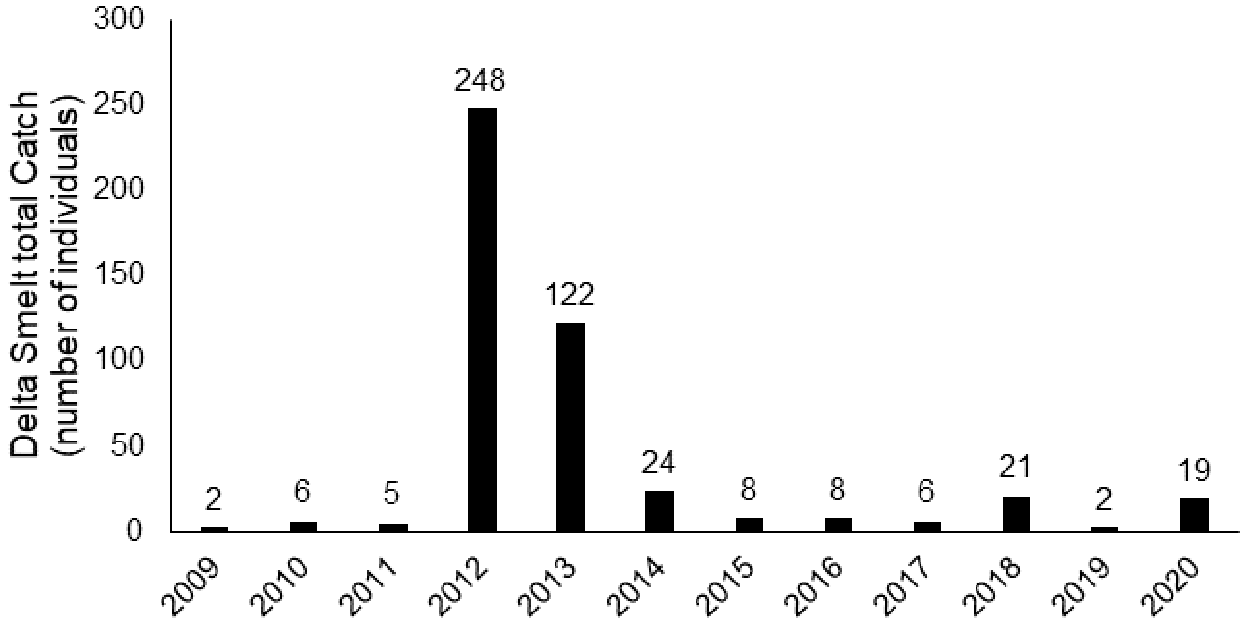

Figure 7. Annual Delta Smelt catch for the California Department of Fish and Wildlife Smelt Larva Survey.

visualizations, see the SLS webpage: https://www.wildlife.ca.gov/Conservation/Delta/Smelt-Larva-Survey, and for Survey data see the FTP site: ftp://ftp.dfg.ca.gov/Delta%20Smelt/.

References

IEP MAST (Interagency Ecological Program Management, Analysis, and Synthesis Team) 2015. An updated conceptual model of Delta Smelt biology: our evolving understanding of an estuarine fish. Interagency Ecological Program for the San Francisco Estuary, Technical Report 90. Available at https://www.waterboards.ca.gov/waterrights/water_issues/programs/bay_delta/california_waterfix/exhibits/docs/petitioners_exhibit/dwr/part2/DWR-1089%20IEP_MAST_Team_2015_Delta_Smelt_MAST_Synthesis_Report_January%202015.pdf

Table 1. Total species catch for the 2020 California Department of Fish and Wildlife Smelt Larva Survey.

Common Name	Total catch (number of individuals)	Percent of catch
Prickly Sculpin	10745	56.03%
Yellowfin Goby	5217	27.20%
Pacific Herring	1649	8.60%
Longfin Smelt	1503	7.84%
Arrow Goby	17	0.09%
Striped Bass	6	0.03%
Bay Goby	6	0.03%
Bigscale Logperch	5	0.03%
Threadfin Shad	4	0.02%
Threespine Stickleback	4	0.02%
Jacksmelt	4	0.02%
Bluegill Sunfish	3	0.02%
Rainwater Killifish	3	0.02%
Longjaw Mudsucker	3	0.02%
Tridentiger spp.	3	0.02%
American Shad	1	0.01%
Northern Anchovy	1	0.01%
Mosquitofish	1	0.01%
Bay Pipefish	1	0.01%
Pacific Staghorn Sculpin	1	0.01%

Discrete Water Quality Monitoring, 2018

Caitlin Miller* and Sarah Perry (DWR)

*Corresponding Author:
Caitlin.Miller@water.ca.gov

Introduction

As dictated by Water Rights Decision 1641 (D-1641), the Department of Water Resources (DWR) and the US Bureau of Reclamation (USBR) are required to monitor long-term water quality trends in the San Francisco Estuary as part of operations for the State Water Project (SWP) and Central Valley Project (CVP). The Environmental Monitoring Program (EMP) achieves this by taking discrete water quality measurements at twenty-four sites located throughout the Estuary on a monthly basis (Figure 1). Here, we report significant trends resulting from these monitoring efforts for 2018. We've highlighted the figures for the four most important lab analytes: ammonia, chlorophyll-a, nitrate/nitrites, and phosphorus.

EMP analyzes twenty parameters that describe the water quality and ecological health of the Delta (Table 1). These analytes include:

- **temperature and pH**: fundamental controlling properties for a variety of chemical and biological processes
- **turbidity**: affects the degree of light penetration in the water
- **total alkalinity**: the capacity of water to neutralize acids and resist changes in pH
- **dissolved oxygen**: a necessary

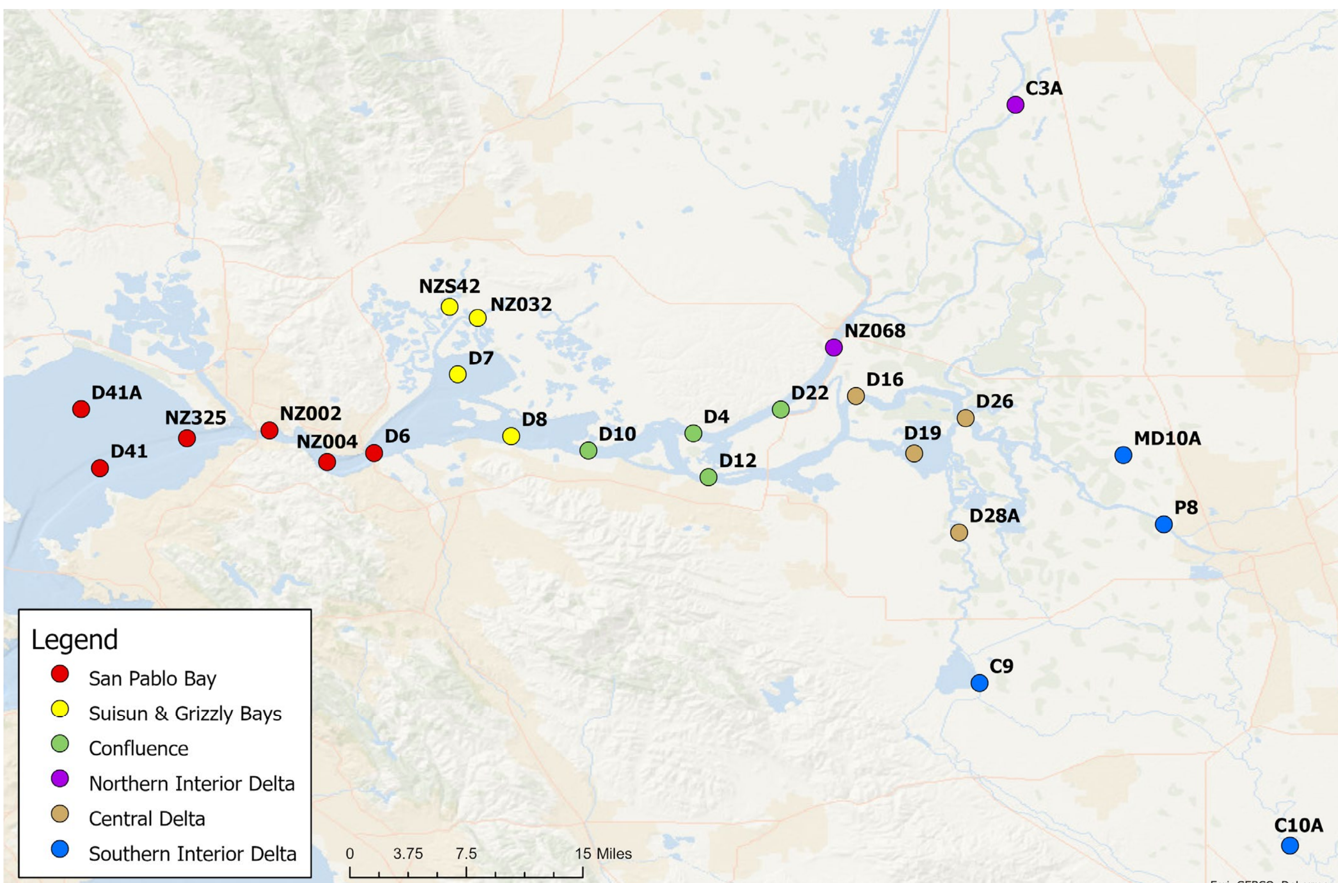

Figure 1. Map of EMP water quality stations. Colors are by region.

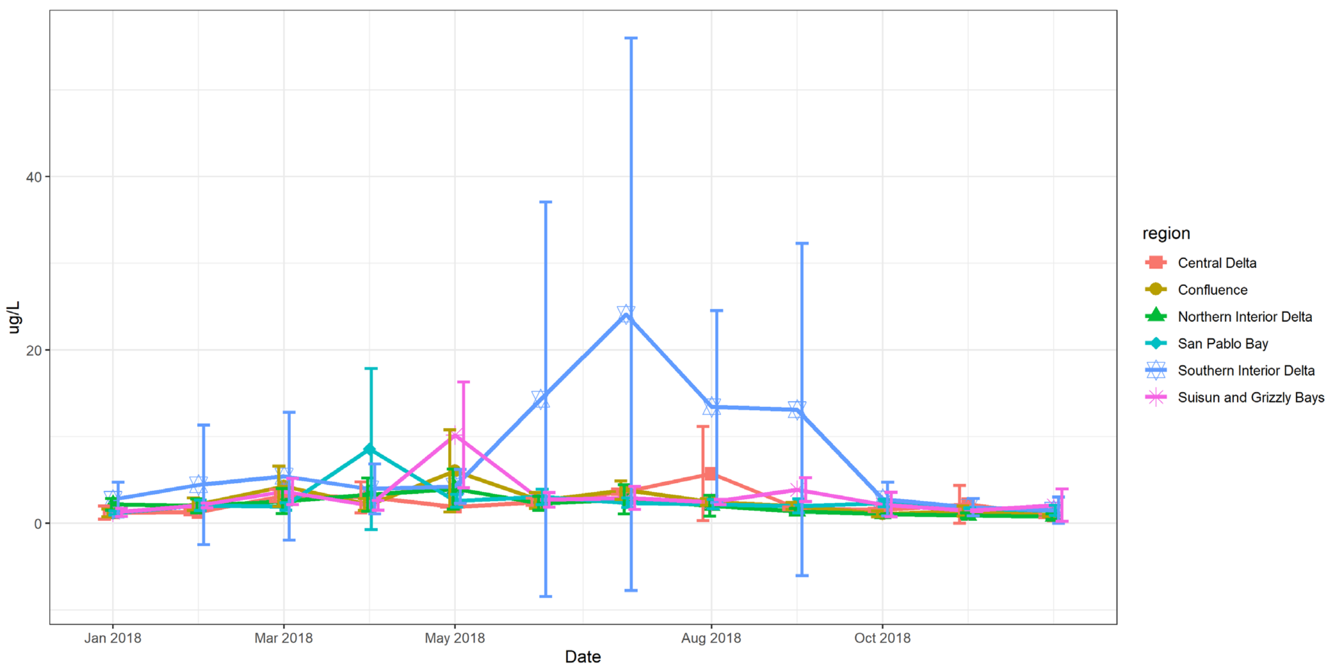

Figure 2. Monthly regional averages for chlorophyll a in 2018. Averages were calculated using the Kaplan-Meier estimator to account for non-detects.

constituent for aquatic life

- **specific conductivity**: corresponds to the salinity of the water
- **nutrients** (nitrogen, calcium, chloride, carbon, phosphorus, and silica): chemicals necessary to support aquatic fauna and flora; excessive nutrients can lead to eutrophication and/or toxicity in aquatic life

Methods

Field Measurements

Temperature, pH, turbidity, dissolved oxygen, and specific conductance are measured using probes on a YSI EXO2 sonde. EMP collects surface readings at three feet below the water's surface and bottom readings three feet above the maximum depth of the water column. Each parameter is calibrated to a relevant standard before deployment and post-calibrated afterward to ensure accurate measurements.

Laboratory Measurements

Nutrients, total alkalinity, and electrical conductivity were determined via the appropriate procedures at a certified chemical laboratory (EMP Field and Lab Manual, 2020). Field sampling for these parameters consisted of collecting filtered and unfiltered water in their appropriate polyethylene containers for further processing.

Containers for unfiltered analytes were filled with sample water taken directly from three feet below the water's surface. Filtered samples were processed by running them through a 0.45 µm Millipore filter using a vacuum pump apparatus, which leaves behind dissolved constituents. The filtered water was then poured into the correct container. All samples were then refrigerated until processed by the lab.

Analysis

Prior to analysis, stations were grouped into their respective regions (Table 2) and the monthly regional concentrations were calculated using the Kaplan-Meier estimate to account for non-detects in the data set (Helsel, 2012).

Results

Chlorophyll a

Chlorophyll a values were low (< 10 µg/L) throughout the year in all regions except the Southern Interior Delta (Figure 2). In the Southern Interior Delta, the average monthly value peaked at 29.73 µg/L in July and was consistently high in the summer months. These elevated average values were due to extremely high chlorophyll concentrations at C10A; other stations in the region continued to have low concentrations. No other region displayed notable seasonal trends, though the Northern Interior Delta and Suisun/Grizzly Bays experienced small average peaks (~10 µg/L) in April and May.

Dissolved Ammonia

Dissolved ammonia values were consistently below 0.25 mg/L throughout the year for all regions except the Northern Interior Delta (Figure 3). All regions except the Northern Interior Delta showed a seasonal trend of lower dissolved ammonia concentrations during the summer months and higher concentrations in the winter. Despite weaker seasonal trends in the Northern Interior Delta, the stations produced a greater range of dissolved ammonia concentrations, peaking in November with an averaged value of 0.72 mg/L and negative peaks occurring in April (0.36 mg/L) and October (0.12 mg/L), which more closely match the other stations' values at those times.

Dissolved Calcium

Dissolved calcium concentrations in San Pablo Bay, Suisun and Grizzly Bays, and the Confluence followed similar seasonal trends; a decrease in concentration in April followed by a steady rise throughout the rest of the year until a slight decrease in December. Concentrations for the Central Delta, Southern Interior Delta, and Northern Interior Delta were relatively consistent throughout the

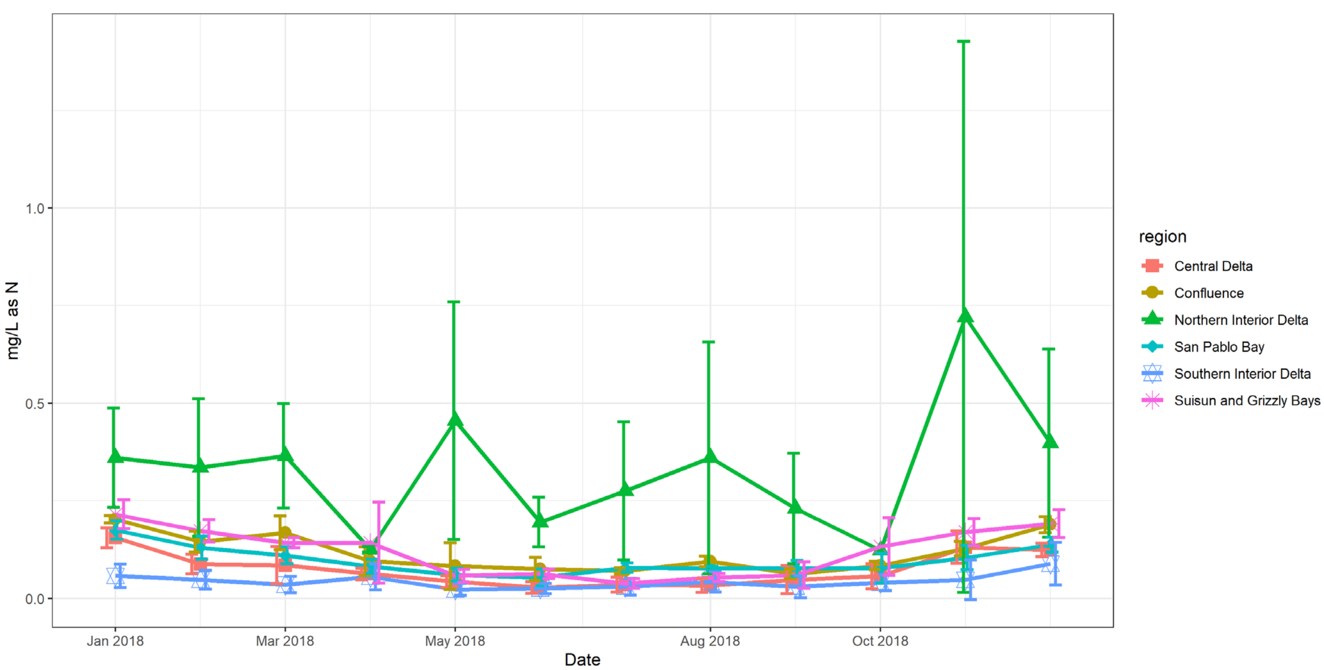

Figure 3. Monthly regional averages for dissolved ammonia in 2018. Averages were calculated using the Kaplan-Meier estimator to account for non-detects.

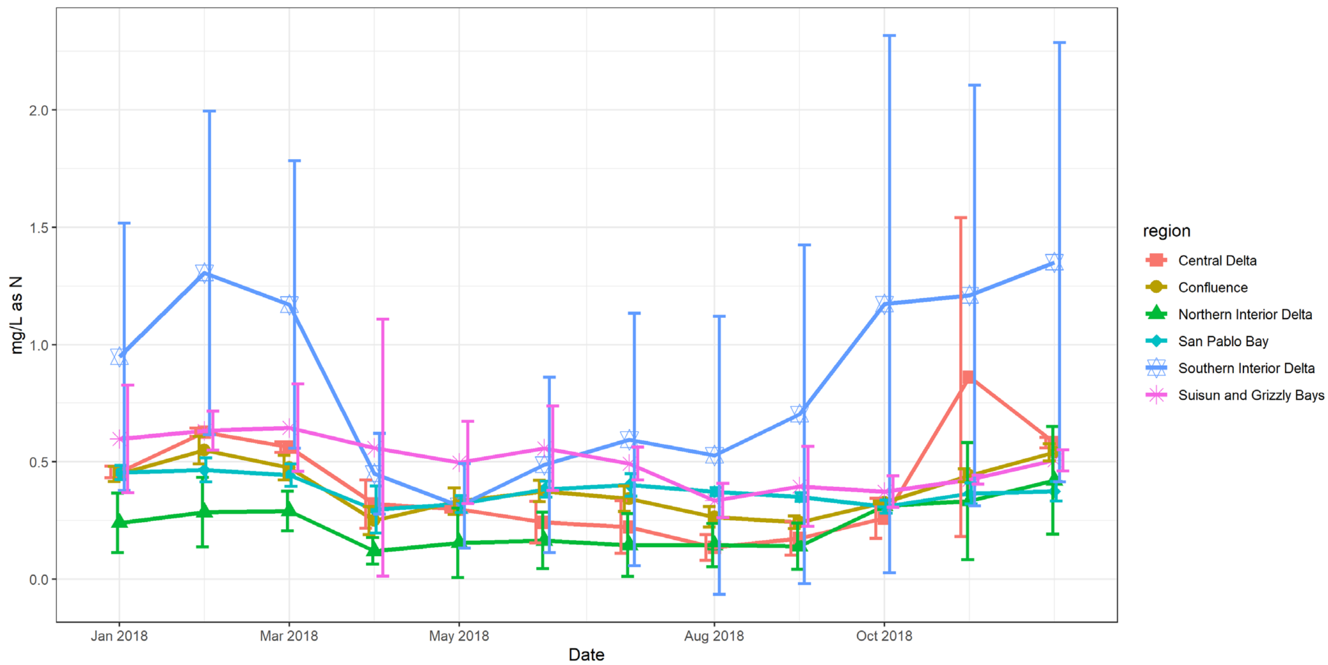

Figure 4. Monthly regional averages for dissolved nitrate nitrite in 2018. Averages were calculated using the Kaplan-Meier estimator to account for non-detects.

year (~ 13 mg/L).

Dissolved Chloride

Dissolved chloride values for the Northern Interior Delta, Southern Interior Delta, and Central Delta stayed consistently low throughout the entire year with minimal seasonal variation. The San Pablo Bay, Suisun and Grizzly Bays, and the Confluence had higher average values and displayed stronger seasonal trends. The month of April yielded the lowest concentration of dissolved chloride in all regions with a gradual increase until November, when all regions except Suisun and Grizzly Bays experienced their highest concentration. In Suisun and Grizzly Bays in the month of August, station D7 experienced a value of 132 mg/L, causing a higher standard deviation.

Dissolved Nitrate Nitrite

Dissolved nitrate nitrite in all regions followed similar seasonal trends of increased concentrations in the cooler months and decreased concentrations in the warmer months (Figure 4). The Southern Interior Delta had the highest averages, with the greatest concentration (~1.3 mg/L) occurring in February.

Dissolved Orthophosphate

Dissolved orthophosphate levels were relatively consistent in all regions except the Southern Interior Delta. Some seasonal variance was present in the Northern Interior Delta, Suisun and Grizzly Bays, San Pablo Bays, and the Confluence. These regions showed negative peaks in April with increases throughout the summer months.

Dissolved Silica

Dissolved silica concentrations ranged from ~6 mg/L (San Pablo Bay) to ~20 mg/L (Northern Interior Delta) throughout the year. All regions except for San Pablo Bay show increased concentrations in the cooler months but peak times were not universal.

Dissolved Organic Carbon

Dissolved organic carbon concentrations remained relatively consistent for each region except in the month of April. The Southern Interior Delta, Suisun and Grizzly Bays, and San Pablo Bay each experienced peak levels at this time, while the Northern Interior Delta experienced its lowest concentration (1.9 mg/L). There is some seasonal variation in all regions except San Pablo Bay when the dissolved organic carbon concentrations decrease during the summer months.

Dissolved Organic Nitrogen

Dissolved organic nitrogen concentrations saw peak concentrations in every region except San Pablo Bay during the cooler months. The Southern Interior Delta experienced the highest levels of dissolved organic nitrogen (0.52 mg/L as N) by a significant margin but minimized the distance between it and the other regions' values in the late spring. San Pablo Bay saw the least seasonal fluctuation, maintaining a concentration between 0.1 and 0.18 mg/L as N throughout the entire year.

Pheophytin

All regions saw minimal seasonal fluctuations in pheophytin concentrations (between ~0.6 and ~2.1 µg/L) with the exception of the Southern Interior Delta and the Central Delta. A slight increase in pheophytin in most regions occurred in late winter and Spring with levels returning to ~0.7 µg/L in June. The Southern Interior Delta experienced a gradual increase in concentration in the summer, ending with a peak of 4.04 µg/L in September and a sharp decline in the following month. The Central Delta peaked in November with a mean value of 4.46 µg/L due to D19 having a concentration of 15.4 µg/L.

Total Dissolved Solids

Strong seasonal trends in total dissolved solids concentrations occurred in the San Pablo Bay, Suisun and Grizzly Bays, and the Confluence. These regions saw a sharp decline in concentrations in April with gradual increases throughout the rest of the

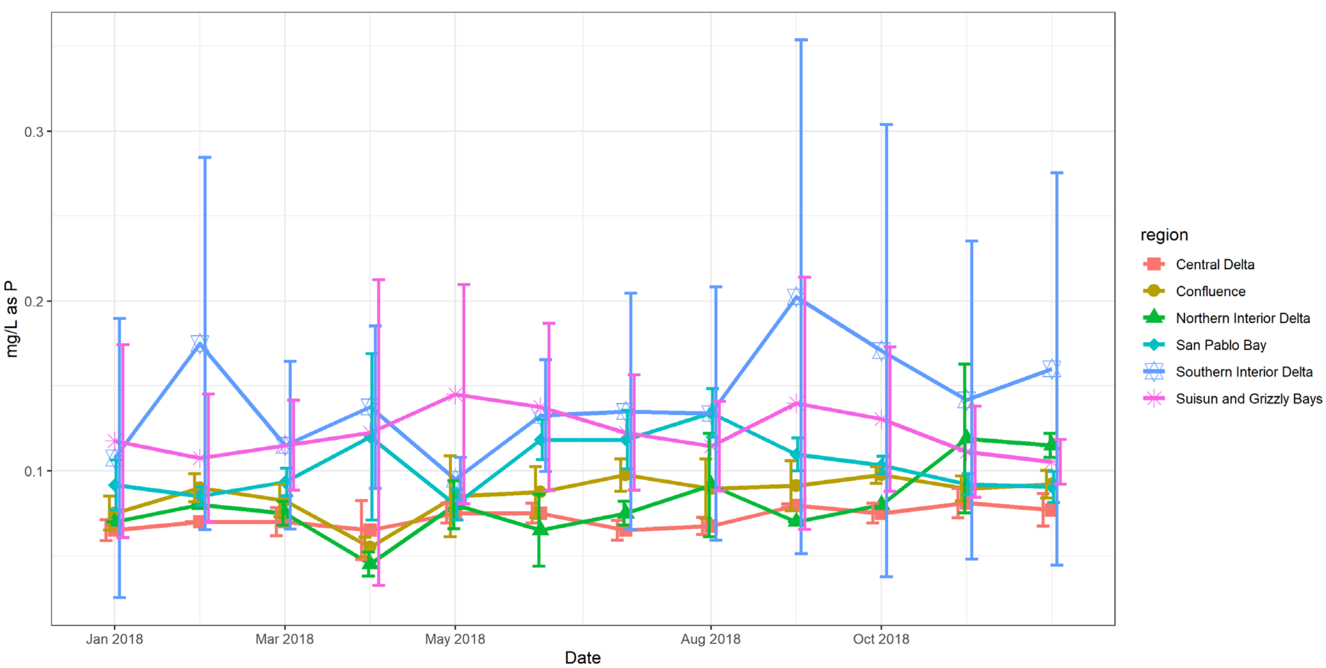

Figure 5. Monthly regional averages for total phosphorus in 2018. Averages were calculated using the Kaplan-Meier estimator to account for non-detects.

year and a slight decrease into December. These regions respectively had the highest concentrations of total dissolved solids. The other regions saw consistently low values throughout the entire year (~1.0 mg/L) with no seasonal variation. This analyte shows similar trends as dissolved calcium and dissolved chloride.

Total Kjeldahl Nitrogen (TKN)

TKN was fairly consistent in each region throughout the year, with average regional values ranging from of 0.5 mg/L to 1.01 mg/L as N. The Interior Deltas were consistently the highest regional values, with the annual peak occurring in the Northern Interior Delta in November. There was high variability in the Northern Interior Delta, with C3A consistently reporting values close to 1 mg/L while NZ068 peaked at 0.6 mg/L in January. Suisun and Grizzly Bays also had high regional variation with NZS42 consistently reporting higher values than other stations within the region. Other regions had lower monthly variation in their stations. There was no obvious seasonal variation in any region.

Total Organic Carbon (TOC)

San Pablo Bay consistently had the lowest average TOC values, with a peak in April of 2.22 mg/L; the Southern Interior Delta and Suisun/Grizzly Bays also reported their annual peaks in this month (5.68 and 6.35 mg/L, respectively). The Southern Interior Delta reported the highest average TOC values in all months with the exception of April and May when Suisun and Grizzly Bays and the Central Delta, respectively, reported higher values. There was high variability in Suisun/Grizzly Bay's average values due to NZ032 and NZS42 consistently reporting higher values than D7 and D8; other regions had fairly lower monthly variability, barring outliers. The Central Delta and Southern Interior Delta displayed some seasonal variation, with higher average values in the late winter and spring months.

Total Phosphorus

The Southern Interior Delta, Suisun/Grizzly Bays, and San Pablo Bay displayed higher average total phosphorus values than the Confluence, Northern Interior Delta, and the Central Delta (Figure 5). The Southern Interior Delta had especially high variation in its monthly averages due to higher reported values at P8. Suisun/Grizzly Bays also had high variation due to values at NZS42 and NZ032 being higher than those at D7 and D8; other regions had low variation, excluding the Northern Interior Delta in November due to high values C3A. There were no strong seasonal trends in any region.

Total Suspended Solids (TSS)

TSS values varied widely by region, with low values in the Northern Interior Delta and Central Delta, and high ones San Pablo Bay and Suisun/Grizzly Bays. Variation in monthly averages was especially high in San Pablo Bay and Suisun/Grizzly Bays, and both regions displayed small seasonal trends, with

Table 1. List of water quality indicators analyzed by EMP. Asterisk denotes analytes collected in the field.

Total Alkalinity	Dissolved Ammonia	Dissolved Calcium
Dissolved Chloride	Total Kjeldahl Nitrogen	Dissolved Nitrate + Nitrite
Dissolved Organic Carbon	Total Organic Carbon	Dissolved Organic Carbon
Dissolved Ortho-Phosphate	Dissolved Oxygen*	pH*
Total Phosphorus	Dissolved Silica	Total Dissolved Solids
Specific Conductance*	Total Suspended Solids	Volatile Suspended Solids
Temperature*		Turbidity*

Table 2. Regions sampled by EMP and the stations contained within each.

REGION NAME	EMP DISCRETE WATER QUALITY STATION
Northern Interior Delta	C3A NZ068
Southern Interior Delta	P8 MD10A C10A C9
Central Delta	D28A D19 D16 D26
Confluence	D10 D4 D12 D22
Suisun & Grizzly Bay	D7 NZ032 NZS42 D8
San Pablo Bay	D41 D41A D6 NZ002 NZ004 NZ325

lower values in the fall months. In addition, values in the Southern Interior The Central Delta region had smaller variation in its monthly averages and did not display strong seasonal trends.

Volatile Suspended Solids (VSS)

Average VSS values were highest in San Pablo Bay throughout the year, except for January and February, where they were highest in Suisun/Grizzly Bays. Variation was also high in these regions. Values were consistently low (< 2.7 mg/L) in the Central Delta and Northern Interior Delta. Values were lowest in the winter months in San Pablo Bay and Suisun/Grizzly Bays; no other region displayed prominent seasonal trends.

References

Helsel, D. R. (2012). Statistics for censored environmental data using Minitab and R. Wiley.

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Benthic Monitoring, 2019

Sarah Perry* and Betsy Wells (DWR)

*Corresponding Author:
Sarah.Perry@water.ca.gov

Introduction

Benthic monitoring conducted by the California Department of Water Resources (DWR) since 1975 has documented changes in the composition, density, and distribution of the macrobenthic biota inhabiting the upper San Francisco Estuary. This monitoring is performed by the Environmental Monitoring Program (EMP) as part of the Interagency Ecological Program (IEP) and is one component of the biological monitoring mandated by Water Right Decision D-1641. Since benthic species respond to changes in physical factors such as freshwater inflows, salinity, and substrate composition, benthic community data provides an indication of physical changes occurring within the Estuary. Benthic monitoring is an important component of the EMP because operation of the State Water Project can change the Estuary's flow characteristics, affecting the density and distribution of benthic biota. Benthic monitoring data is also used to detect and document the presence of new, non-native species in the Upper Estuary, such as the 1986 arrival and subsequent wide spread of the overbite clam, Potamocorbula amurensis. This article summarizes benthic community characteristics at EMP monitoring sites in 2019 and contextualizes these observations using community data from the previous decade.

Methods

Benthic monitoring was conducted monthly at 10 sampling sites distributed

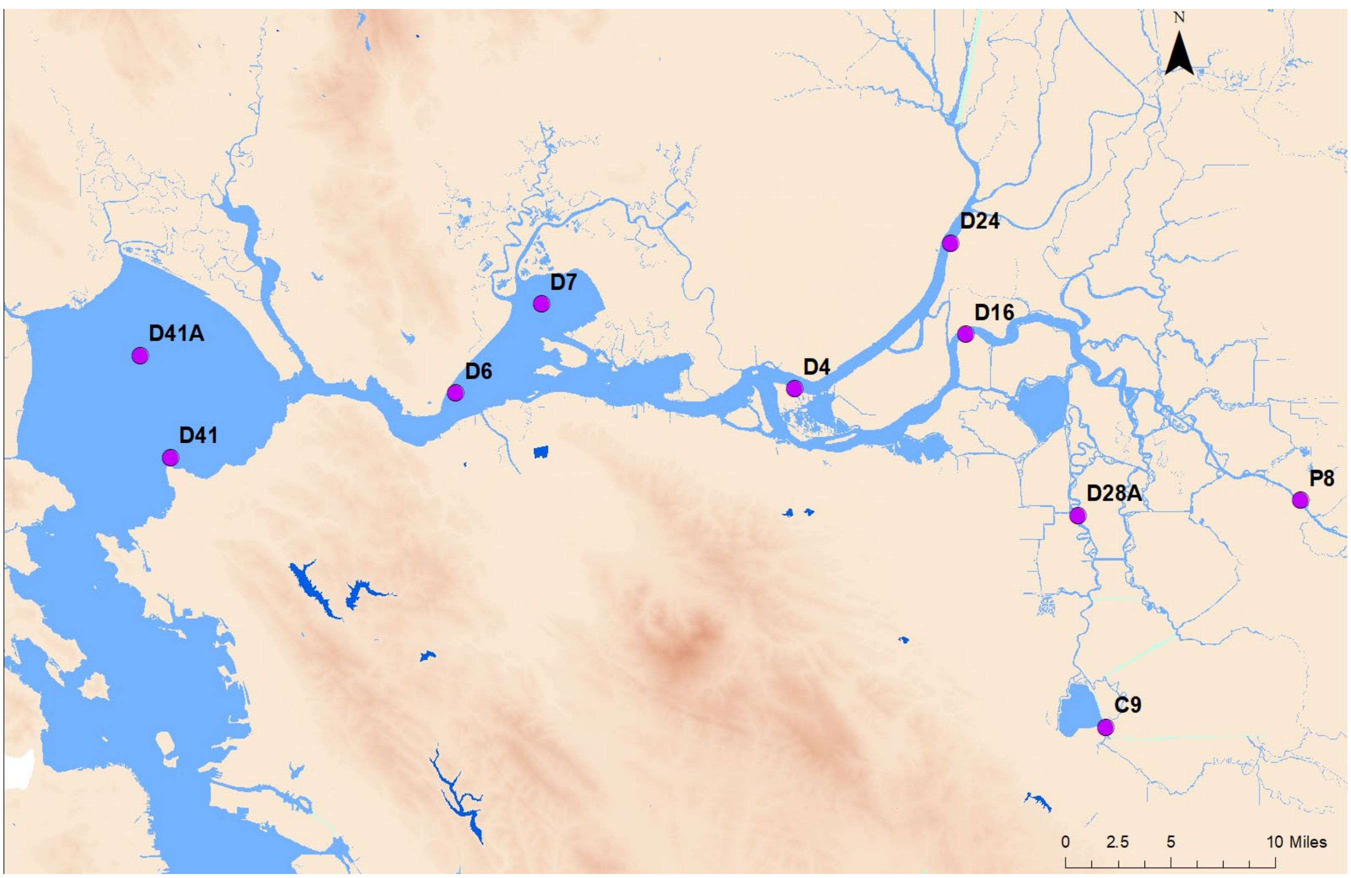


Figure 1. Locations of the Environmental Monitoring Program's (EMP) benthic monitoring stations.

throughout the Estuary, from San Pablo Bay upstream through the Sacramento-San Joaquin Delta (Figure 1). Department of Water Resources staff collected five bottom grab samples at each station using a Ponar dredge with a sampling area of 0.052 m2. Four replicate grab samples were collected for benthic macrofauna analysis and the fifth sample was used for sediment analysis. Benthic macrofauna samples were analyzed by Hydrozoology, a private laboratory under contract with DWR. All organisms were identified to the lowest taxon possible and enumerated. Sediment composition analysis was conducted at the DWR Soils and Concrete Laboratory. Field collection methodology and laboratory analysis of benthic macroinvertebrates and sediment composition are described in detail in the benthic metadata found at http://californiaestuaryportal.com/ .

Prior to analysis, the units for individual organisms were transformed from raw counts to densities. Species were then grouped by phyla, and time series for each station were constructed to depict seasonal patterns in benthic communities. Rare phyla (< 5% of the total organisms for the given year) were omitted from the plots. We did not report

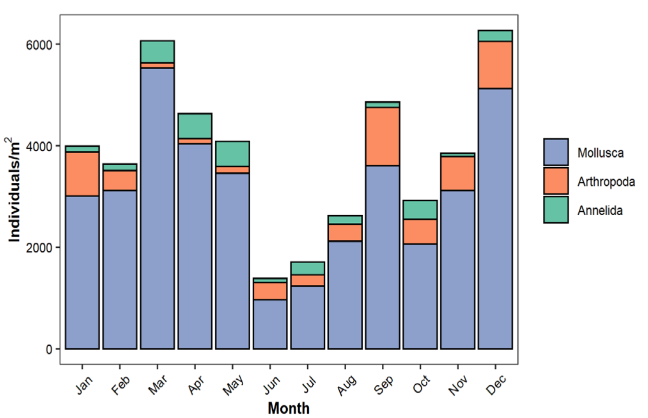


Figure 2. Density of benthic organisms, grouped by phylum, collected at station D24 (Sacramento River at Rio Vista) by month in 2019. Rare phyla (< 5% of the total organisms for the given year) were omitted from this figure.

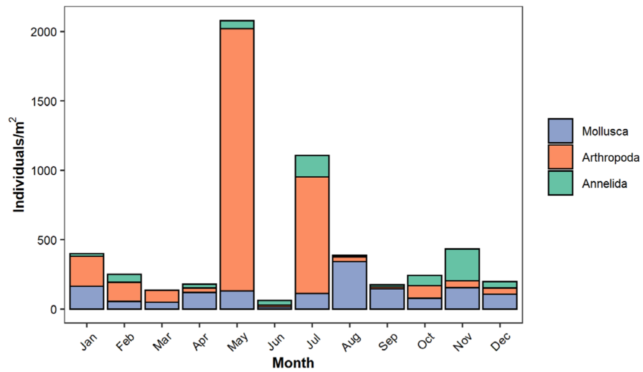


Figure 3. Density of benthic organisms, grouped by phylum, collected at station D16 (San Joaquin River at Twitchell Island) by month in 2019. Rare phyla (< 5% of the total organisms for the given year) were omitted from this figure.

sediment compositions for 2019 because the data for most months was not yet available.

The 2019 water year was designated as “Wet” for both the Sacramento Valley and the San Joaquin Valley according to the DWR’s Water Year Hydrologic Classification Indices. Benthic communities in 2019 were expected to be like previous “Wet” years (2011 and 2017) and differ from years designated Critical, Dry, or Below Normal both in species composition and in species abundances.

Results

The benthic fauna collected in 2019 comprised nine phyla: Mollusca (35% of total organisms), Arthropoda (34%), Annelida (29%), Phoronida (1%), Nemotoda (1%), Nemertea (< 1%), Platyhelminthes (<1%), Chordata (< 1%), and Cnidaria (< 1%). Of the 184 benthic species collected in 2019, the ten most abundant species represented 83% of all individuals collected throughout the year (Table 1). These include five species of amphipod, two clams, two tubificid worms, and an ostracod. Refer to Fields and Messer (1999) for descriptions of the habitat requirements, physical attributes, and feeding methods of these species.

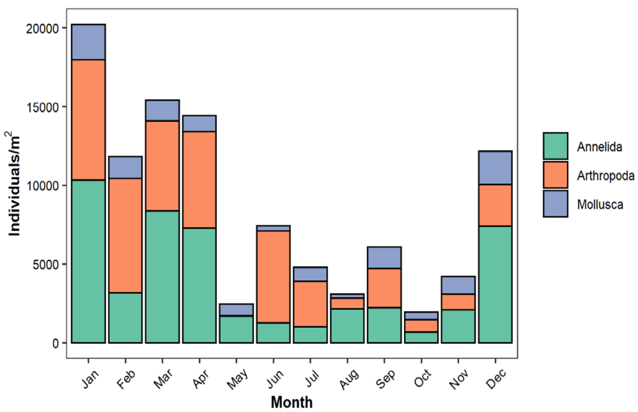


Figure 4. Density of benthic organisms, grouped by phylum, collected at station D28A (Old River) by month in 2019. Rare phyla (< 5% of the total organisms for the given year) were omitted from this figure.

In the site descriptions that follow, many species densities are reported as the annual densities of individuals/m2, sometimes noting drastic seasonal peaks. Some species, especially arthropods, display strong seasonal variability, with peak monthly densities several times higher than their annual densities. In these cases, we reported the time and magnitude of the peaks as well as the annual densities. Readers who wish to see the full dataset can access it at http://californiaestuaryportal.com/ .

North Delta (D24)

The site known as D24 is located on the Sacramento River, just south of the Rio Vista Bridge (Figure 1). There was a total of 54 species in six phyla at D24. Mollusca was by far the most abundant phylum for much of the year and made up 81% of all organisms collected at the station (Figure 2). A large majority (79%) of the organisms found at D24 in 2019 were the invasive clam *Corbicula fluminea*, with an annual density of 3,016 individuals/m2. The second most abundant organism was the amphipod *Gammarus daiberi*, with an annual density of 349 individuals/m2. *Corbicula fluminea* density in 2019 resembled the 3,576 individuals/m2 seen in 2018; the two years are by far the highest densities of the last decade. Otherwise, the benthic community found at D24 in 2019 was similar in species composition to other years over the last decade.

Central Delta (D16, D28A)

The benthic monitoring program sampled at two stations, in the Central Delta, D16 and D28. Site D16 is on the lower San Joaquin River near Twitchell Island (Figure 1). There were 32 species in five phyla at D16 in 2019, with the highest total organism densities occurring in May and July (Figure 3). Arthropoda was the most abundant phylum and accounted for 61% of all organisms collected through the year. The most abundant species at D16 was the amphipod *G. daiberi*, which accounted for 45% of all organisms in 2019. It peaked in May at 1,832 individuals/m2, over eight times its annual density of 214 individuals/m2. *Corbicula fluminea* was the second most abundant organism with an annual density of 113 individuals/m2; Mollusca made up 26% of all organisms collected at the station. Annelids accounted for 13% of organisms with the oligochaete worm, *Varichaetadrilus angustipenis* having the highest annual density at 35 individuals/m2. The amphipod

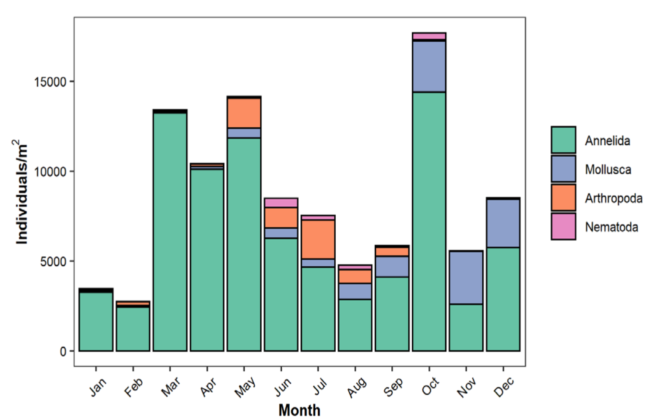


Figure 5. Density of benthic organisms, grouped by phylum, collected at station P8 (San Joaquin River at Buckley Cove) by month in 2019. Rare phyla (< 5% of the total organisms for the given year) were omitted from this figure.

Table 1. The ten most numerous benthic invertebrate species in 2019.

Species	Organism Type	Native/ introduced status	Station(s) at which species was found*	Month(s) in which species was abundant**	Total number of individuals***
Potamocorbula amurensis	Asian clam	Introduced	D6, D7, D41, D41A, D4, D24	All Months	50,436
Varichaetadrilus angustipenis	Tubificidae worm	Introduced	C9, D4, D28A, P8, D24, D16, D7, D41	Feb – Aug, Oct – Dec	19,340
Americorophium spinicorne	Amphipod	Native	D4, D28A, P8, C9, D16, D7, D24, D6	Jan – Feb, June – Sept, Dec	19,312
Manayunkia speciosa	Sabellidae polychaete worm	Introduced	P8, D28A, C9, D24	Jan, March – July, Oct, Dec	16,865
Corbicula fluminea	Asian clam	Introduced	D24, D4, P8, D28A, D16, C9, D7	Feb – May, July - Dec	13,016
Ampelisca abdita	Amphipod	Introduced	D41A, D41, D6	Jan – Feb, July – Dec	11,868
Corophium alienense	Amphipod	Introduced	D7, D6, D41A, D4	Jan, July – Dec	11,618
Gammarus daiberi	Amphipod	Introduced	D4, D28A, D24, D16, D7, P8, C9, D6, D41	June, Sept	7,081
Cyprideis sp. A	Ostracod	Unknown	D28A, C9, P8, D4	Jan – April	6,404
Limnodrilus hoffmeisteri	Tubificidae worm	Unknown; cosmopolitan	C9, P8, D4, D28A, D24, D16, D7, D41	June	6,394
Hyalella sp. A	Amphipod	Unknown	C9, D28A, D4, D24, D16	Nov – Dec	3,582

* Stations are listed in order from highest to lowest total annual abundance.

** Across all stations; abundant is defined as > 5% of total organisms.

*** Total number of individuals was the sum of individuals at all sites at all months in 2019.

Americorophium spinicorne, had large density peaks in 2016 (923 individuals/m2) and 2018 (804 individuals/m2), but dropped down to an annual density of 53 individuals/m2 in 2019, the second lowest density of the decade. Aside from the variability in densities of this amphipod, the community composition at D16 has remained largely consistent through the last decade.

The site on Old River near Rancho Del Rio is known as D28A (Figure 1). In 2019, there were 77 species in seven phyla at D28A. The most abundant phyla were Annelida and Arthropoda (46% and 41% of all individual organisms, respectively) (Figure 4). The most abundant species was the arthropod *Cyprideis* sp. A, with an annual density of 2,466 individuals/m2; it was most abundant from February through April. The second most abundant species was the annelid *Manayunkia speciosa*, with an annual density of 1,585 individuals/m2 and a peak density of 7,303 individuals/m2 in January. Overall, the community composition at D28A in 2019 did not differ much from other years this decade, and there was no clear pattern of community composition according to water year classification type.

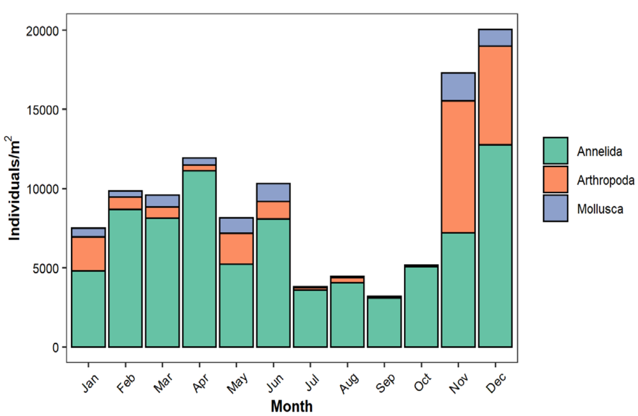


Figure 6. Density of benthic organisms, grouped by phylum, collected at station C9 (Clifton Court) by month in 2019. Rare phyla (< 5% of the total organisms for the given year) were omitted from this figure.

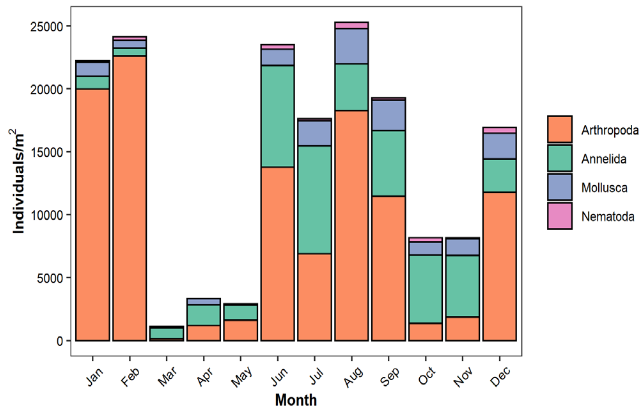


Figure 7. Density of benthic organisms, grouped by phylum, collected at station D4 (Confluence) by month in 2019. Rare phyla (< 5% of the total organisms for the given year) were omitted from this figure.

South Delta (P8, C9)

The benthic monitoring program sampled at two stations in the South Delta. Site P8 is on the San Joaquin River at Buckley Cove (Figure 1). Station P8 had a total of 59 species in six phyla. Annelida was the most abundant phyla at this station in 2019, accounting for 79% of all organisms collected, followed by Mollusca at 12% (Figure 5). The dominant species was the annelid *M. speciosa*, which accounted for 59% of all organisms at the station. It had an annual density of 5,096 individuals/m2 and peaked in October and March with monthly densities of 12,058 and 11,438 individuals/m2, respectively. *Manayunkia speciosa* experienced a dramatic increase in density between 2012 and 2015, peaking at 11,338 individuals/m2 in 2015, before declining sharply to a decade low of 656 individuals/m2 in 2018. All other organisms had similar annual densities over the past decade.

Site C9 is on Old River at the Clifton Court Forebay intake (Figure 1). There were 79 species in seven phyla at C9 in 2019. Annelida was the dominant phylum throughout the year, accounting for 73% of all organisms collected in 2019 (Figure 6).

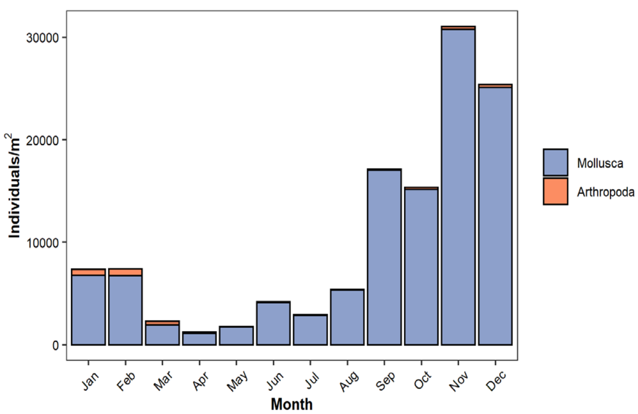


Figure 8. Density of benthic organisms, grouped by phylum, collected at station D6 (Suisun Bay) by month in 2019. Rare phyla (< 5% of the total organisms for the given year) were omitted from this figure.

The most abundant organism was the annelid *Varichaetadrilus angustipenis*, accounting for 38% of all organisms, with an annual density of 3,513 individuals/m2. The annelid *Limnodrilus hoffmeisteri* and amphipod *Hyalella* sp. A were the second and third most abundant species, accounting for 15% and 13% of the total organisms. *Hyalella* sp. A was virtually unseen until the end of the year, with peaks of 7,769 and 5,591 individuals/m2 in November and December. Arthropoda accounted for 20% all organisms collected. *Hyalella* sp. A, *L. hoffmeisteri,* and *V. angustipenis* all saw moderate increases from their 2018 densities, with *V. angustipenis* reaching its highest density since 2013, while most other organisms experienced little change through the last decade.

Confluence (D4)

Site D4 is located near the confluence of the Sacramento and San Joaquin Rivers, just above Point Sacramento (Figure 1). There were 57 species in seven phyla at D4 in 2019. Arthropoda was the most abundant phylum (64% of all organisms) followed by Annelida (25% of all organisms) (Figure 7). The amphipod *Americorophium spinicorne* was the most abundant species at this station (47% of organisms) with a seasonal peak of 21,154 individuals/m2 in February before dropping to an annual low of 67 individuals/m2 in March. The annelid *V. angustipenis* was the second most abundant organism in 2019 (18% of all individuals) followed by the amphipod *G. daiberi* at 11%. Community composition varied widely over the past decade at this station, but without a discernable pattern clearly caused by water year classification type.

Suisun Bay (D6 and D7)

The benthic monitoring program sampled at two stations in the Suisun Bay area, D6 and D7. Site D6 is in Suisun Bay near the I-680 bridge (Figure 1) and had 30 species in four phyla in 2019. Mollusca was the dominant phylum, accounting for 97% of all organisms collected (Figure 8). Most of the organisms collected were the invasive Asian clam *Potamocorbula amurensis*, which had an annual density of 9,891 individuals/m2. *Potamocorbula amurensis* was most abundant in the fall months, reaching a peak density of 30,793 individuals/m2 in November. The other organisms found at this site were predominately from phylum Arthropoda, and they each individually contributed <1% to the community composition. Site D6 has the highest annual density of invasive clams

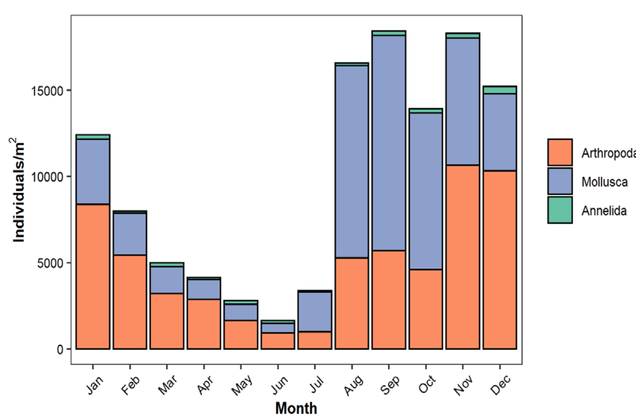


Figure 9. Density of benthic organisms, grouped by phylum, collected at station D7 (Grizzly Bay) by month in 2019. Rare phyla (< 5% of the total organisms for the given year) were omitted from this figure.

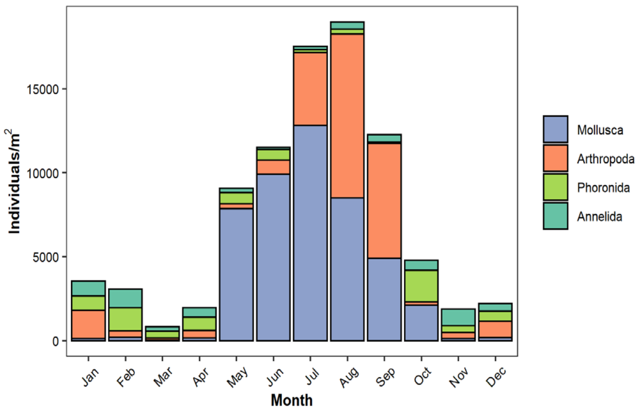


Figure 10. Density of benthic organisms, grouped by phylum, collected at station D41 (San Pablo Bay) by month in 2019. Rare phyla (< 5% of the total organisms for the given year) were omitted from this figure.

among all EMP benthic monitoring sites. *Potamocorbula amurensis* reached a decade-high annual density at D6 in 2018 at 17,340 individuals/m2 before dropping to 9,891 in 2019, which is more consistent with previous years. The overall community composition has been consistent at D6 through the decade.

Site D7 is in Grizzly Bay, near the entrance to Suisun Slough (Figure 1). There were 30 species in five phyla in 2018. Arthropoda made up 50% of all organisms counted at D7 with Mollusca comprising 48%. The invasive clam *P. amurensis* and amphipod *Corophium alienense* were the two most abundant species, comprising 48% and 46% of the total community through the year, respectively. *Potamocorbula amurensis* was most abundant in the summer months, reaching a peak density of 12,471 individuals/m2 in September, about 2.5 times its annual density. *Corophium alienense* decreased from the beginning of year until June, where it reached an annual low of 408 individuals/m2, before increasing through the rest of the year to peak in November at 10,428 individuals/m2. *Potamocorbula amurensis* increased in annual density in 2019 compared to 2018 (11,902 vs. 7,063) while *C. alienense* decreased slightly (4,634 vs. 5,526). Other species' densities remained consistent with 2018 patterns.

San Pablo Bay (D41, D41A)

The benthic monitoring program sampled at two stations in San Pablo Bay, D41 and D41A. Station D41 is near Point Pinole (Figure 1) and has a benthic community primarily comprised of marine organisms, especially in drier water years. There were 70 species in nine phyla at D41 in 2019. Mollusca was the most abundant phylum (53%) followed by Arthropoda (30%) (Figure 10). *Potamocorbula amurensis* made up 51% of the organisms at this station and was most abundant in the late spring and summer months, peaking at 12,587 individuals/m2 in July. The amphipod *Ampelisca abdita* was the second most abundant species at 25% of all organisms and was also abundant in the summer months, peaking in August at 8,563 individuals/m2. In the relatively wet years of 2017 and 2019, *P. amurensis* hit decadal density peaks (3,762 and 3,755 individuals/m2, respectively) while *A. abdita* densities were low relative to their extremely high peaks in drier water years. The inverse pattern was true in 2018, when no *P. amurensis* were

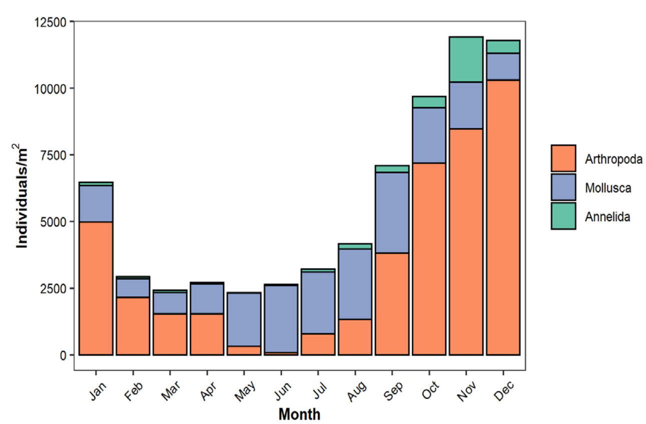


Figure 11. Density of benthic organisms, grouped by phylum, collected at station D41A (San Pablo Bay) by month in 2019. Rare phyla (< 5% of the total organisms for the given year) were omitted from this figure.

collected but *A. abdita* reached a decadal peak of 11,137 individuals/m2. This pattern is likely due to 2017 and 2019 being “Wet” water years, lowering the salinity in San Pablo Bay enough that it was habitable to *P. amurensis* and less habitable to the more marine-adapted *A. abdita,* while 2018’s lower outflow brought higher salinity conditions to San Pablo Bay than *P. amurensis* prefers, but made the benthos more habitable for *A. abdita*.

Station D41A is in San Pablo Bay near the mouth of the Petaluma River (Figure 1). There were 47 species in seven phyla at D41A in 2019. The most abundant phyla were Arthropoda (63% of all organisms) and Mollusca (32%) (Figure 11). The dominant species was the amphipod *A. abdita*, comprising 51% of the community composition with an annual density of 2,899 individuals/m2. It was most abundant in winter months, peaking at 9,846 individuals/m2 in December. The invasive clam *P. amurensis* was the second most abundant organism (30% of organisms) with an annual density of 1,686 individuals/m2. The overall community composition was consistent with that of 2018.

Conclusion

In summary, 2019 saw an overall decrease in invasive clam density from 2018 (13% for *P. amurensis* and 10% for *C. fluminea*). Other notable features of 2019 were the sharp decrease in overall density of the amphipod *A. abdita* in Grizzly Bay, after reaching a decadal peak in 2018, likely due to 2019’s decreased salinity, as well as the 2019 increase in the annelid *M. speciosa*, after its steady decrease from 2015 – 2018.

Our ability to recognize these changes highlights the importance of monitoring benthic invertebrates to a high taxonomic resolution across the entire estuarine salinity gradient since the community has important interactions with various abiotic conditions as well as key parts of the estuarine food web.

References

Fields W, Messer C. 1999. Life on the bottom: Trends in species composition of the IEP-DWR Benthic Monitoring Program. IEP Newsletter 12(4): 38-41.

2018 and 2019 20-mm Survey

Trishelle Tempel* and Adam Chorazyczewski (CDFW)

*Corresponding Author:
Trishelle.Tempel@wildlife.ca.gov

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

The 20-mm survey uses a conical net with 1600-micron nylon mesh to collect young of the year fish. This mesh size was chosen based on the minimum width of a 20mm long Delta Smelt. The net is 5.1 meters long with a mouth area of 1.51 square meters and is attached to a rigid steel D-ring frame that is mounted on skis. Nine biweekly surveys are conducted annually from March through July, which corresponds to the time of year the appropriately sized Delta Smelt are in the system. Each survey typically samples 47 fixed sites, or “stations” (Figure 1). During periods of high flow, 5 additional “high outflow stations” are sampled each survey in San Pablo Bay to better capture potential Delta

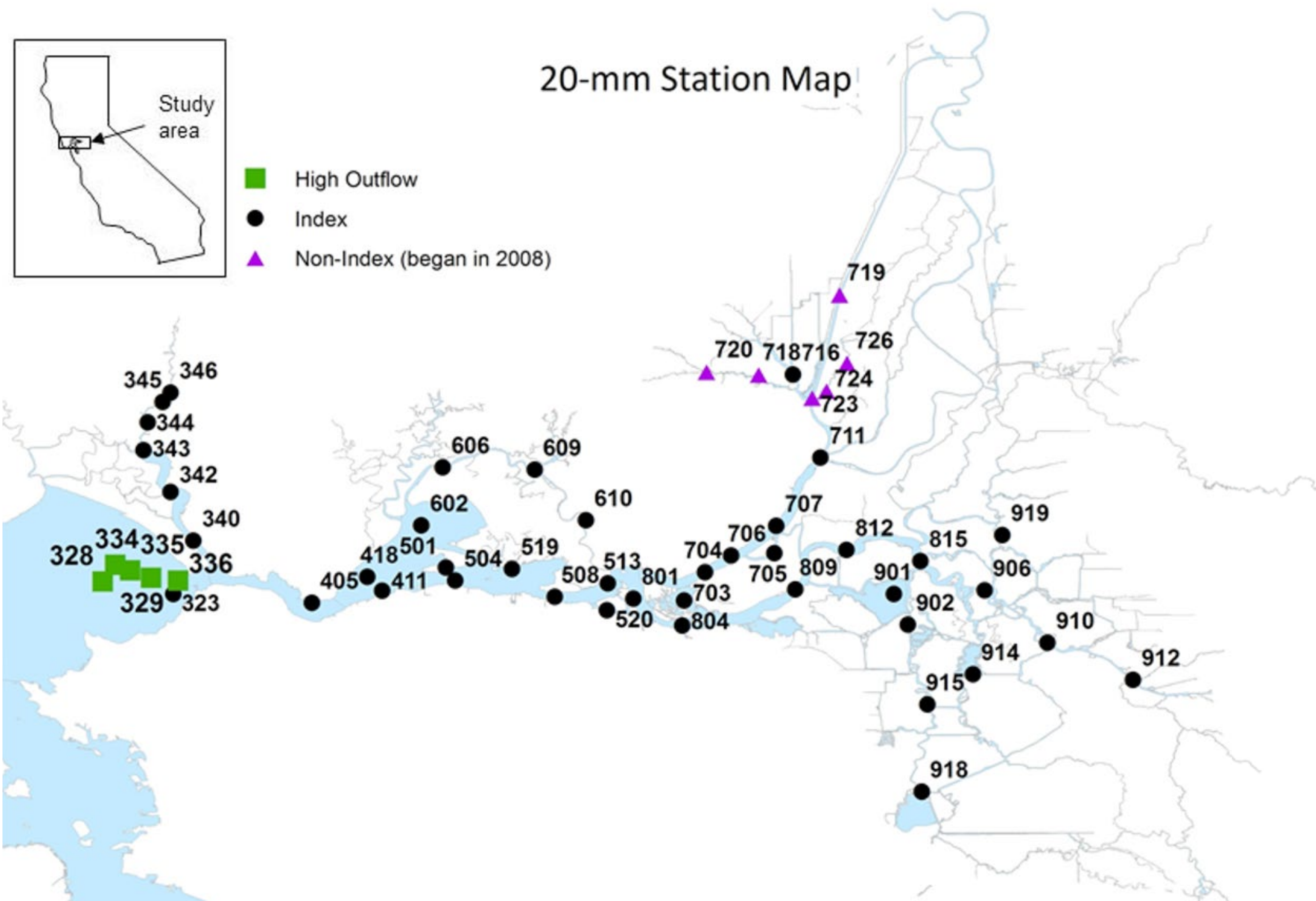


Figure 1. Station locations for the California Department of Fish and Wildlife’s 20-mm Survey.

Smelt distribution. At each station, the entire water column is sampled using 3 stepped-oblique fish tows and a single concurrent zooplankton tow. All samples are preserved in 10% buffered formalin dyed with Rose Bengal for later identification and enumeration in the laboratory. Fish are measured to the nearest millimeter by fork length if the caudal fin is forked or total length if the caudal fin is not forked.

2018 Catch Summary

From March 12 to July 6, 2018, CDFW completed nine biweekly surveys. High outflow stations were not sampled due to relatively low flow throughout the sampling period. We were not always able to sample all stations in a given survey, predominantly due to boat breakdowns, gear snags, excessive weeds, peat, or excessive jellyfish. All stations were sampled during Surveys 1, 2, 4, and 6. Two stations were not sampled during Survey 3 (Stations 918 and 724). Two stations were not sampled during Survey 5 (Stations 724 and 726). Two stations were not sampled during Survey 7 (Stations 901 and 726). One station was not sampled during Survey 8 (Station 346). Eighteen stations were not sampled during Survey 9 (Stations 323, 340, 342, 343, 344, 345, 346, 405, 411, 418, 501, 504, 703, 711, 718, 720, 724, and 726).

A total of 25,421 fish representing 38 taxa were collected (Table 1). *Tridentiger* spp. (gobies) was the most abundant organism caught, making up about 53% of the total catch, followed by Striped Bass (*Morone saxatilis*), making up about 16% of total catch. Longfin Smelt was the 3rd most abundant organism caught, making up about 13% of total catch. Delta Smelt was the 23rd most abundant species caught, making up less than 0.1% of catch.

2019 Catch Summary

From March 11 to July 3, 2019 CDFW

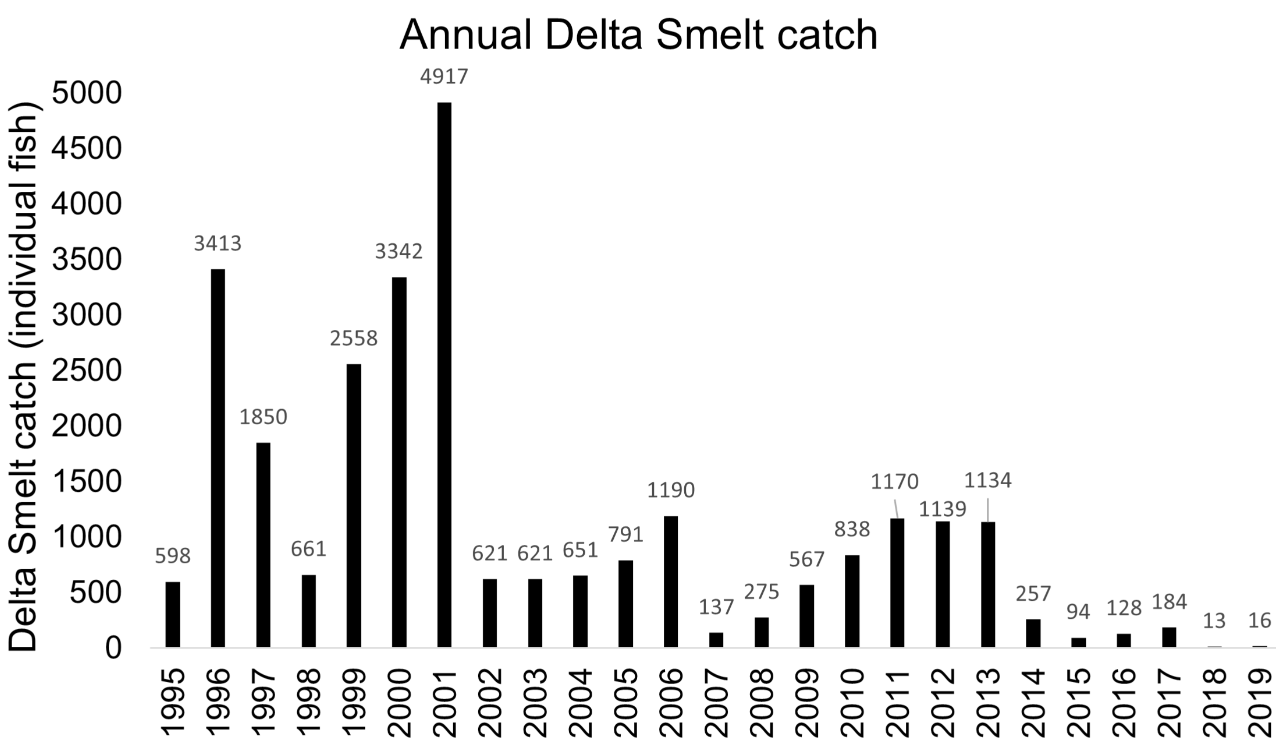


Figure 2. Annual Delta Smelt Catch for the California Department of Fish and Wildlife's 20-mm Survey.

Table 1. Total species catch for the 2018 California Department of Fish and Wildlife's 20-mm Survey.

Common Name	Catch (number of individuals)	Percent of catch
Tridentiger spp.	13524	53.20%
Striped Bass	4168	16.40%
Longfin Smelt	3377	13.28%
Threadfin Shad	1155	4.54%
Yellowfin Goby	977	3.84%
Pacific Herring	752	2.96%
Prickly Sculpin	724	2.85%
Northern Anchovy	130	<1%
American Shad	96	<1%
Threespine Stickleback	70	<1%
Centrarchids (Unid)	66	<1%
Arrow Goby	64	<1%
White Catfish	38	<1%
Sacramento Sucker	33	<1%
Shokihaze Goby	31	<1%
Jacksmelt	25	<1%
Shimofuri Goby	22	<1%
Channel Catfish	21	<1%
Bay Goby	20	<1%
Bigscale Logperch	19	<1%
Wakasagi	17	<1%
Longjaw Mudsucker	16	<1%
Delta Smelt	13	<1%
Chinook Salmon	10	<1%
Starry Flounder	9	<1%
Pacific Lamprey	8	<1%
Carp	7	<1%
Topsmelt	7	<1%
White Sturgeon	6	<1%
Splittail	4	<1%
Bay Pipefish	2	<1%
Bluegill Sunfish	2	<1%
English Sole	2	<1%
Pacific Staghorn Sculpin	2	<1%
Cheekspot Goby	1	<1%
Cyprinids (Unid)	1	<1%
Silversides (Unid)	1	<1%
Spotted Bass	1	<1%

Table 2. Total species catch for the 2019 California Department of Fish and Wildlife's 20-mm Survey

Common Name	Catch (number of individuals)	Percent of catch
Tridentiger spp.	50636	50.51%
Pacific Herring	18533	18.49%
Striped Bass	12405	12.38%
Longfin Smelt	8983	8.96%
Threadfin Shad	2816	2.81%
Yellowfin Goby	2663	2.66%
Northern Anchovy	1232	1.23%
Prickly Sculpin	1048	1.05%
American Shad	336	<1%
Threespine Stickleback	298	<1%
Centrarchids (Unid)	205	<1%
Arrow Goby	139	<1%
White Catfish	127	<1%
Longjaw Mudsucker	123	<1%
Splittail	112	<1%
Bay Goby	82	<1%
Cheekspot Goby	59	<1%
Bigscale Logperch	50	<1%
Cyprinids (Unid)	49	<1%
Sacramento Sucker	47	<1%
Jacksmelt	40	<1%
White Sturgeon	34	<1%
Shimofuri Goby	33	<1%
Speckled Sanddab	31	<1%
Wakasagi	21	<1%
Channel Catfish	18	<1%
Carp	16	<1%
Delta Smelt	16	<1%
Chinook Salmon	13	<1%
English Sole	12	<1%
Pacific Staghorn Sculpin	9	<1%
Shokihaze Goby	9	<1%
Inland Silverside	8	<1%
Rainwater Killifish	6	<1%
Topsmelt	6	<1%
White Croaker	5	<1%
Starry Flounder	4	<1%
Black Crappie	3	<1%
Bluegill Sunfish	3	<1%
Tule Perch	3	<1%
Mosquitofish	2	<1%
Bay Pipefish	1	<1%
Golden Shiner	1	<1%
Pacific Lamprey	1	<1%
Sacramento Blackfish	1	<1%
Spotted Bass	1	<1%

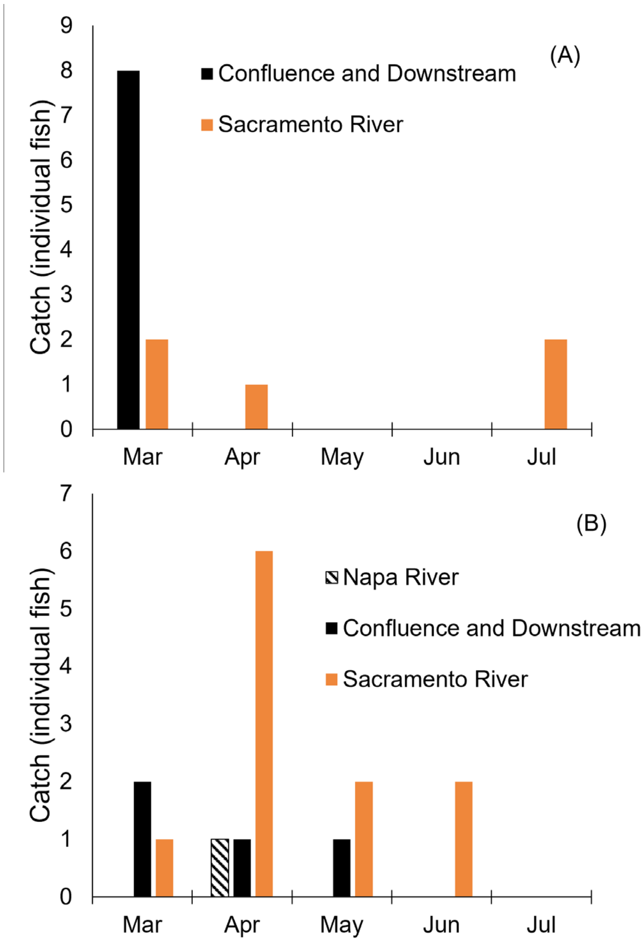


Figure 3. Delta Smelt catch during the (A) 2018 and (B) 2019 California Department of Fish and Wildlife's 20-mm Survey by month and region.

completed nine biweekly surveys. High outflow stations were sampled during Surveys 1 through 7 (mid-March through early-June). We were not always able to sample all stations in a given survey. All stations were sampled during Surveys 2, 3, 4, and 5. Five stations were not sampled during Survey 1 (Stations 344, 345, 346, 724, and 726). One station was not sampled during Surveys 6, 7, 8, or 9 due to excessive weeds (Station 901). One additional station was not sampled during surveys 8 and 9 (stations 323 and 346, respectively).

A total of 100,240 representing 46 taxa were collected (Table 2). *Tridentiger* spp. (gobies) was the most abundant organism caught, making up about 51% of the total catch, followed by Pacific Herring (*Clupea pallasi*), making up about 19% of total catch, and Striped Bass, making up about 12% of total catch. Longfin Smelt was the 4th most abundant organism caught, making up about 9% of total catch. Delta Smelt was the 28th most abundant species caught, making up less than 0.1% of catch.

Smelt Summary 2018 and 2019

2018 and 2019 had record low Delta Smelt catch with 13 and 16, respectively (Figure 2). In 2018, ten Delta Smelt were caught in March, one was caught in April, and two were caught in July. 62% of catch occurred near or downstream of the confluence of the Sacramento and San Joaquin Rivers (Stations 405, 411, 508, and 513), and 38% of catch occurred in the Sacramento River system (Stations 704, 706, and 718, Figure 3A). In 2019 Delta Smelt catch was more evenly distributed in time and space. Delta Smelt were collected each month from March through June, with 63% of catch occurring in the Sacramento River system (Stations 704, 719, 720, 723, and 726), 31% of catch occurring near or downstream of the confluence of the Sacramento and San Joaquin Rivers (Stations 335, 519, 520, and 606), and 6% of catch occurring in the Napa River (Station 344, Figure 3B). Low catch for these two years make it difficult to infer population-level distribution patterns.

A total of 3,377 and 8,983 Longfin Smelt were caught in 2018 and 2019, respectively (Figure 4). 2019 had the highest Longfin Smelt catch since 2013, however this catch is much lower than the historic average of 22,277 (min= 451, max= 143,019). Longfin Smelt had a more westward distribution in 2019 than in 2018 (Figure 5). In 2018, 96.6% of Longfin Smelt were collected between the confluence of the Sacramento and San

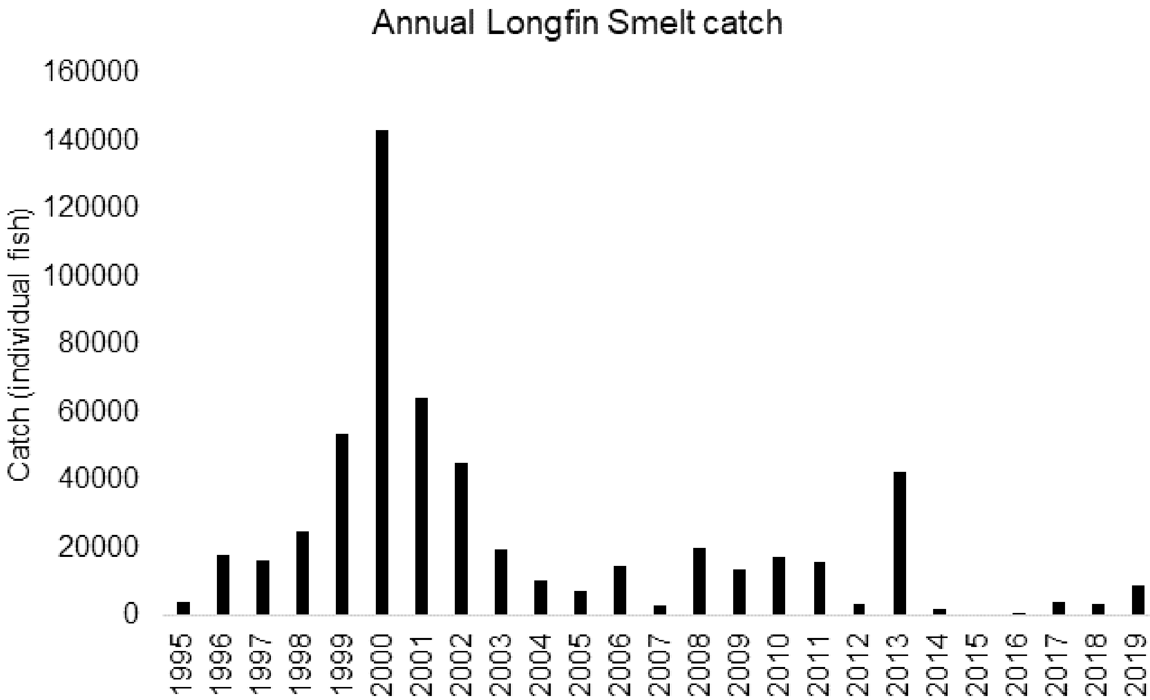


Figure 4. Annual Longfin Smelt Catch for the California Department of Fish and Wildlife's 20-mm Survey.

Joaquin Rivers and Carquinez Strait, 3.3% were collected in the Napa River, and <1% were collected in the Sacramento River (Figure 5A). In 2019, 66% of Longfin Smelt were caught in the Napa River, 26% were collected in San Pablo Bay (predominantly from the high outflow stations), and 8% were collected between the confluence of the Sacramento and San Joaquin Rivers and Carquinez Strait (Figure 5B). The distribution of Longfin Smelt in 2019 closely matches the observed distribution in 2017 with the majority of the catches coming from the western edge of the sampling area. This indicates that the distribution of Longfin Smelt was likely centered outside of the 20-mm sampling area, which is consistent with historic catch distributions of Longfin Smelt in high outflow years (Tempel 2017).

Current and past graphical data is available on the 20-mm Survey webpage http://dfg.ca.gov/delta/projects.asp?ProjectID=20mm. Data and metadata

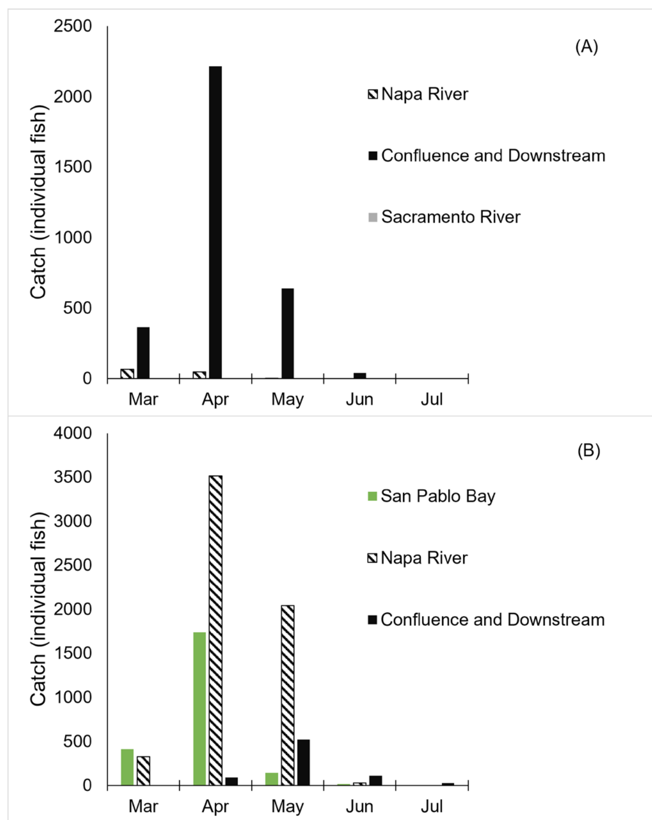


Figure 5. Longfin Smelt catch during the (A) 2018 and (B) 2019 California Department of Fish and Wildlife's 20-mm Survey by month and region.

are available through our FTP site ftp://ftp.dfg.ca.gov/Delta%20Smelt/.

References

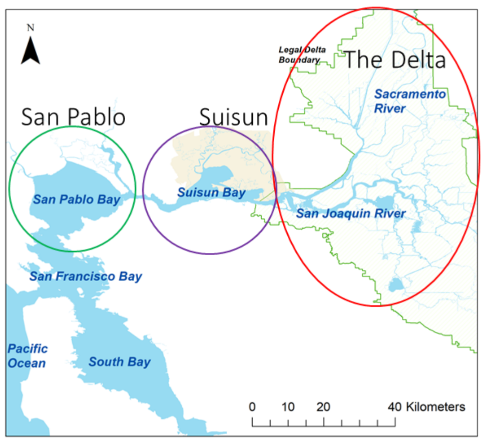
Tempel, T. 2017. 2017 Smelt Larva Survey Summary. Interagency Ecological Program Newsletter. 30 (3): 23-24.

Winter 2018-2019
IEP Seasonal Monitoring Report

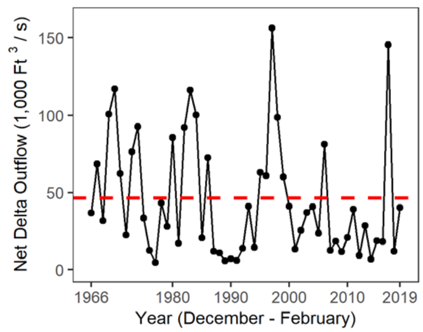
Interagency Ecological Program for the San Francisco Estuary
This report shows trends in water quality, plankton, and fish across multiple IEP surveys for December of 2018, January and February of 2019.

Contents

Regions of the Estuary



Delta Outflow



•Freshwater flow influences water quality, plankton, and fish populations.
•Winter flow is driven primarily by rainfall and upstream dam releases.
•The winter of 2019 had about average outflow.

Disclaimer: While substantial efforts are made to ensure the accuracy of these data, complete accuracy of data sets cannot be guaranteed. This report was developed by the IEP Synthesis Team.
For questions, comments, or corrections, contact Rosemary Hartman – Rosemary.Hartman@water.ca.gov

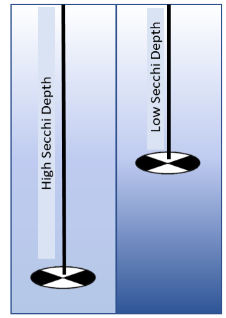
Secchi Depth

Background

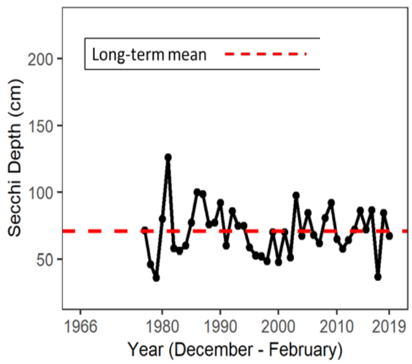
- Organisms in this ecosystem are adapted to high turbidity conditions, and reductions in turbidity can have many negative ecological effects.
- Higher values for Secchi depth indicate lower turbidity.
- Secchi depth is measured monthly by DWR's Environmental Monitoring Program by dropping a black-and-white disk in the water until it disappears.

For more information, see: Schoellhamer, D. H. 2011. Sudden clearing of estuarine waters upon crossing the threshold from transport to supply regulation of sediment transport as an erodible sediment pool is depleted: San Francisco Bay, 1999. Estuaries and Coasts 34(5):885-899.

Secchi disk

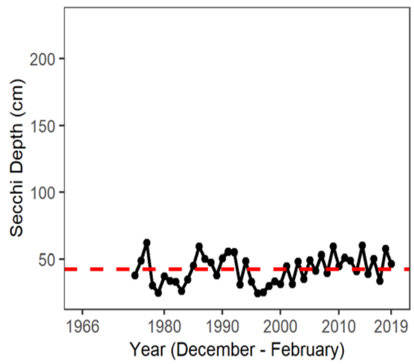


San Pablo Bay



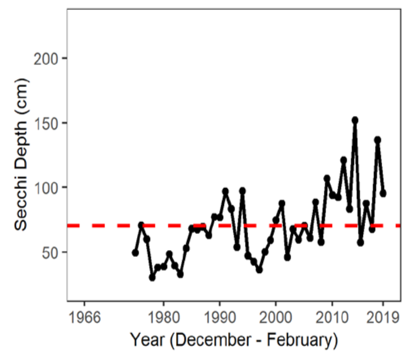
In 2019, San Pablo bay secchi was close to the long-term average.

Suisun Bay



In 2019, Suisun Bay was also close to the long-term average.

The Delta



In 2019, the Delta was clearer than average

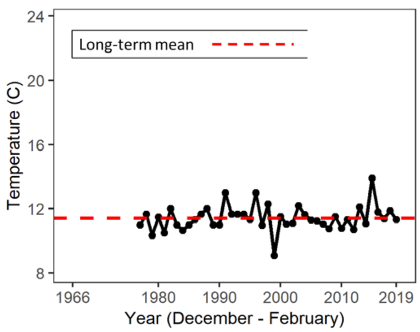
Temperature

Background

- Temperature is monitored monthly by DWR’s Environmental Monitoring Program.
- Fish growth and reproduction is highest in certain temperature ranges.
- Increasing winter temperatures may lower Delta Smelt reproduction.
- Winter temperatures are higher closer to the ocean and lower in the Delta.

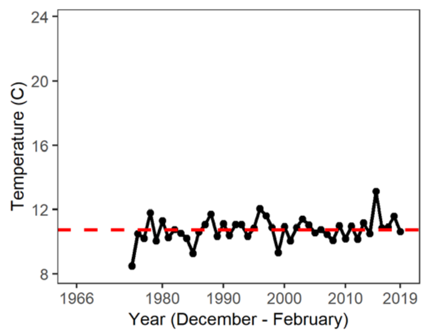
For more information see: Jeffries, et al.. 2016. Effects of high temperatures on threatened estuarine fishes during periods of extreme drought. The Journal of Experimental Biology 219(11):1705-1716.

San Pablo Bay



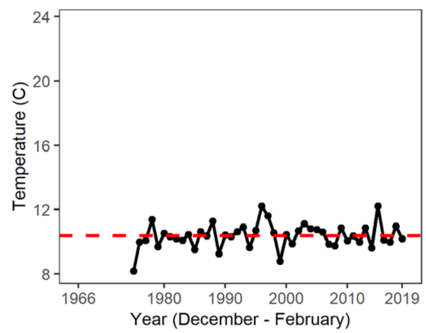
In 2019, San Pablo Bay temperatures were similar to the long-term average.

Suisun Bay



In 2019, Suisun Bay was also similar to the long-term average

The Delta



In 2019, the Delta was also similar to the long-term average.

Chlorophyll

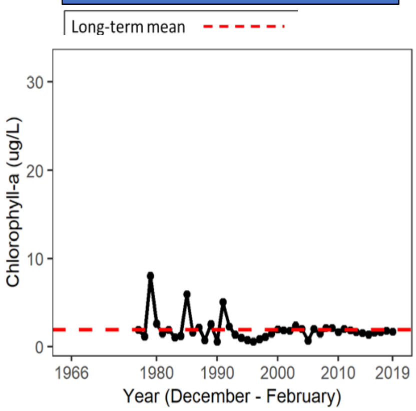
Background

- Chlorophyll is an indicator of phytoplankton production, which is low during the winter.
- Phytoplankton are the base of the pelagic food web. It is sampled monthly by DWR's [Environmental Monitoring Program](#).
- The invasive clam *Potamocorbula amurensis* caused a decline in phytoplankton and zooplankton after 1986 – especially in Suisun Bay.

For more information see: Arena, B., and B. Wells. 2018. Phytoplankton, Chlorophyll-a and Pheophytin-a Status and Trends 2017. IEP Newsletter 32(1):14-20.

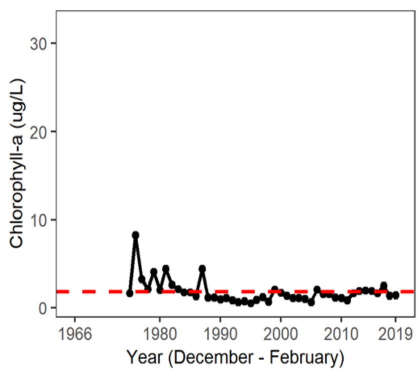
Phytoplankton

San Pablo Bay



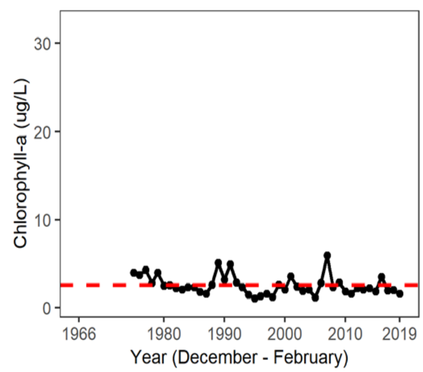
In 2019, San Pablo Bay chlorophyll was about average.

Suisun Bay



In 2019, Suisun Bay chlorophyll was also about average

The Delta



In 2019, the Delta had about average chlorophyll.

Zooplankton

Background

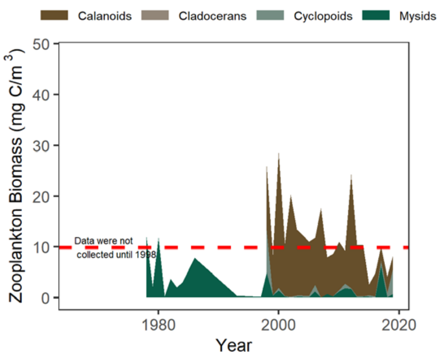
- Zooplankton is sampled monthly by the CDFW/DWR Environmental Monitoring Program, but sampling in winter did not begin until 1995.
- Zooplankton are an important food source for pelagic fish.
- Calanoid copepods and mysids are particularly good fish food. Cyclopoid copepods are not as good for fish food.
- Biomass tends to be low in the winter across all regions.

For more information see: Hennessy, A. 2018. Zooplankton Monitoring 2017. IEP Newsletter 32(1):21-32.

Copepod

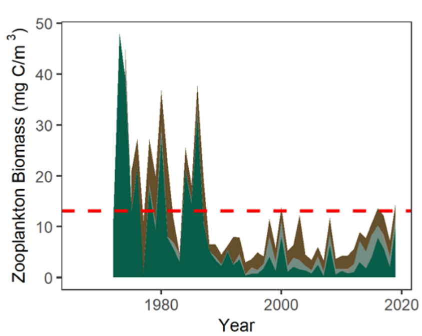
Mysid

San Pablo Bay



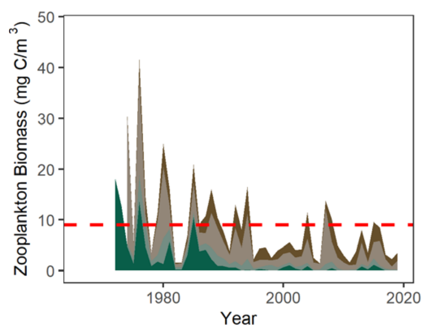
In 2019, San Pablo Bay had about average biomass, mostly calanoid copepods

Suisun Bay



In 2019, Suisun Bay had higher than average total biomass, mostly cyclopoid copepods

The Delta



In 2019, the Delta had much lower than average biomass

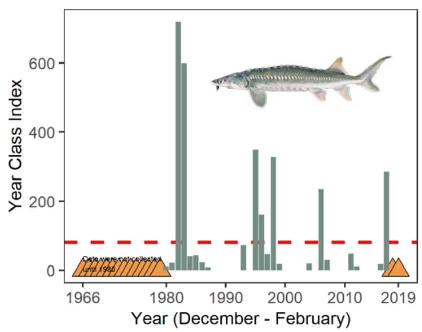
Fish

Background

- White sturgeon support a recreational fishery. Juvenile sturgeon are sampled by in the CDFW Bay Study otter trawl, which samples in the San Francisco Bay, Suisun Bay, and the Delta.
- Longfin Smelt are listed as Threatened under the California Endangered Species Act. Spawning adults are sampled in winter by the CDFW Bay Study midwater trawl.
- Juvenile Winter-Run Chinook Salmon are sampled by the USFWS's ChippsIsland Trawl, located at the confluence of the Sacramento and San Joaquin Rivers.

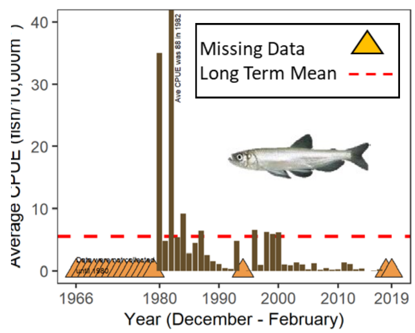
For more information, see: Hieb, K., J. Bautista, and J. Giannetta. 2018. Bay Study Fishes Status and Trends Report for the San Francisco Estuary, 2012–2016. IEP Newsletter 31(2):3-43.

White Sturgeon



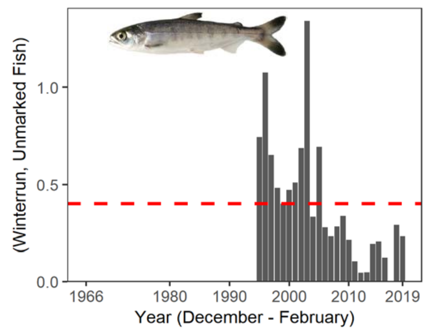
Bay Study data from 2019 is not complete, but the most recent year with a complete survey (2017) was much higher than average.

Longfin Smelt



Bay Study data from 2019 is not complete, but the most recent year with a complete survey (2017) was lower than average

Chipps Island Winter-Run Chinook



In 2019, wild Chinook catch was lower than average.

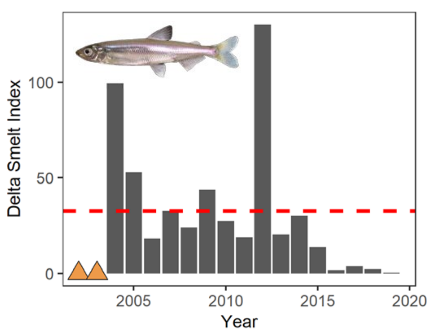
Fish: 2004-2019

Background

- Delta Smelt and Longfin Smelt have been in decline since the early 2000s. The CDFW Spring Kodiak Trawl was designed to sample spawning Delta Smelt, and samples in San Pablo, Suisun, and the Delta.
- Longfin Smelt frequently spawn further downstream than Delta Smelt, so are better sampled by the CDFW Bay Study. The Bay Study samples throughout the San Francisco Bay, Suisun Bay, and the Delta.
- Juvenile Chinook pass Red Bluff Diversion Dam on the upper Sacramento as they migrate from spawning grounds to the ocean.

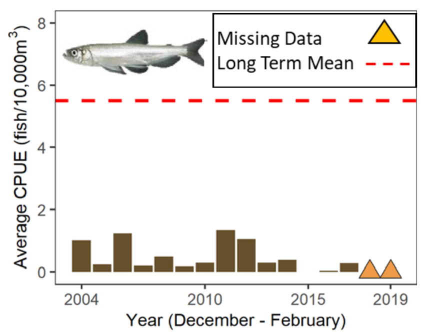
For more information, see: Tempel, T. 2019. 2018 Spring Kodiak Trawl Summary. IEP Newsletter 34(1):22-24.

Delta Smelt



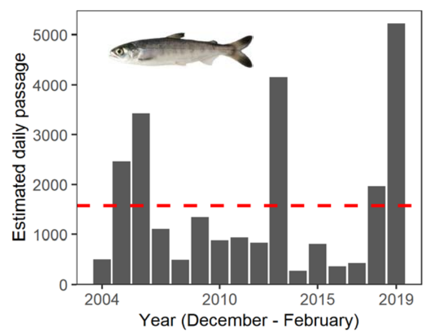
The Delta Smelt SKT index in 2019 was the lowest index on record. (mean line is from 2004-2019)

Longfin Smelt



Bay Study data is not complete for 2019, but the last complete survey found abundance was much lower than the long-term average.

Red Bluff Winter-Run Chinook



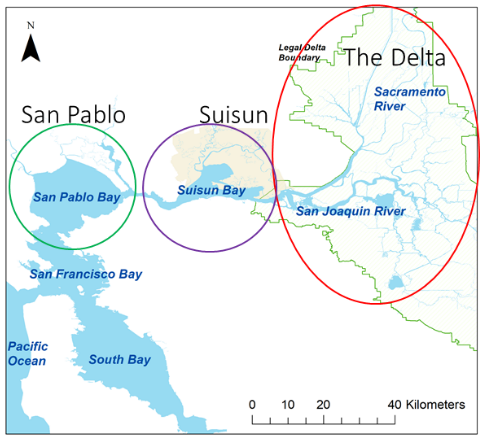
Juvenile winter-run Chinook Salmon had a much higher passage rate in 2019 than the historical average.

Spring 2018
IEP Seasonal Monitoring Report

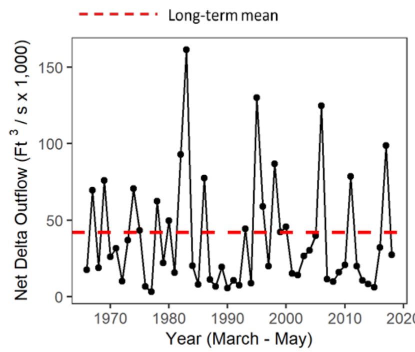
Interagency Ecological Program for the San Francisco Estuary
This report shows trends in water quality, plankton, and fish across multiple IEP surveys for March, April, and May of 2018.

Contents

Regions of the Estuary



Delta Outflow



- Freshwater flow influences water quality, plankton, and fish populations.
- Spring flow is driven primarily by rainfall, snowmelt, and upstream dam releases.
- The spring of 2018 had slightly lower outflow than normal.

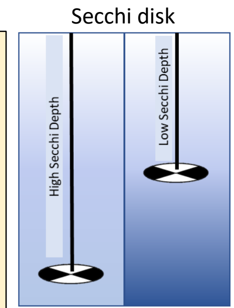
Disclaimer: While substantial efforts are made to ensure the accuracy of these data, complete accuracy of data sets cannot be guaranteed. This report was developed by the IEP Synthesis Team.
For questions, comments, or corrections, contact Rosemary Hartman – Rosemary.Hartman@water.ca.gov

Secchi Depth

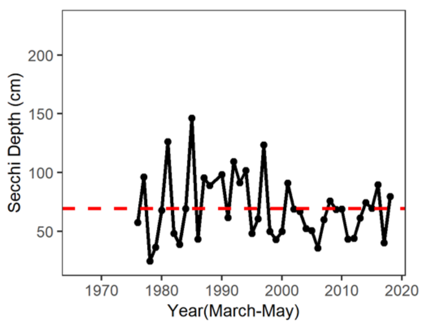
Background

- Organisms in this ecosystem are adapted to high turbidity conditions, and reductions in turbidity can have many negative ecological effects.
- Higher values for Secchi depth indicate lower turbidity.
- Secchi depth is measured monthly by DWR's Environmental Monitoring Program by dropping a black-and-white disk in the water until it disappears.

For more information, see: Schoellhamer, D. H. 2011. Sudden clearing of estuarine waters upon crossing the threshold from transport to supply regulation of sediment transport as an erodible sediment pool is depleted: San Francisco Bay, 1999. Estuaries and Coasts 34(5):885-899.

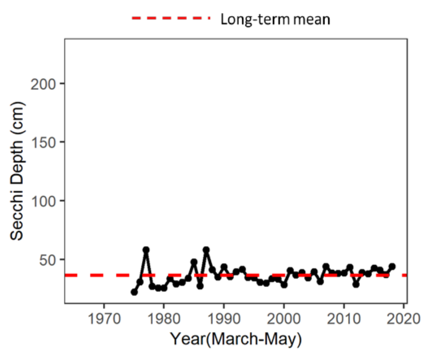


San Pablo Bay



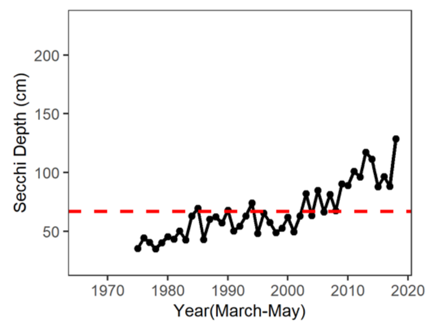
In 2018, San Pablo bay was close to the long-term average.

Suisun Bay



In 2018, Suisun Bay was also close to the long-term average

The Delta



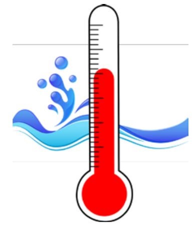
In 2018, the Delta was much clearer than average, the clearest Spring on record.

Water Temperature

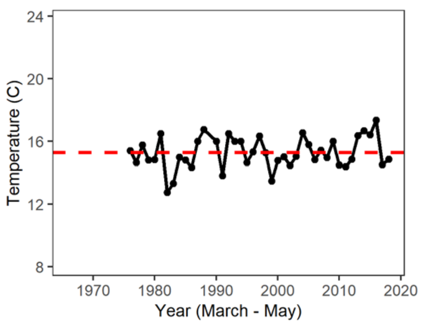
Background

- Water temperature is monitored monthly by DWR's Environmental Monitoring Program
- Fish growth and reproduction is highest in certain temperature ranges.
- Increasing Spring temperatures may lower Delta Smelt reproduction.
- Temperatures tend to be similar between regions in the spring.

For more information see: Jeffries, et al.. 2016. Effects of high temperatures on threatened estuarine fishes during periods of extreme drought. The Journal of Experimental Biology 219(11):1705-1716.

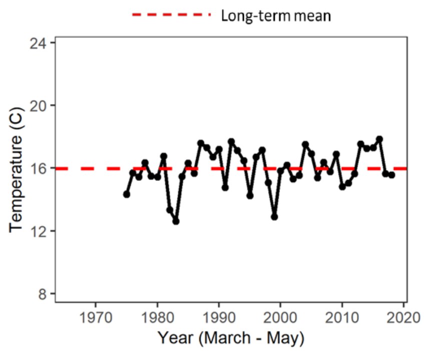


San Pablo Bay



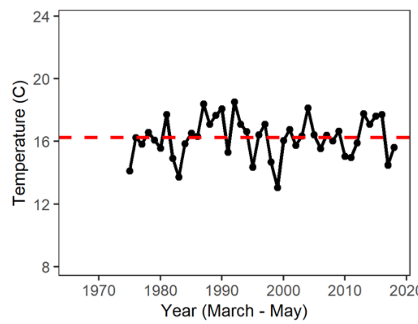
In 2018, San Pablo Bay temperatures were similar to the long-term average.

Suisun Bay



In 2018, Suisun Bay was similar to the long-term average.

The Delta



In 2018, the Delta was slightly cooler than average.

Interagency Ecological Program 2018 Spring Season Report

Chlorophyll

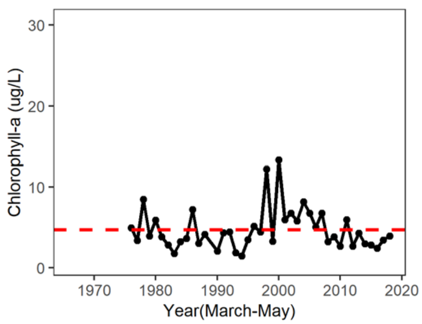
Background

- Chlorophyll is an indicator of phytoplankton production, which is low during the Spring.
- Phytoplankton are the base of the pelagic food web. It is sampled monthly by DWR's Environmental Monitoring Program.
- The invasion of the clam *Potamocorbula amurensis* caused a decline in phytoplankton and zooplankton after 1986 – especially in Suisun Bay.

For more information see: Cahoon, T. and T. Brown. 2018. Phytoplankton, Chlorophyll-a and Pheophytin-a Status and Trends 2017. IEP Newsletter 32(1):14-20.

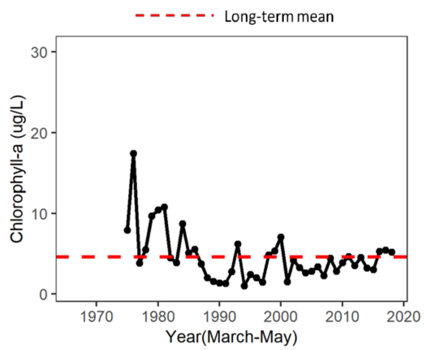
Phytoplankton

San Pablo Bay



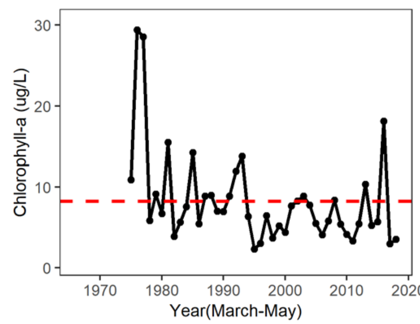
In 2018, San Pablo Bay chlorophyll was about average.

Suisun Bay



In 2018, Suisun Bay chlorophyll was also about average.

The Delta



In 2018, the Delta had lower than average chlorophyll.

Zooplankton

Background

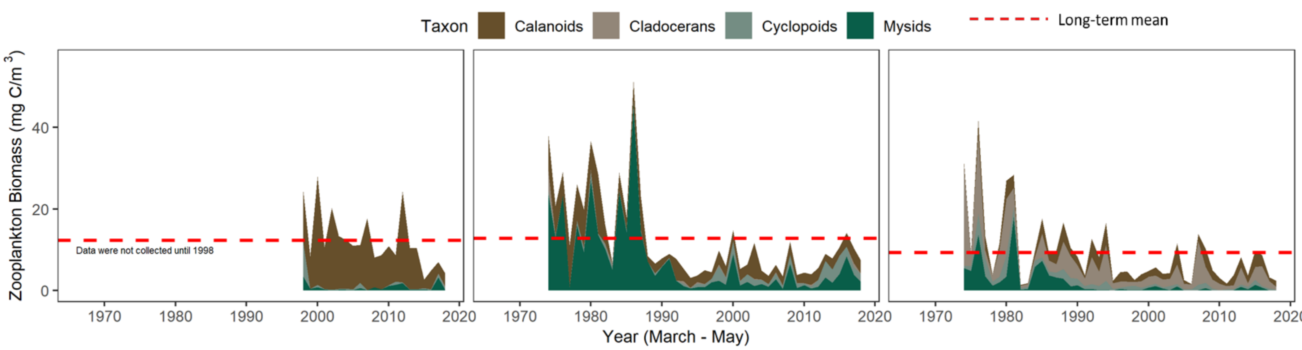
- Zooplankton is sampled monthly by the CDFW/DWR Environmental Monitoring Program, but sampling in San Pablo Bay did not begin until 1998.
- Zooplankton are an important food source for pelagic fish.
- Calanoid copepods and mysids are particularly good fish food. Cyclopoid copepods are not as good for fish food.
- Biomass in Spring tends to be higher than Winter, but lower than Summer.

For more information see: Hennessy, A. 2018. Zooplankton Monitoring 2018. IEP Newsletter 32(1):21-32.

Copepod

Mysid

San Pablo Bay | **Suisun Bay** | **The Delta**



In 2018, San Pablo Bay had much lower than average biomass, mostly calanoid copepods

In 2018, Suisun Bay also had lower than average total biomass.

In 2018, the Delta also had much lower than average total biomass.

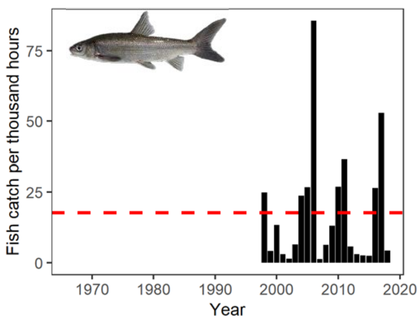
Fish

Background

- Splittail are a native minnow that spawn on floodplains, so have high reproduction during high flow years when floodplains are inundated. Juvenile Splittail are sampled by DWR's Yolo Bypass Monitoring Program.
- Spring-run Adult salmon returns return from the ocean during the spring. Populations are calculated by CDFW based on redd counts, carcass surveys, fish entering hatcheries, and live fish counts.
- Juvenile Winter-Run Chinook Salmon out-migrate to the ocean in spring, and are sampled by the USFWS's Chipps Island Trawl, located at the confluence of the Sacramento and San Joaquin Rivers.

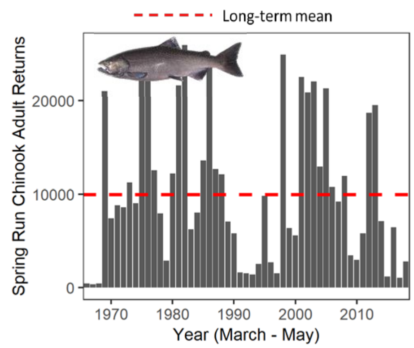
For more information, see: Kwan, N., J. Jenkins, C. Stuart, A. Shakya, and B. Schreier. 2019. 2011-2016 Yolo Bypass Fisheries Monitoring Status and Trends Report. IEP Newsletter 36(1):27-36.

Yolo Bypass Juvenile Splittail



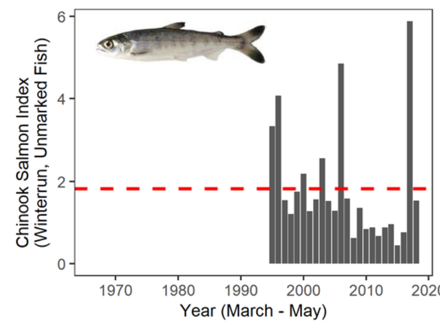
2018 did not have substantial Yolo Bypass flooding, and catch was in line with other similar years

Spring-Run Chinook Adult Returns



In 2018, adult Chinook returns were lower than average

Juvenile Winter-Run Chinook (Chipps Island)



In 2018, juvenile winter-run salmon survival was about average.

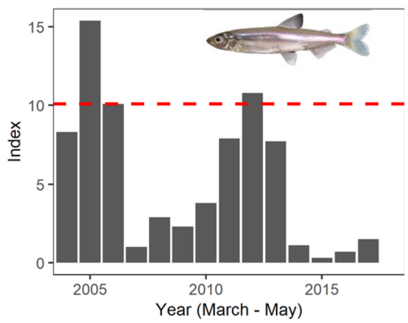
Fish: 2004-2018

Background

- Delta Smelt and Longfin Smelt have been in decline since the early 2000s. The CDFW 20mm Survey was designed to sample post-larval and juvenile Delta Smelt, and samples in San Pablo, Suisun, and the Delta.
- Longfin Smelt frequently spawn further downstream than Delta Smelt, so the 20 mm Survey does not cover their entire range, but still provides an indication of population-level trends.
- Juvenile Chinook Salmon are sampled by the USFWS's Chipps Island Trawl, located at the confluence of the Sacramento and San Joaquin Rivers.

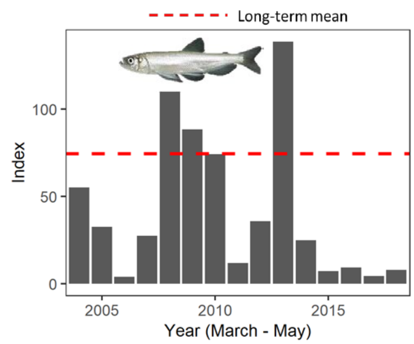
For more information, see: Tempel, T. 2017. Evaluation of Adding Index Stations in Calculating the 20-mm Survey Delta Smelt Abundance Index. IEP Newsletter 30(1):21-23.

Delta Smelt



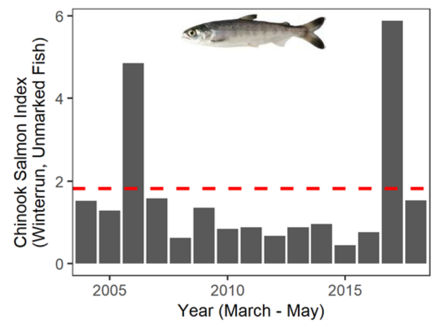
The Delta Smelt 20mm index was zero in 2018, the lowest index on record.

Longfin Smelt



The Longfin smelt index in 2018 was much lower than the long-term average.

Juvenile Winter-Run Chinook (Chipps Island)



In 2018, Juvenile winter-run Chinook had slightly lower survival than the long-term average, but better than many recent years.

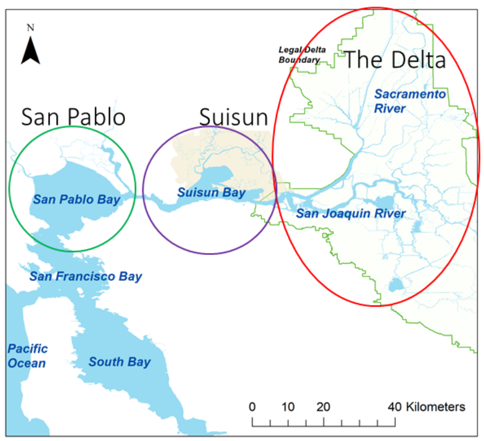
Appendix C. Summer Report

Summer 2018
IEP Seasonal Monitoring Report

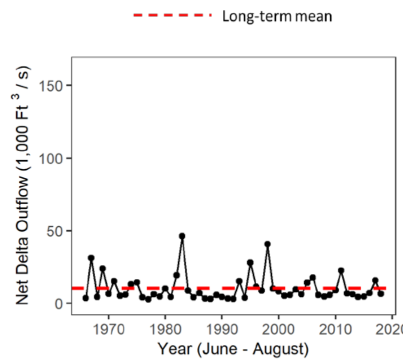
Interagency Ecological Program for the San Francisco Estuary
This report shows trends in water quality, plankton, and fish across multiple IEP surveys for June, July, and August of 2018.

Contents

Regions of the Estuary



Delta Outflow



- Freshwater flow influences water quality, plankton, and fish populations.
- Summer flow is driven primarily by exports and upstream dam releases.
- The Summer of 2018 had slightly lower outflow than normal.

Disclaimer: While substantial efforts are made to ensure the accuracy of these data, complete accuracy of data sets cannot be guaranteed. This report was developed by the IEP Synthesis Team.
For questions, comments, or corrections, contact Rosemary Hartman – Rosemary.Hartman@water.ca.gov

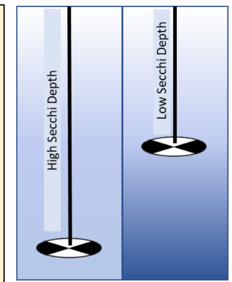
Secchi Depth

Background

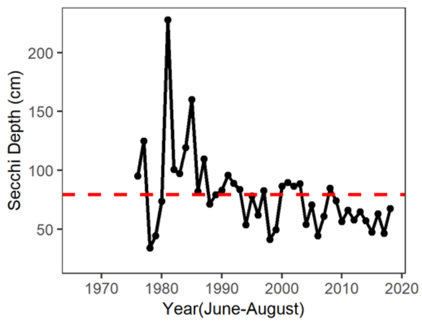
- Organisms in this ecosystem are adapted to high turbidity conditions, and reductions in turbidity can have many negative ecological effects.
- Higher values for Secchi depth indicate lower turbidity.
- Secchi depth is measured monthly by DWR's Environmental Monitoring Program by dropping a black-and-white disk in the water until it disappears.

For more information, see: Schoellhamer, D. H. 2011. Sudden clearing of estuarine waters upon crossing the threshold from transport to supply regulation of sediment transport as an erodible sediment pool is depleted: San Francisco Bay, 1999. Estuaries and Coasts 34(5):885-899.

Secchi disk

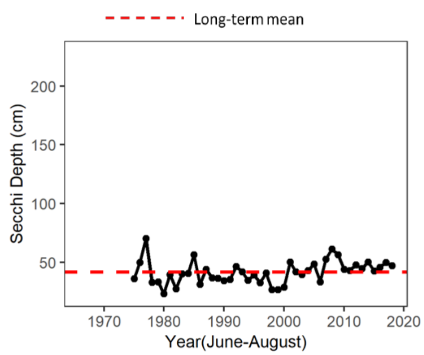


San Pablo Bay



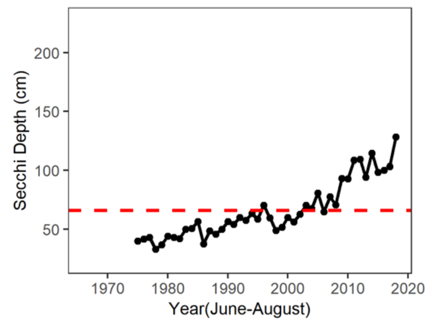
In 2018, San Pablo bay was close to the long-term average.

Suisun Bay



In 2018, Suisun Bay was also close to the long-term average.

The Delta



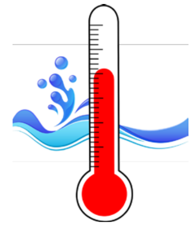
In 2018, the Delta was much clearer than average, the clearest Summer on record.

Water Temperature

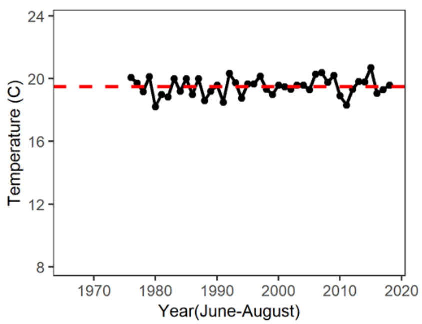
Background

- Water temperature is monitored monthly by DWR's Environmental Monitoring Program.
- High temperature can increase productivity and may trigger harmful algal blooms.
- Increasing Summer temperatures may limit juvenile smelt survival.
- Summer temperatures are lower closer to the ocean and slightly higher in the Delta.

For more information see: Lehman, P. W., T. Kurobe, S. Lesmeister, D. Baxa, A. Tung, and S. J. Teh. 2017. Impacts of the 2014 severe drought on the *Microcystis* bloom in San Francisco Estuary. Harmful Algae 63(Supplement C):94-108.

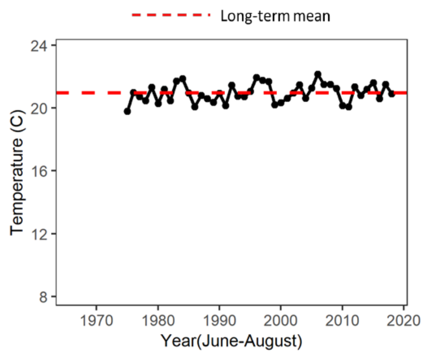


San Pablo Bay



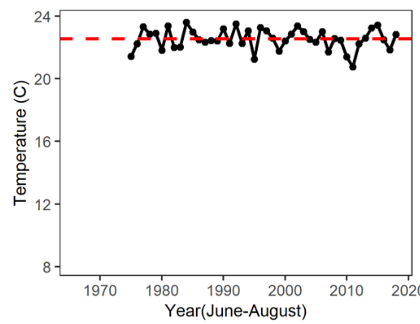
In 2018, San Pablo Bay temperatures were similar to the long-term average.

Suisun Bay



In 2018, Suisun Bay was similar to the long-term average.

The Delta



In 2018, the Delta was similar to the long-term average.

Chlorophyll

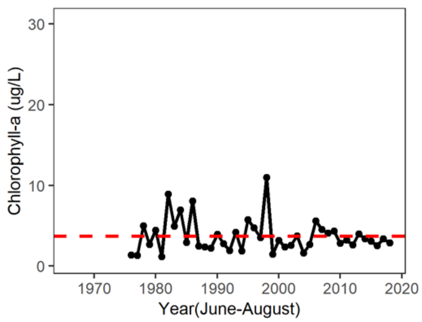
Background

- Chlorophyll is an indicator of phytoplankton production, which is highest during the Summer.
- Phytoplankton is the base of the pelagic food web. It is sampled monthly by DWR's Environmental Monitoring Program.
- The invasion of the clam *Potamocorbula amurensis* caused a decline in phytoplankton and zooplankton after 1986 – especially in Suisun Bay.

For more information see: Cahoon, T. and T. Brown 2018. Phytoplankton, Chlorophyll-a and Pheophytin-a Status and Trends 2017. IEP Newsletter 32(1):14-20.

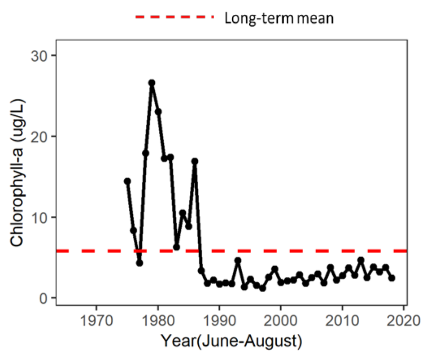
Phytoplankton

San Pablo Bay



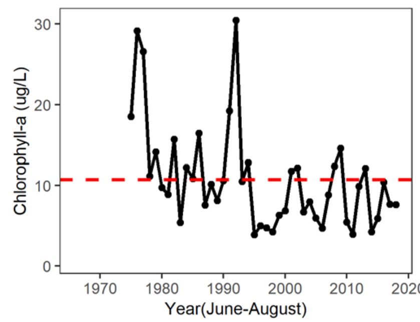
In 2018, San Pablo Bay chlorophyll was about average.

Suisun Bay



In 2018, Suisun Bay chlorophyll was slightly below average.

The Delta



In 2018, the Delta chlorophyll was also slightly below average.

Zooplankton

Background

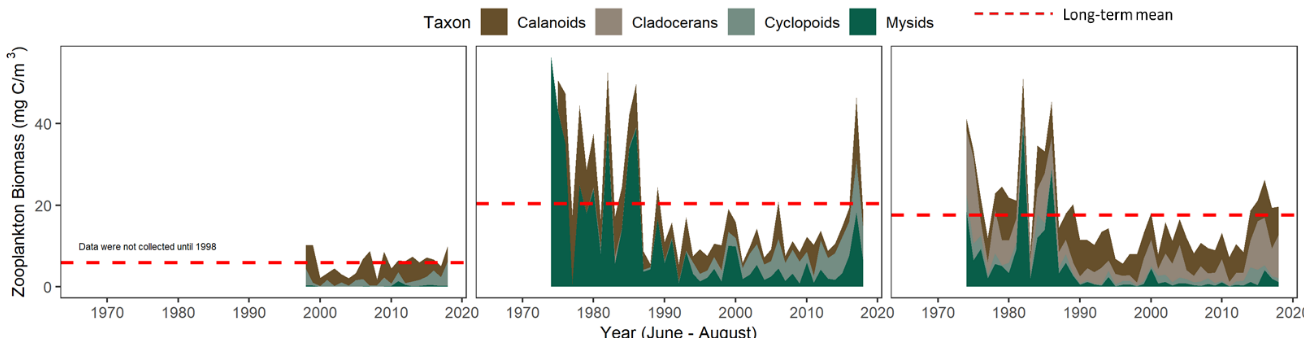
- Zooplankton is sampled monthly by the CDFW/DWR Environmental Monitoring Program, but sampling in San Pablo Bay did not begin until 1998.
- Zooplankton are an important food source for pelagic fish.
- Calanoid copepods and mysids are particularly good fish food. Cyclopoid copepods are not as good for fish food.
- Biomass tends to be highest in summer.

For more information see: Hennessy, A. 2018. Zooplankton Monitoring 2017. IEP Newsletter 32(1):21-32.

Copepod

Mysid

San Pablo Bay | **Suisun Bay** | **The Delta**



In 2018, San Pablo Bay had about average biomass, mostly cyclopoid copepods

In 2018, Suisun Bay also had about average total biomass, mostly mysids and cyclopoids.

In 2018, the Delta had about average total biomass, mostly cladocerans

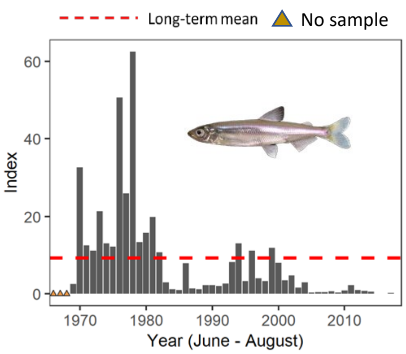
Fish

Background

- Delta Smelt, listed as threatened by the Endangered Spices Act, have been tracked by [CDFW's Townet Survey] since 1959 in Suisun Bay, San Pablo Bay, and the Delta.
- Northern Anchovy are an important forage fish in the brackish-saline regions of the estuary. They are sampled best by [CDFW's San Francisco Bay Study].
- Sacramento Pikeminnow is a native cyprinid that is one of the few piscivorous native fish in the Delta. They are sampled by [DJFMP's beach seine surveys] throughout the estuary.

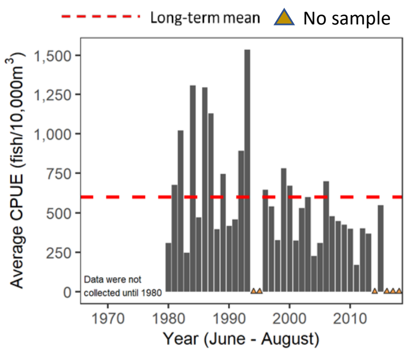
For more information, see: Hieb, K., J. Bautista, and J. Giannetta. 2018. Bay Study Fishes Status and Trends Report for the San Francisco Estuary, 2012–2016. IEP Newsletter 31(2):3-43.

Delta Smelt - Townet



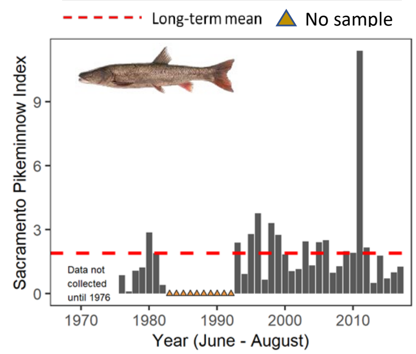
2018 was lower than the long-term average.

Northern Anchovy – Bay Study



The Bay Study has not been able to finish a survey in recent years, but previous catches were slightly lower than average.

DJFMP – Sac Pikeminnow



In 2018, Pikeminnow were less abundant than average

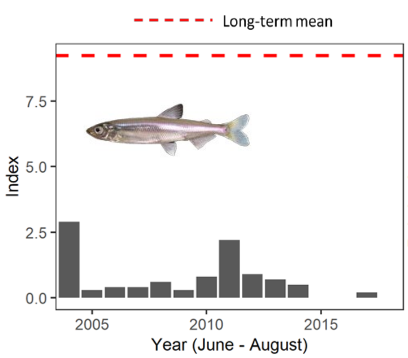
Recent Trends: 2004-2018

Background

- Delta Smelt have been in severe decline over the past two decades, with a Summer Townet index of zero in 2015, 2016 and 2018.
- *Microcystis* is a toxic cyanobacteria first found in the Delta in 1998. *Microcystis* presence has been documented by EMP and the Summer Townet Survey during their water quality sampling.
- Aquatic vegetation in the Delta has increased significantly in recent years. This vegetation is composed mostly of non-native invasive plant species and is categorized as either floating or submerged types. Coverage is estimated by UC-Davis using remote sensing of the North and Central Delta.

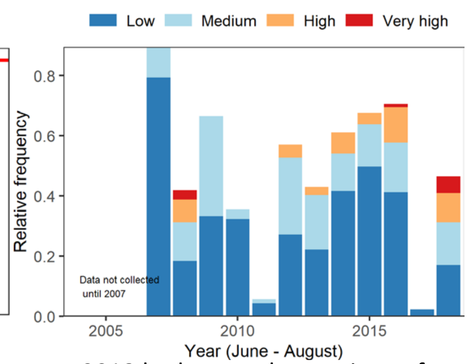
For more information, Ta et al. 2017. Invasive aquatic vegetation management in the Sacramento–San Joaquin River Delta: status and recommendations. San Francisco Estuary and Watershed Science 15(4)

Delta Smelt - Townet



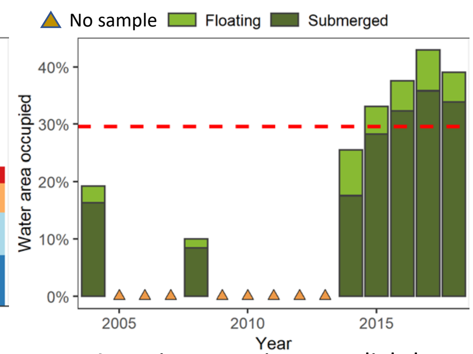
The 2018 Delta Smelt index was 0.

Microcystis



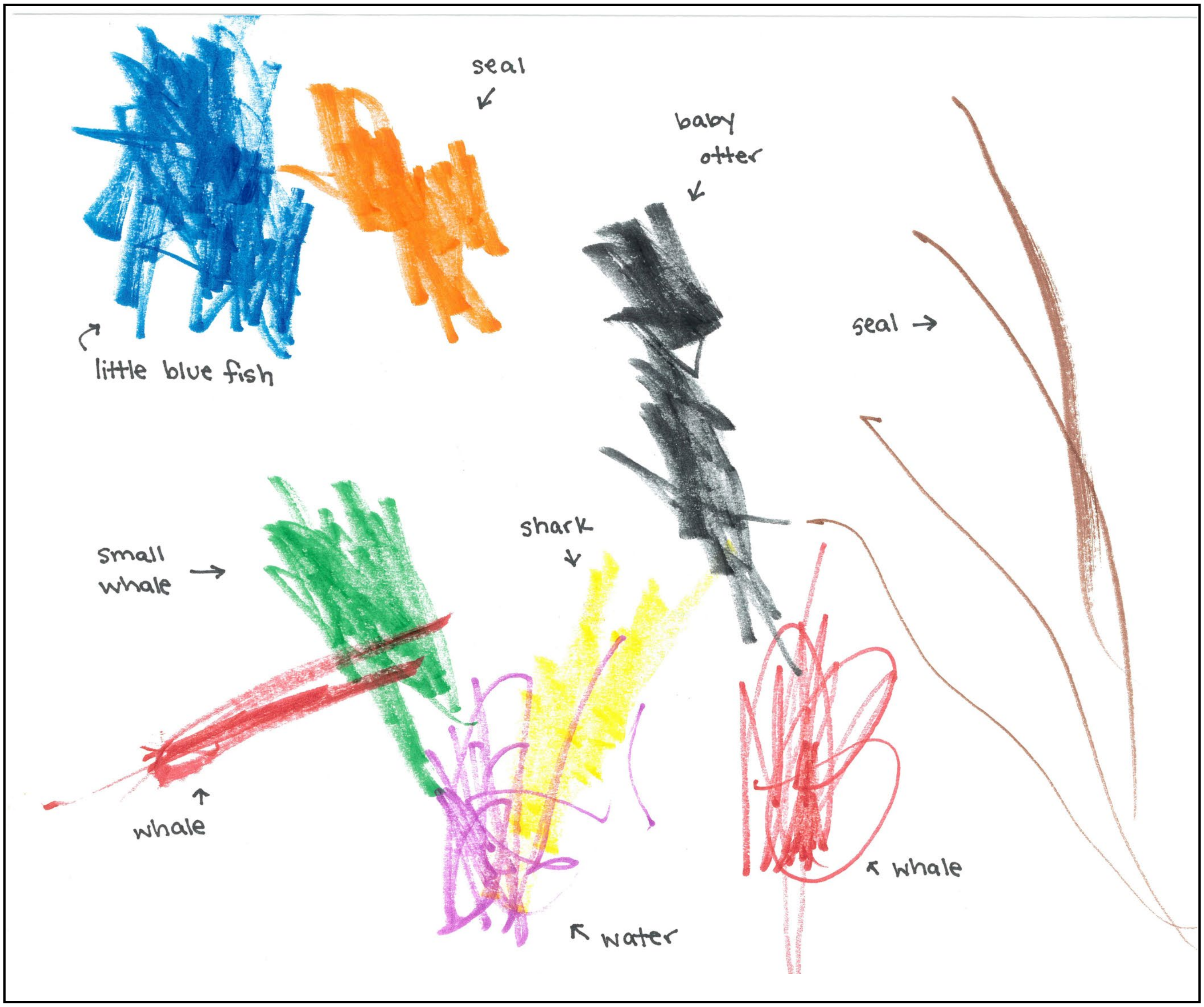
2018 had more observations of very high *Microcystis* than previous years.

Aquatic Vegetation



Aquatic vegetation was slightly lower than 2017, but higher than average.

End Matter



A collection of aquatic animals drawn by Alex Flynn, age 2, daughter of Ted Flynn (DWR). While her art speaks for itself, her parents have provided annotations as a guide for the untrained eye.

Emily Dege, age 6, daughter of Tiffany Brown (DWR). The large black and white striped fish are a mommy and daddy tiger shark; there are 2 baby tiger sharks swimming behind. The spotted fish are eels (again, mom, dad, and baby eel), and the curved green structure with eggs is an eel nest. There's also a very small clownfish to the right. The deeper water is darker blue, and the shallower water is lighter blue. The green leaves are bits of seaweed.

Interagency Ecological Program for the San Francisco Estuary

IEP NEWSLETTER

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

California Department of Water Resources

State Water Resources Control Board

U.S. Bureau of Reclamation

U.S. Army Corps of Engineers

California Department of Fish and Wildlife

U.S. Fish and Wildlife Service

U.S. Geological Survey

U.S. Environmental Protection Agency

National Marine Fisheries Service

Interagency Ecological Program

COOPERATIVE ECOLOGICAL INVESTIGATIONS SINCE 1970

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