Interagency Ecological Program for the San Francisco Estuary

IEP NEWSLETTER

VOLUME 37, NUMBER 2, 2019

Contents

Of Interest to Managers

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Of Interest to Managers

This issue of the Interagency Ecological Program (IEP) features five articles providing updates on a variety of issues relevant to current programs.

1. **Adam Chorazyczewski (CDFW)** summarizes the 2019 Spring Kodiak Trawl (SKT) Survey results. The SKT has been conducted annually since 2002 by CDFW to determine the distribution and abundance of adult Delta smelt. Only two Delta Smelt were caught by the SKT during the 2019 season, which represents a historic low, and for the first time in the history of the survey there were no Delta smelt caught in the Sacramento Deep Water Shipping Channel. The article provides additional context as to how the 2019 survey results continue the declining trends observed in the species abundance over the last several years.
2. **Adam Chorazyczewski (CDFW)** also summarizes the 2019 Smelt Larva Survey (SLS), an annual survey conducted by CDFW since 2009 to monitor the distribution and abundance of larval Longfin smelt. Significantly fewer Longfin smelt were caught in 2019 compared to prior years, and the article provides additional details as to how the 2019 survey results continue the declining population trend observed over the past 6 years.
3. **Ryan McKenzie (USFWS)** reports on Chinook Salmon distribution and abundance as observed by the Delta Juvenile Fish Monitoring Program (DJFMP) in field year 2018. The article describes Chinook salmon immigration into, residency within, and emigration from the Delta between August 2017 and July 2018. Notable among the results was that 25 hatchery-origin spring-run juvenile Chinook salmon released by the San Joaquin River Restoration Program (SJRRP) were observed entering the San Joaquin River Basin in early 2018, and the author notes the increasing value of the DJFMP in its ability to provide information to restoration efforts like the SJRRP on timing and distribution of salmon migration as well as patterns of habitat use as detected by different survey methods used by the program.
4. **Sarah Perry (DWR)** presents the results of phytoplankton monitoring conducted in calendar year 2018 by DWR and the USBR as required by Water Right Decision 1641 (D-1641). The article presents seasonal and regional differences in phytoplankton communities and biomass observed across the Delta in 2018. Notable results include that cyanobacteria constituted the vast majority of all organisms collected (over 96%) and that monthly chlorophyll a concentrations throughout much of the estuary were relatively low, with approximately 95% of sites having levels considered limiting for zooplankton growth.
5. **Brooke Watkins (DWR)** summarizes the benthic communities observed by the DWR Environmental Monitoring Program (EMP) in 2018 and provides context for these results compared to data obtained over the previous decade. Notable results from the 2018 monitoring include an almost doubling of observed numbers of the invasive clam *Corbicula fluminea* at all sites compared to the prior year as well as the addition of several new species to the benthic species list. The article highlights the importance of benthic monitoring to provide both a record of abiotic conditions and allow detection of changes to estuarine food webs.

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

https://water.ca.gov/Programs/Environmental-Services/Interagency-Ecological-Program

Contributed Papers

2019 Spring Kodiak Trawl Summary

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Summary

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 and listed under the California and United States Endangered Species Acts. SKT started in 2002 as a change to the spring midwater trawl, and the survey standardized in 2004. 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 (FMWT). The SKT conducts one survey each month, which consists of sampling 40 stations throughout the upper San Francisco Estuary (Figure 1). Each station is sampled using a Kodiak Trawl, which is towed 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. In 2019, all stations were sampled during surveys 1, 3, 4, and 5. During Survey 2 station 724 was dropped due to high flow rates. More information on the SKT's gear, objectives, methods, and prior year summary reports, are available in previous articles by Souza (2002, 2003) and in other articles on our online bibliography .

The 2019 SKT collected 2,761 organisms representing 34 species (Table 1). Threadfin Shad (*Dorosoma petenense*), Longfin Smelt (*Spirinchus thaleichthys*), and American Shad (*Alosa sapidissima*) were the most abundant species, together comprising about 55% of the total catch (Table 1). Longfin Smelt, which is listed as a threatened species under the California Endangered Species Act, comprised a significantly higher percentage of the catch than in recent years which has ranged from 0.5%-5% of the total catch each year from 2016-2018 (Figure 2). Longfin Smelt with fork lengths greater than 82 mm were collected in January and February, at stations downstream of the confluence (n=6).

Larval Longfin Smelt (fork length (FL) ≤ 37 mm) were collected in April and May in Suisun Bay, Montezuma Slough, and the mouth of the Napa River

Figure 1. Station locations for the 2019 CDFW Spring Kodiak Trawl in the upper San Francisco Estuary. Black dots represent stations that have been sampled since the survey's inception; the green triangle represents a station added in 2005.

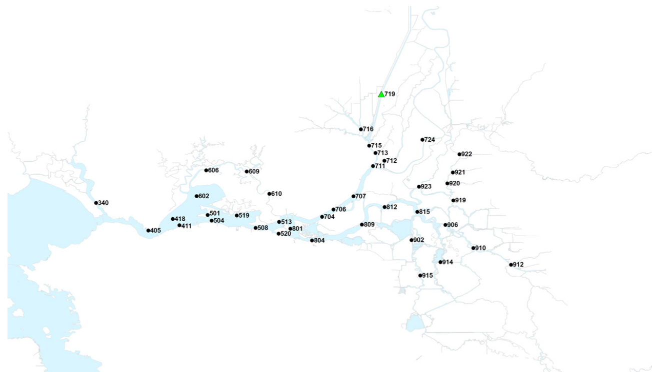


Figure 2: Annual Longfin Smelt catch for the California Department of Fish and Wildlife's Spring Kodiak Trawl compared to all other species. Subset graph shows percentage contribution to total catch by Longfin Smelt. Catch from supplemental surveys, including December sampling, is not included.

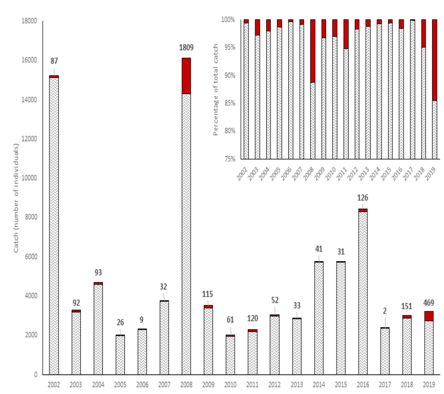


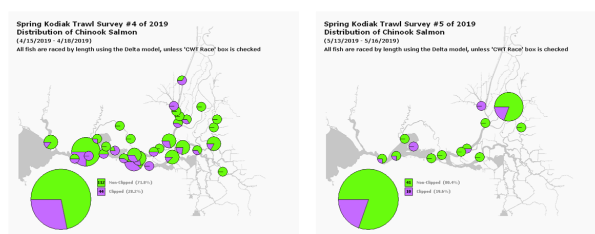
Table 1. 2019 CDFW Spring Kodiak Trawl organism catch for all stations and surveys combined. Catch from supplemental surveys, including December 2018 sampling, is not included.

Common Name	*Catch (number of individuals)*	*Percent*
Threadfin Shad	691	25.03%
Longfin SWmelt	469	16.99%
American Shad	354	12.82%
Chinook Salmon	302	10.94%
Pacific Herring	237	8.58%
Inland Silverside	200	7.24%
Splittail	143	5.18%
Threespine Stickleback	115	4.17%
Siberian Prawn	81	2.93%
Palaemon Shrimp	37	1.34%
Steelhead	24	0.87%
Northern Anchovy	24	0.87%
Striped Bass	21	0.76%
Crangon Shrimp	14	0.51%
Golden Shiner	8	0.29%
Bluegill	8	0.29%
Common Carp	6	0.22%
Shimofuri Goby	4	0.14%
Sacramento Pikeminnow	3	0.11%
White Crappie	2	0.07%
Hitch	2	0.07%
Wakasagi	2	0.07%
Delta Smelt	2	0.07%
Jacksmelt	1	0.04%
Goldfish	1	0.04%
Lamprey (ammocoete)	1	0.04%
Mosquitofish	1	0.04%
Rainwate0r Killifish	1	0.04%
Yellowfin Goby	1	0.04%
Redear Sunfish	1	0.04%
Starry Flounder	1	0.04%
Tule Perch	1	0.04%
Pacific Staghorn Sculpin	1	0.04%
White Sturgeon	1	0.04%
Unidentified (UNID)	1	0.04%

(n=445). Eighteen Longfin Smelt (FL ranging from 37-82 mm) were collected throughout the sampling season in Suisun Bay, Montezuma Slough, and the Lower Sacramento River. Chinook Salmon (*Oncorhynchus tshawytscha*) were observed throughout the sampling area (Figure 3) and were the 4th most abundant species (n=302). Roughly 70% of the Chinook Salmon were collected in April and May. Starting in 2015, Chinook salmon collected with adipose fin clips are retained and their coded wire tags (CWTs) identified. The CWTs can be used to verify the Delta Model race key, which assigns races to juvenile Salmon based on their fork lengths at the date of catch. Of the 61 Chinook Salmon caught with clipped adipose fins, 19 were incorrectly assigned a race. This corresponds to 31% error rate for race identification for Chinook Salmon caught in the field. This error rate is consistent with previous years, except for 2018 which had an error rate of 17%, however relatively few Chinook Salmon were caught in 2018 (n=125).

Only 2 Delta Smelt were caught during the 2019 season, representing another historic low (Figure 4). One ripe female was collected in January in the lower

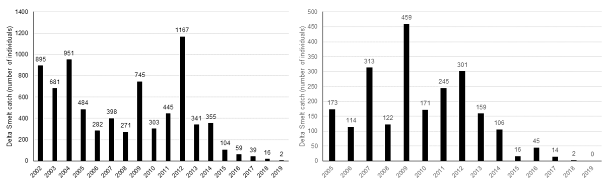
Figure 3. Geographic bubble plot of Chinook Salmon catch and adipose fin status from April and May of the 2019 CDFW Spring Kodiak Trawl. Bubble size is proportional to total catch and ranges from 1 to 9.



Sacramento River (Station 706, FL=71 mm), and one pre-spawn female was collected in February near the confluence of the Sacramento and San Joaquin rivers (Station 508, FL=68 mm). For the first time in the history of the survey, no Delta Smelt were collected in the Sacramento Deep Water Shipping Channel (SDWSC), continuing the trend of declining Delta Smelt in this region (Figure 4). From 2005 – 2014 the annual catch of Delta Smelt in the SDWSC ranged from 106 – 459 with an average catch of 216. Beginning in 2015 we have observed a dramatic decrease in annual catch with total Delta Smelt catch in the SDWSC ranging from 0 – 45 fish with an average catch of 15. This trend in the SDWSC mirrors the decline in Delta Smelt catch throughout the upper San Francisco Estuary, but is particularly concerning given the contribution of freshwater residents to the population (Hobbs et al. in press).

In December 2018, 38 of the total 40 stations were sampled in an additional week-long supplemental survey. The supplemental survey was implemented in 2014 to ensure adequate Delta Smelt catch to calculate Deltas Smelt index. Additionally, the supplemental survey was used to compare gear efficiencies between the FMWT and SKT. Two stations, 724 and 921, were not sampled due high flow rates and excessive vegetation, respectively. A total of 525 organisms representing 12 species were collected (Table 2). American Shad and Threadfin Shad were by far the most abundant species, followed by Northern Anchovy (*Engraulis mordax*) and Inland Silverside (*Menidia beryllina*). Together these four species comprised approximately 93% of the total catch. Five Delta Smelt were collected, 4 in the Lower Sacramento River and 1 in Montezuma Slough (FL 62-65 mm). These fish were dissected for gonadal staging; all were males that had not yet reached sexual maturity.

Figure 4. A: Annual Delta Smelt catch from the CDFW Spring Kodiak Trawl excluding December 2018 supplemental sampling. B: Annual Delta Smelt catch in the Sacramento Deep Water Shipping Channel from 2005-2019 (SDWSC).



Data from the SKT is reported in near real-time to the Smelt Working Group (SWG), the Delta Operations for Salmonids and Sturgeon Work Group (DOSS), and the Data Assessment Team (DAT) 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 CWT results.

The 2020 Spring Kodiak Trawl is scheduled to begin in December 2019 and run through May 2020. Data and metadata are available on the FTP website .

Table 2. December 2018 CDFW Spring Kodiak Trawl organism catch.

Common Name	***Catch (number of individuals)***	***Percent***
American Shad	223	42.23%
Threadfin Shad	129	24.43%
Northern Anchovy	73	13.83%
Inland Silverside	65	12.31%
Topsmelt	12	2.27%
Black Crappie	9	1.70%
Threespine Stickleback	5	0.95%
Delta Smelt	5	0.95%
Wakasagi	3	0.57%
Golden Shiner	2	0.38%
Rainwater Killifish	1	0.19%
Chinook Salmon	1	0.19%

References

[1]http://www.dfg.ca.gov/delta/data/skt/bibliography.asp
[2]https://www.wildlife.ca.gov/Conservation/Delta/Spring-Kodiak-Trawl
[3]ftp://ftp.dfg.ca.gov/Delta%20Smelt/

2019 Smelt Larva Survey Summary

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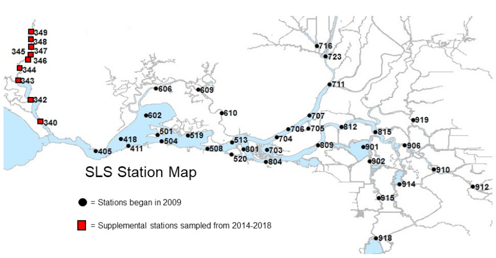
Summary

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 Longfin Smelt's risk of entrainment at water export facilities. The survey also collects data on other larval fishes in the upper SFE, including Delta Smelt.

The SLS began in 2009, and each year six biweekly 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 Nitex 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.

Figure 1. Station locations sampled by the California Department of Fish and Wildlife Smelt Larva Survey (SLS).



The 2019 SLS Survey ran from January 2nd through March 14nd. All stations were sampled during Surveys 2, 3, 5, and 6; excessive weeds prevented sampling at one station in Franks Tract (901) during Surveys 1 and 4. A total of 7,393 fish representing 19 taxa were collected (Table 1). Each year four species have comprised over 98% of total SLS catch: Pacific Herring (Clupea pallasi), Prickly Sculpin (Cottus asper), Yellowfin Goby (Acanthogobius flavimanus), and Longfin Smelt. This trend continued in 2019, with those species totaling 99.2% of total catch (Figure 2).

Table 1. Total species catch for the 2019 California Department of Fish and Wildlife Smelt Larva Survey.

Common Name	Catch (number of individuals)	Percent of Catch
Prickly Sculpin	5495	74.33%
Pacific Herring	859	11.62%
Longfin Smelt	561	7.59%
Yellowfin Goby	416	5.63%
White Catfish	22	0.30%
Threespine Stickleback	7	0.09%
White Croaker	7	0.09%
White Sturgeon	6	0.08%
Bigscale Logperch	4	0.05%
Bluegill Sunfish	4	0.05%
Shimofuri Goby	2	0.03%
Northern Anchovy	2	0.03%
Delta Smelt	2	0.03%
Shokihaze Goby	1	0.01%
Threadfin Shad	1	0.01%
Pacific Staghorn Sculpin	1	0.01%
Longjaw Mudsucker	1	0.01%
Arrow Goby	1	0.01%
Chinook Salmon	1	0.01%

A total of 561 Longfin Smelt were collected in 2019, which is significantly less than last year's catch (n=2,041 in 2018). Despite the relatively large catch in 2018, Longfin Smelt catch has been consistently lower during the past 6 years than it was in the years prior (Figures 2 and 3). From 2009-2013 Longfin Smelt catch ranged from 7,764 to 22,727 with an average of 13,788 and contributed 14-45% of total annual catch. From 2014-2019 Longfin Smelt catch ranged from 79 to 5,631 with an average of 1,670 and contributed less than 10% of total annual catch.

Figure 2. Annual species composition for the California Department of Fish and Wildlife Smelt Larva Survey (SLS).

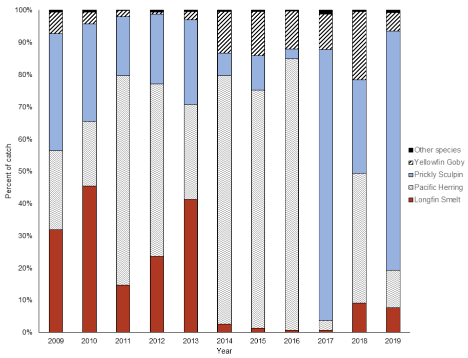


Figure 3. Annual Longfin Smelt catch for the California Department of Fish and Wildlife Smelt Larva Survey.

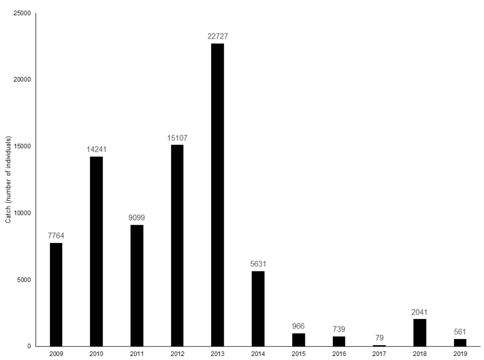
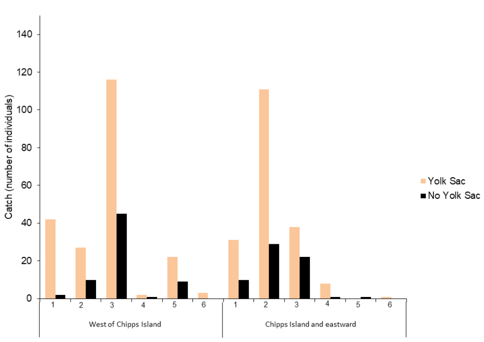


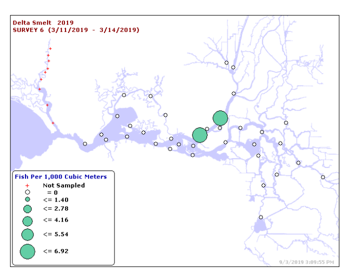
Figure 4. 2019 Longfin Smelt catch by survey, geographical area, and yolk sac status for the California Department of Fish and Wildlife Smelt Larva Survey.



Longfin Smelt were first collected in early January, during Survey 1. They were observed during each of the six surveys, with the highest catch in Survey 3 (1/28/19-1/30/19). Yolk-sac larvae were collected during each survey and in each region of the estuary, which indicates that hatching occurred throughout the survey season and was widespread (Figure 4). The ratio of yolk-sac larval/no yolk sac larval Longfin Smelt was relatively similar west of Chipp's Island and east of Chipp's Island throughout the survey season (Figure 4), indicating hatching occurred simultaneously throughout the upper estuary.

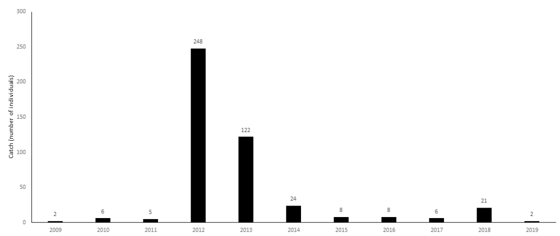
Young of the year Delta Smelt (*Hypomesus transpacificus*) were also collected this year (n=2), which matches a historic low for SLS and continues the trend of low annual Delta Smelt catch with the exception of 2 years, 2012 and 2013 (Figure 6). The fall and winter of 2011 and 2012 provided favorable spawning conditions for Delta Smelt and resulted in longer and more productive spawning seasons (IEP MAST, 2015). The 2 Delta Smelt caught in 2019 were both observed in the lower Sacramento River (Figure 5) and both were collected in mid-March during the last survey of the year. This timing suggests that spawning likely began in early March, which is normal in most years.

Figure 5. Distribution and catch per unit effort of Delta Smelt for Survey 6 of the 2019 California Department of Fish and Wildlife Smelt Larva Survey. Taken from the SLS webpage: https://www.wildlife.ca.gov/Conservation/Delta/Smelt-Larva-Survey



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

Figure 6. Annual Delta Smelt catch for the California Department of Fish and Wildlife Smelt Larva Survey



Reference

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

2018 Delta Juvenile Fish Monitoring Program- Chinook Salmon Annual Report

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Introduction

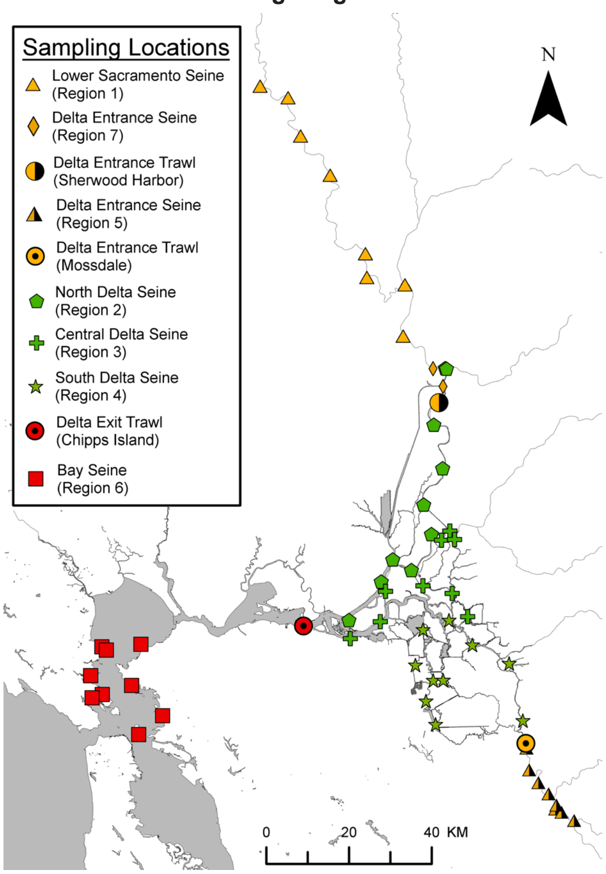
Out-migrating juvenile Chinook Salmon Oncorynchus tshawytscha of the Central Valley, California, must travel from their natal tributaries into the Sacramento-San Joaquin Delta (Delta) prior to reaching the Pacific Ocean to rear in the marine environment. The Central Valley Project (CVP) and State Water Project (SWP), water diversion projects that supply water to over 27 million Californians, have the potential to affect these Chinook Salmon and their rearing habitats throughout the Delta (Kimmerer 2008, NMFS 2009). The effects of these water operations, in part, depends on the timing and distribution of Chinook Salmon throughout the system, which can be highly variable from year to year due to a variety of environmental factors (Munsch et al. 2019). Since 1976, the U.S. Fish and Wildlife Service's Delta Juvenile Fish Monitoring Program (DJFMP) has monitored the annual timing, distribution, and relative abundance of juvenile Chinook Salmon throughout the Delta to better our understanding, inform the management, and mitigate the impacts of the CVP and SWP water export operations on their populations.

The purpose of this report is to provide brief communication on the distribution of juvenile Chinook observed during the DJFMP 2018 field year (August 2017 to July 2018) in terms of their: 1) immigration to the Delta; 2) residency within the Delta; and 3) emigration from the Delta. We also report on recent trends of relative abundance and cohort size distributions. The complete DJFMP dataset—including environmental data not included in this report—and a complete description of sampling procedures is available at DJFMP's Environmental Data Initiative Data Portal (IEP et al. 2019).

Methods

Over the years, the DJFMP has used a variety of gear types deployed at different time periods and frequencies throughout the year to examine the temporal and spatial distribution of fishes throughout the littoral and in-channel habitats of the Delta and San Francisco Estuary (Figure 1). A complete description of the historical and current methods are available at the DJFMP Environmental Data Initiative Data Portal (IEP et al. 2019). In this report we use relative location names in place of our traditional seine region numbers and trawl location names to aid in the spatial orientation of readers, thus: Seine Region 1 = Lower Sacramento; Seine Region 2 = North Delta; Seine Region 3 = Central Delta; Seine Region 4 = South Delta; Seine Region 5 = Delta Entrance Seine (San Joaquin River Basin); Seine Region 6 = Bay Seine; Seine Region 7 = Delta Entrance Seine (Sacramento River Basin); Sherwood Harbor Trawl = Delta Entrance Trawl (Sacramento River Basin); Mossdale Trawl = Delta Entrance Trawl (San Joaquin River Basin); Chipps Island Trawl = Delta Exit.

Figure 1: Long-term sampling sites for the USFWS Delta Juvenile Fish Monitoring Program.



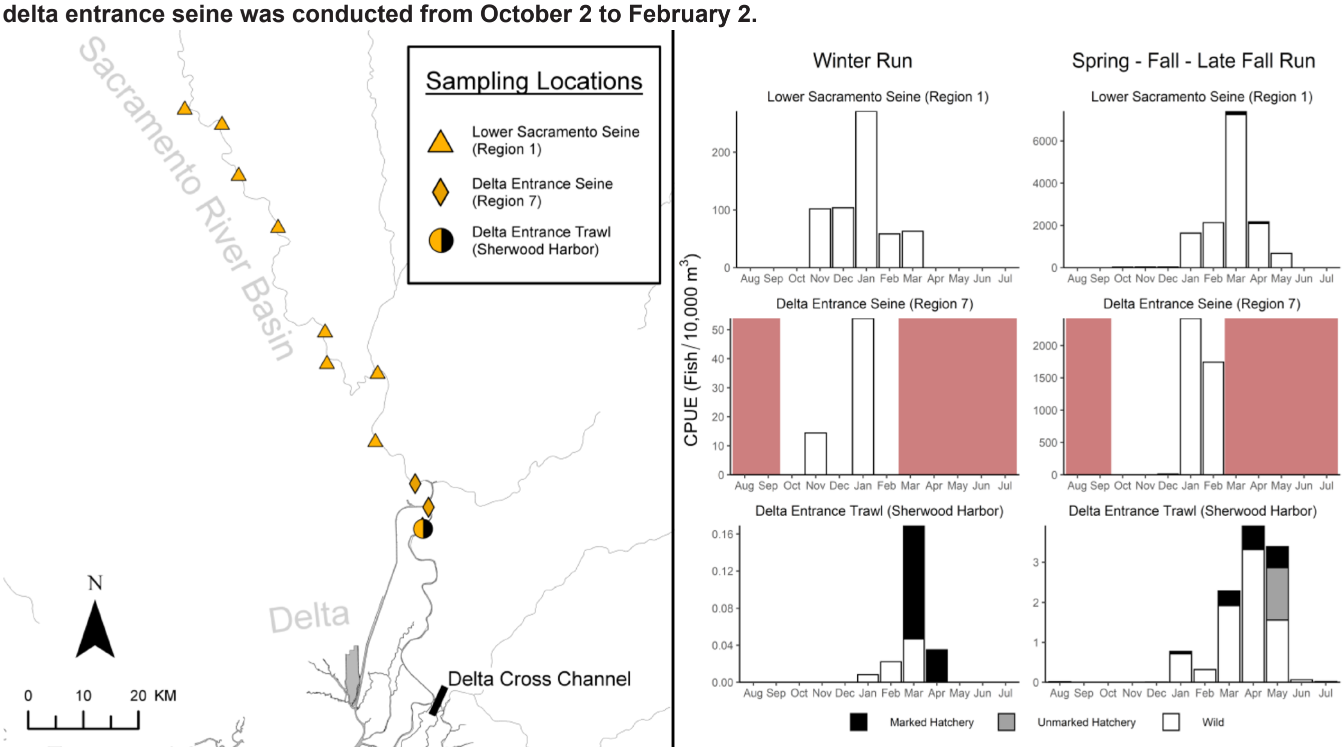
During the 2018 field year the DJFMP used a combination of beach seines and surface trawling (mid-water and Kodiak trawls) to monitor the distribution of juvenile Chinook Salmon (Figure 1). Monitoring was conducted during daylight hours (between 7:00 am and 1:00 pm) year round, with the exception of the Delta entrance seine (Sacramento River Basin; discussed below). Typically, ten 20-minute trawls were conducted a minimum of three days per week at each trawling location and all seine sites were sampled once per week, except for: 1) Bay Seines, which were sampled bi-weekly throughout the year, and 2) Delta entrance seines (Sacramento River Basin) and a few North Delta seines, which were sampled three times per week from October 1st through the last week of January, to intensely monitor for juvenile winter-run Chinook Salmon entering into the Delta from the Sacramento River Basin. The California Department of Fish and Wildlife (CDFW) sampled the Delta entrance trawl site (San Joaquin River Basin) in place of DJFMP between the months of April and June following similar methods. Data collected from both DJFMP and CDFW efforts are included in this report.

Captured fish ≥ 25 mm fork length (FL) were measured to the nearest 1 mm FL (with the exception of a few species that can be easily identified at < 25 mm fork length). The race of all unmarked juvenile Chinook Salmon were determined using the river Length at Date Criteria (LDC) developed by Fisher (1992) and modified by Greene (1992), except for individuals captured at the Mossdale Trawl Site and Lower San Joaquin River Seine Region. These individuals were classified as non-winter-run regardless of LDC since winter-run Chinook Salmon are not known to occur within the San Joaquin River and its main tributaries (Yoshiyama et al. 1998). If more than 50 individuals of a Chinook Salmon race were captured, a subsample of 50 individuals were randomly selected and measured. The rest of the captured fish were counted, but not measured (referred to as a "plus count"). All juvenile Chinook Salmon with missing (clipped) adipose fins, pelvic fin clips (used to mark a specific broodstock of winter-run hatchery fish in the 2018 field year), and other forms of marks or tags (e.g., stain dye, disc tags, acoustic tags) were recorded as marked along with their respective marking type. All juvenile Chinook Salmon with missing (clipped) adipose fins observed and intact pelvic fins were considered hatchery-reared and were brought back to the lab for coded wire tag extraction and race determination via the Regional Mark Information System database (RMIS 2019). Juvenile Chinook Salmon with missing (clipped) adipose fins and pelvic fin clips were recorded as hatchery-reared winter-run and were released. Water quality variables (i.e., water temperature, dissolved oxygen, turbidity, and conductivity) were measured immediately before each trawl and during or after each seine haul, but are not included in this report.

Before estimating relative abundance, we filtered the dataset by excluding samples collected during poor sampling conditions (i.e., gear condition code > 2 in the DJFMP dataset), when debris was present on flow meters, and outliers in sampling volumes identified by the boxplot.stats function in R (R Core Team 2019). This resulted in a total of 3,138 out of 90,140 trawl and 77 out of 39,681 seine samples being removed from our final dataset. All juvenile Chinook Salmon with missing (clipped) adipose fins were treated as marked hatchery fish in our dataset. Chinook Salmon used in directed studies that possessed other forms of marks or tags (e.g., stain dye, disc tags, acoustic tags), were not considered part of regular hatchery releases and were excluded from our catch dataset to avoid biasing our calculations of the proportion of hatchery and wild origin fish in samples. Using the filtered data, we estimated the number of unmarked hatchery and wild origin fish in samples collected from the 2000 to 2018 field years using the methods detailed in Graham et al. (2018) with a slight modification—all unmarked non-winter-run Chinook Salmon collected before the implementation of the Central Valley Constant Fractional Marking Program (Buttars 2013) were classified as unknown origin instead of attempting to estimate the proportion of unmarked hatchery fish in samples.

To compare the relative abundance of juvenile Chinook Salmon across space and time we calculated mean monthly and annual catch-per-unit-effort (CPUE) values for each seine region and trawl site. The mean monthly and annual CPUE values were calculated with a series of averages of averages to avoid overweighting sampling locations due to differences in sampling frequency. First, we calculated a sample CPUE value

Figure 2: Timing of juvenile Chinook Salmon entering the Delta from the Sacramento River basin. Seine and trawl sampling locations are located upstream of the Delta Cross Channel water diversion. The Sacramento River basin delta entrance seine was conducted from October 2 to February 2.



for each specific fish type (e.g., hatchery winter-run, wild winter-run, hatchery non-winter-run) by dividing the total number of individuals caught by the total volume of water sampled, for each sample. We then averaged sample CPUE values by month within sampling locations, and then averaged the mean monthly CPUE values for sampling locations across their respective seine region or trawling site within each month, to obtain the mean monthly CPUE for each seine region and trawl site reported here. We calculated mean annual CPUE values for each seine region and trawl site by averaging monthly CPUE values for each seine region and trawl site across months, within each field year. To aid in the interpretation of results we expanded our mean CPUE values by 10,000 m^3.

Results and Discussion

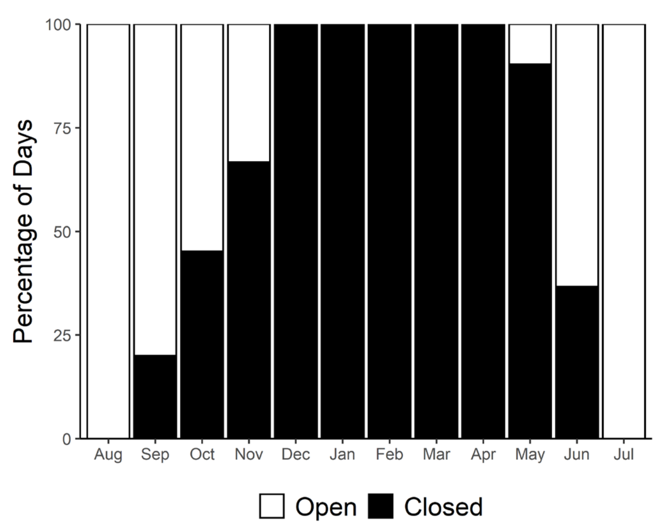
Delta Immigration- Sacramento River Basin

In the 2018 field year, we detected winter-run sized juvenile Chinook Salmon entering the Delta from the Sacramento River Basin from November 22 to April 11. Their relative abundance for the Lower Sacramento River and Delta entrance seines peaked in the month of January, while the Delta entrance trawl relative abundance peaked in March (Figure 2). Winter-run hatchery releases occurred primarily in the month of March (RMIS 2019) and resulted in a concurrent spike in the relative abundance of hatchery Winter-run Chinook Salmon at the Delta entrance trawl. There was a higher proportion of hatchery fish caught in trawls compared to seines. This trend has been common in this region over the years and is likely the result of body size and habitat use differences between hatchery origin and wild-stock fish. Salmonids in near-shore habitats are found to be smaller (wild-stock), while larger, hatchery origin fish tend to reside in deep channel habitats (Roegner et al. 2016).

At the Lower Sacramento River and Delta entrance seine sites, spring-, late fall-, and fall-run sized juvenile Chinook Salmon were detected from October 23 to May 31, with putative hatchery origin fish making up a consistently low proportion of catches. At seine sites, peak relative abundance occurred in March (Lower Sacramento River) and January (North Delta Entrance). At the Delta entrance trawl site we detected spring-, late fall-, and fall-run sized juvenile Chinook Salmon from August 14 to July 20, with peak relative abundance in April (Figure 2). The proportion of hatchery fish in trawl catches coincided with the timing and magnitude of hatchery releases, which occurred from the months of December through May (RMIS 2019).

The full operation details of the Delta Cross Channel water diversion during the 2018 field year can be found in the annual reports of the Delta Operations for Salmonids and Sturgeon Technical Working Group (DOSS 2019). In general, the Sacramento Catch Index (SCI) generated by our trawl and beach seine surveys triggered the DCC closure action response on six occasions during the 2018 field year. The overall timing and duration of DCC closures corresponded with the monthly relative abundance of juvenile Chinook Salmon we observed (Figure 2), suggesting that the DCC was closed during the periods when a large number of juvenile Chinook Salmon were at risk of entrainment (Figure 3).

Figure 3: Summary of the Delta Cross Channel operations during the 2018 field year (August 2017 to July 2018).



Delta Immigration- San Joaquin River Basin

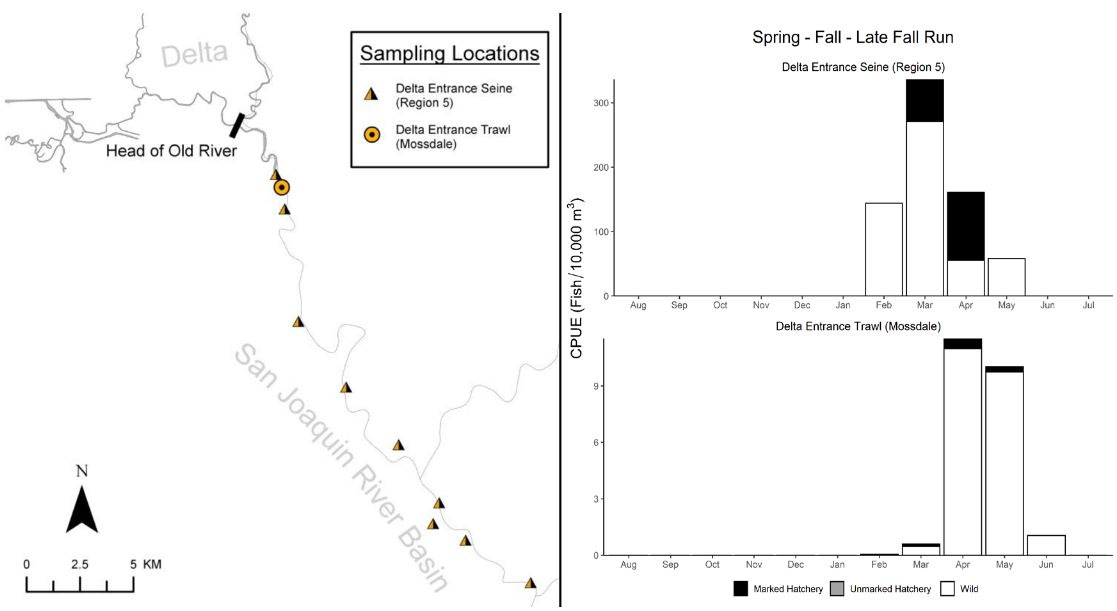
At the San Joaquin River Delta entrance, we detected juvenile spring-, fall-, and late-fall sized juvenile Chinook Salmon entering the Delta from February 9 to June 18, with the highest relative abundance occurring in March (seines) and April (trawls) (Figure 4). From February 9 to April 17 we observed a total of 25 hatchery-origin-spring-run juvenile Chinook Salmon entering the Delta from the San Joaquin River Basin. These fish originated from hatchery releases conducted by the San Joaquin River Restoration Program (SJRRP 2019). Central Valley spring-run Chinook Salmon are currently listed as 'threatened' under the Endangered Species Act (NOAA 1999) and the SJRRP has begun restoration efforts to re-introduce this species to the San Joaquin River basin. As these restoration efforts continue, the DJFMP will become increasingly valuable to the SJRRP by providing annual updates on the timing and distribution of these juvenile spring-run Chinook Salmon as they migrate through the Delta and San Francisco Estuary. Unlike our Sacramento River sampling, these hatchery-origin fish made up a higher proportion of seine catches (3 out of 32 Chinook Salmon) than trawl catches (22 out of 1561 Chinook Salmon). These results could indicate a high degree of littoral habitat use by these hatchery-origin fish, however, these results are not very robust given the small number of Chinook Salmon captured in seines this field year. We will continue to monitor this pattern in the future, and as more data is collected, we will be able to refine our assessment of their habitat use during their immigration to the Delta.

During the 2018 field year, installation of the spring fish barrier at the head of Old River was attempted on March 16 but could not be completed due to high San Joaquin River flows (DWR 2019). Therefore, it is likely that some proportion of the juvenile Chinook Salmon entering the Delta from the San Joaquin River Basin used the Old River migratory corridor (Buchanan et al. 2013).

Delta Residency

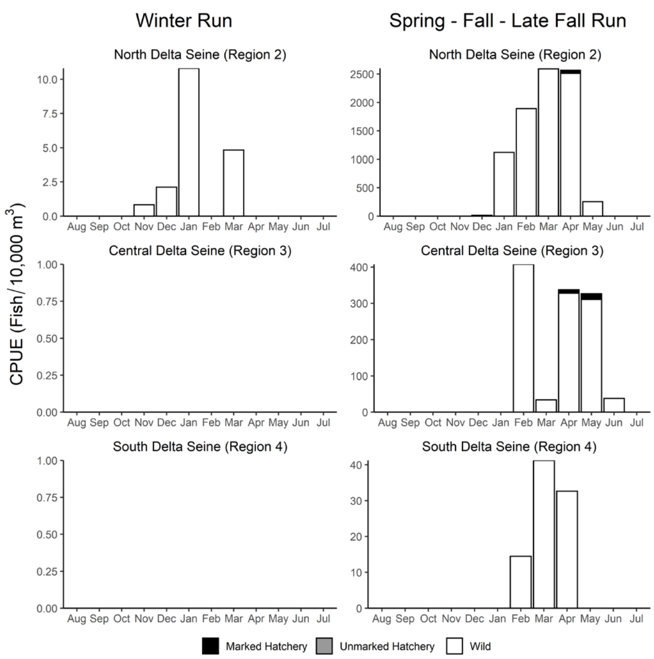
We observed a total of 7 winter-run sized juvenile Chinook Salmon in the North Delta Region this field year from November 24 to March 26, with a peak relative abundance occurring in the month of January (Figure 5). The low number we observed within the North Delta was consistent with the low relative abundance we have observed since the 2014 field year (Figure 6). We did not observe winter-run sized Chinook Salmon in the Central Delta and South Delta Regions, suggesting that the operation of the DCC for the 2018 field year was relatively effective at reducing the number of winter-run sized juveniles diverted to these regions compared to previous years (Figure 6).

Figure 4: Timing of juvenile Chinook Salmon immigration to the Delta from the San Joaquin River basin. Delta entrance seine and trawl sampling sites are located upstream of the head of Old River.



We observed a total of 1,585 spring- fall- late fall- run sized juvenile Chinook Salmon within the North, South, and Central Delta Regions this field year from December 13 (North Region) to June 5 (Central Region) (Figure 5). The relative abundance of these juvenile Chinook Salmon was substantially lower than the 2016 and 2017 field years in all Delta Regions (Figure 6). Relative abundance differed between regions and remained consistent with previous years- the North Delta had the highest relative abundance, followed by the Central Delta and then the South Delta.

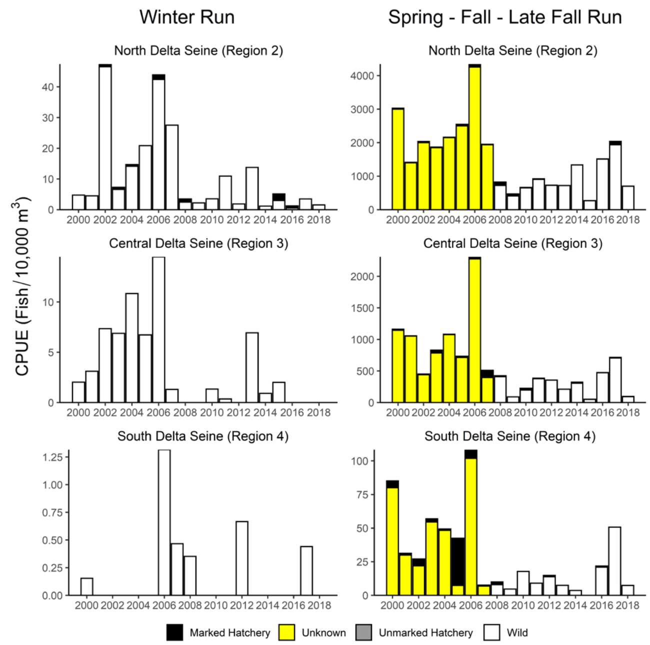
Figure 5: Timing of juvenile Chinook Salmon littoral habitat residency in the Delta.



Delta Emigration

Winter-run sized juvenile Chinook Salmon exited the Delta between January 9 and April 21, with peak emigration occurring in the month of March (Figure 7). Spring-, fall-, and late fall-run sized juvenile Chinook Salmon emigrated from the Delta between January 9 and June 11, with peak emigration occurring in the month of April. From January to March, the relative abundance of emigrating spring-, fall-, and late fall-run sized Chinook Salmon was low and primarily consisted of hatchery origin fish (Figure 7). Wild origin Chinook Salmon were not common in catches until April. The earlier emigration of hatchery origin juveniles could be due to a combination of factors that affected their residency time within the Delta including the relative size and maturation state of individuals and the timing and location of their release (Pearcy et al. 1989). The relative abundance of wild origin juvenile Chinook Salmon exiting from the Delta this field year was substantially lower than the 10-year high we observed in 2017 and fell within the range we observed from 2008 to 2014 (Figure 8).

Figure 6: Annual relative abundance trends of juvenile Chinook Salmon in the Delta.



We observed juvenile Chinook Salmon in our Bay Seine, which indicated that fry- and parr-sized juveniles emigrated from the Delta and contributed additional migratory phenotypes to the overall Central Valley Chinook Salmon cohort this field year (Figure 7). The maintenance of these migratory phenotypes has been highlighted as a potential long-term driver of successful recruitment (Miller et al. 2010). This was the second year in a row that we have recorded a relatively high number of these juveniles in the Bay (Figure 8).

At the Delta exit, we observed a significant increase (Welch Two Sample t-test, $P < 0.05$) in the average size of winter-run (mean = 112.7 mm FL) and spring-run hatchery reared fish (mean = 90.4 mm FL) this year compared to the running average (winter-run = 102.8 mm FL; spring-run = 87.0 mm FL) in recent years (Figure 9). Meanwhile, the median size of late

Figure 7: Timing of juvenile Chinook Salmon emigration from the Delta.

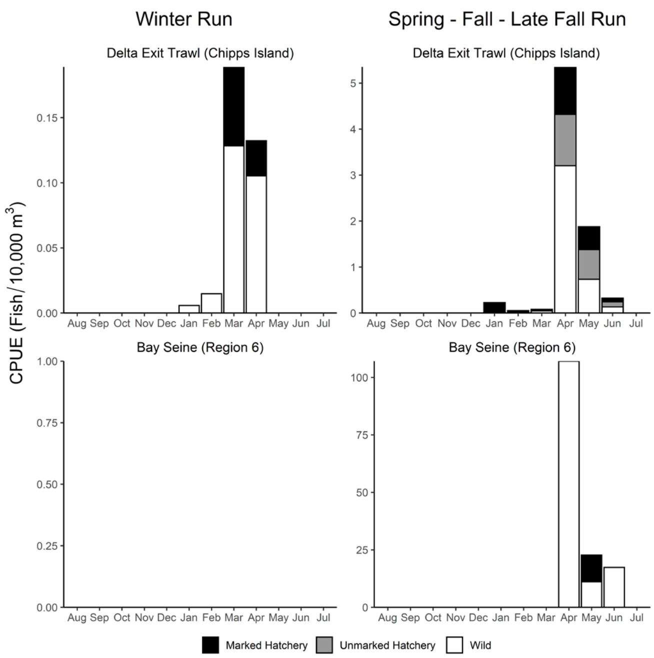
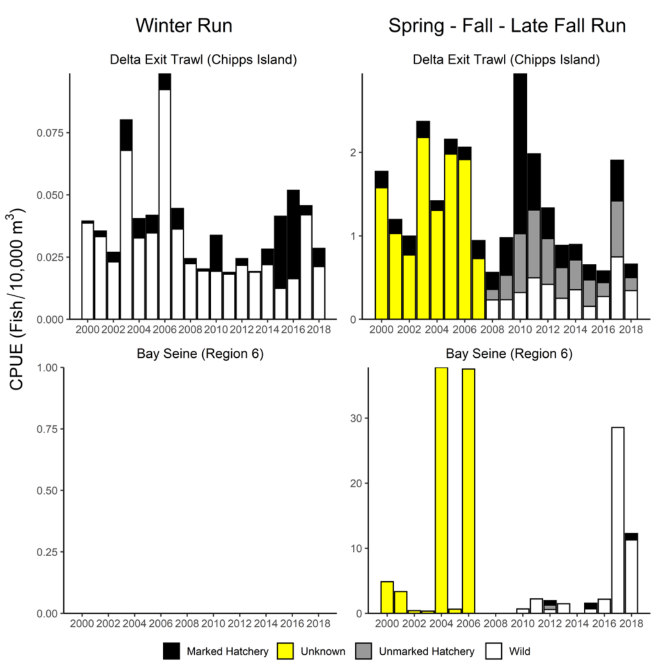
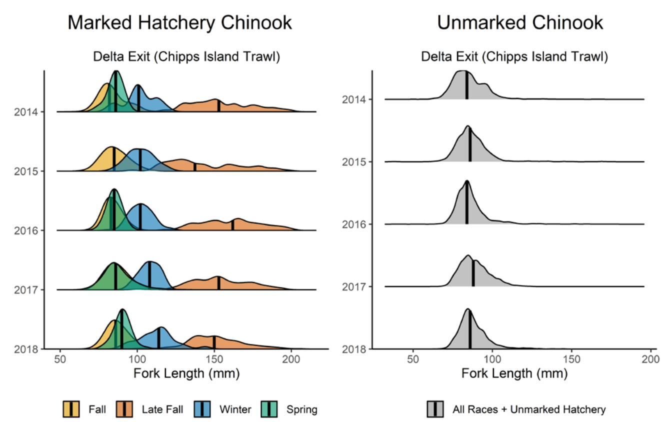


Figure 8: Annual relative abundance trends of juvenile Chinook Salmon emigrating the Delta.



fall-run and fall-run hatchery reared and unmarked fish have remained generally consistent. The increase in median size of winter- and spring-run hatchery fish may improve the survival of these individuals during their early ocean residency periods for this year (Woodson et al. 2013). However, the influence that this has on recruitment will not be known for another few years, as body length at ocean entry is just one of many factors that affect the long-term survival of Chinook Salmon in the ocean (Henderson et al. 2019; Woodson et al. 2013).

Figure 9: Size distributions of juvenile Chinook Salmon cohorts emigrating the Delta (medians are indicated by vertical bar).



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Article Submission Deadlines for this Calendar Year

Issue	*Article Submission Deadline*
Issue 1 (Winter)	January 15
Issue 2 (Spring)	April 15
Issue 3 (Summer)	July 15
Issue 4 (Fall)	October 15

Submit articles to Sarah Lesmeister.

Phytoplankton, Chlorophyll-a and Pheophytin-a Status and Trends 2018

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Introduction

The Department of Water Resources (DWR) and the US Bureau of Reclamation (USBR) are required by Water Right Decision 1641 (D-1641) to collect phytoplankton and chlorophyll a samples to monitor algal community composition and biomass at select sites in the upper San Francisco Estuary (Estuary). The twenty-four sites range from San Pablo Bay to the inland rivers of the Sacramento-San Joaquin Delta ("the Delta"). These sites represent a variety of aquatic habitats, from narrow, freshwater channels to broad, estuarine bays. This newsletter describes the results of these monitoring efforts for calendar year 2018.

Phytoplankton are small, free-floating organisms that occur as unicellular, colonial, or filamentous forms (Horne and Goldman, 1994). They primarily serve as an important food source for zooplankton, invertebrates, and certain fish species, although they also have direct effects on water chemistry. Primary production by phytoplankton, primarily via carbon fixation through photosynthesis, is one of the key processes that influence water quality in the Estuary. Via this process, phytoplankton can affect pH, dissolved oxygen, color, taste, and odor. Under certain conditions, some species (e.g., *Microcystis aeruginosa*) can cause harmful algal blooms (HABs), resulting in animal deaths and human illness (Carmichael, 1981). In freshwater, cyanobacteria, or blue-green algae (class Cyanophyceae), are responsible for producing toxic blooms, particularly in waters that are polluted with phosphates (van den Hoek et al., 1995). Phytoplankton monitoring is also useful for assessing water quality (Gannon and Stemberger, 1978); their short life cycles allow them to respond quickly to environmental changes, meaning their standing crop and species composition are indicative of source water characteristics (APHA, 2012). However, because of their transient nature, patchiness, and free movement in a lotic environment, the utility of phytoplankton as water quality indicators is limited and should be interpreted in conjunction with other biological and physiochemical data (APHA, 2012).

In addition to collecting phytoplankton samples to assess community composition, we use chlorophyll a concentrations as proxies to calculate phytoplankton biomass. Chlorophylls are complex phytopigment molecules found in all photosynthetic organisms. There are several types of chlorophyll, which are distinguished by slight differences in their molecular structures and constituents. These include chlorophyll a, b, c, and d, with a being the principal photosynthetic pigment in the majority of phytoplankton. This makes the chlorophyll a pigment a reliable proxy measurement for phytoplankton biomass. Furthermore, water samples were analyzed for pheophytin a. Pheophytin a is a primary degradation product of chlorophyll a. Its concentration, relative to chlorophyll a, is useful for estimating the general physiological state of phytoplankton populations. When phytoplankton are actively growing, the concentrations of pheophytin a are normally expected to be low in relation to chlorophyll a. Conversely, when the phytoplankton have died and are decaying, levels of pheophytin a are expected to be high in relation to chlorophyll a.

Phytoplankton biomass and the resulting chlorophyll a concentrations in some areas of the Estuary may be influenced by extensive filtration of the water column by the introduced Asian clam, *Potamocorbula amurensis* (Alpine and Cloern, 1992). Well-established benthic populations of *P. amurensis* in Suisun and San Pablo bays are thought to have contributed to the low chlorophyll a concentrations (and increased water clarity) measured in these westerly bays since the mid-1980s (Alpine and Cloern, 1992).

Methods

Phytoplankton

Phytoplankton samples were collected monthly at 24 monitoring sites throughout the Upper Estuary, which were grouped into regions based on their geographic location (Figure 1; Table 1). Samples were collected 1 meter below the water's surface using a submersible pump and stored in 50 mL amber glass bottles. 200 µL of Lugol's solution was added to each sample as a stain and preservative. All samples were kept at room temperature and away from direct sunlight until they were analyzed. Phytoplankton identification and enumeration were performed by BSA Environmental, Inc. according to the Utermöhl microscopic method (Utermöhl, 1958) and modified Standard Methods (APHA, 2012). An aliquot was placed into a counting chamber and allowed to settle for a minimum of 12 hours. The aliquot volume, normally 10-20 mL, was adjusted according to the algal population density and the turbidity of the sample. Phytoplankton taxa were enumerated in randomly chosen transects for each settled aliquot. This process was performed at 800x magnification using a Leica DMIL inverted microscope. For each aliquot, a minimum of 400 total algal units were counted, with the dominant taxon accounting for a minimum of 100 algal units. For taxa that were in filaments or colonies, the number of cells per filament or colony was recorded. Raw organism counts were normalized to the sample volume using the following formula:

$$\text{Organisms} = (C \times Ac) / (V \times Af \times F)$$

where:

Organisms = Number of organisms (#/mL)
C = Count obtained
Ac = Area of cell bottom (mm^2)
Af = Area of each grid field (mm^2)
F = Number of fields examined (#)
V = Volume settled (mL)

This simplifies to:

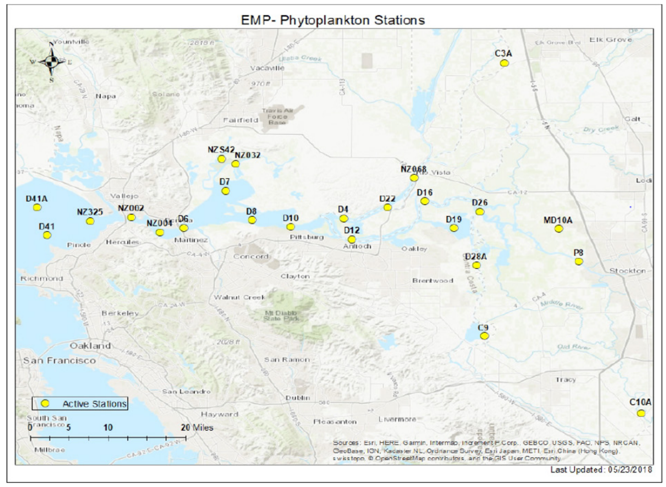
$$\text{Organisms} = C / cV$$

where:

cV = Counted volume (mL)
(Note: $cV = Ac / (V \times Af \times F)$)

The 10 most common genera were determined by summing the normalized organism counts across all stations and months for each genus. For the bar graphs, average organism counts were calculated per month and per region and normalized to the number of stations.

Figure 1. Map of phytoplankton stations sampled by the Environmental Monitoring Program.



Chlorophyll a and Pheophytin a

Chlorophyll a and pheophytin a samples were collected monthly at 24 monitoring sites throughout the upper Estuary (Figure 1; Table 1) using a submersible pump positioned 1 meter below the water's surface. The analytes were collected by filtering a known volume of sample water through a glass-fiber filter (1.0 µm pore size) at a pressure of 10 mm Hg. If the turbidity was 20 NTU or greater, a 200 mL volume was used, while 500mL of water was filtered through if the turbidity was less than 20 NTU; this was done to prevent clogging of the filtering apparatus. The filters were immediately frozen and transported to DWR's Bryte Laboratory for analysis using the spectrophotometric procedure, in accordance with the Standard Methods (APHA, 2012). Samples were processed by mechanically grinding the glass-fiber filters and extracting the phytopigments with acetone. Chlorophyll a and pheophytin a pigment absorptions were measured with a spectrophotometer before and after acidification of the sample. Concentrations were calculated according to Standard Method's formula (APHA, 2012). For the bar graphs, average analyte concentrations were calculated per month and per region and were normalized to the number of stations.

Table 1. Stations included within each region of the Delta.

Region	*Stations*
Northern Interior Delta	C3A and NZ068
Southern Interior Delta	C9, C10A, M10A and P8
Central Delta	D16, D19, D26 and D28A
The Confluence	D4, D10, D12 and D22
Grizzly and Suisun Bay	D7, D8, NZ032 and NZS42
San Pablo Bay	D6, D41, D41A, NZ002, NZ004 and NZ325

Results

Phytoplankton Identification

All organisms collected in 2018 fell into these ten algal groups:

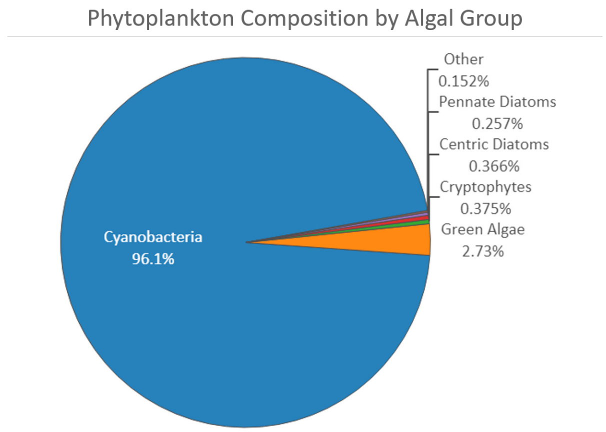
- Pennate diatoms
- Centric diatoms
- Chrysophytes
- Ciliates
- Cyanobacteria
- Cryptophytes
- Dinoflagellates
- Euglenoids
- Haptophytes
- Green Algae

The 10 most common genera collected in 2019 were, in order:

- *Eucapsis* (cyanobacteria)
- *Chroococcus* (cyanobacteria)
- *Chlorella* (green alga)
- *Plagioselmis* (cryptophyte flagellate)
- *Cyclotella* (centric diatom)
- *Coccomyxa* (green alga)
- *Ochromonas* (chrysophycea)
- *Microcystis* (cyanobacteria)
- *Nitzschia* (pennate diatom)
- *Skeletonema* (centric diatom)

Of the ten groups identified, cyanobacteria constituted the vast majority (96.1%) of the organisms collected (Figure 2).

Figure 2. Phytoplankton composition by algal group. "Other" consists of chrysophytes, dinoflagellates, euglenoids, haptophytes, and ciliates.



Pigment Concentrations

Some stations showed seasonal patterns in chlorophyll a concentration, while others did not. Most maxima occurred in spring and summer, while minima occurred in fall or winter.

Monthly chlorophyll a concentrations throughout much of the estuary were relatively low. Of the 280 samples taken in 2018, 94.7% (269 samples) had chlorophyll a levels below 10 µg/L. Chlorophyll a levels below 10 µg/L are considered limiting for zooplankton growth (Müller-Solger et al., 2002). Of the 11 samples with chlorophyll a concentrations equal to or above 10 µg/L, six were at C10A (February-March, June-September) and one each were at D10 (May), D26 (August), MD10A (August), NZ002 (April), and NZ032 (May).

The mean chlorophyll a concentration for all samples in 2018 was 3.51 µg/L; the median value was 2.12 µg/L. Both values are similar to their 2017 equivalents (mean = 3.41 µg/L, median = 2.18 µg/L). The maximum chlorophyll a concentration in 2018 was 71.87 µg/L, recorded in July at C10A. This is much higher than the maximum value for 2017 (24.93 µg/L) but similar to the maximum observed in 2016 (71.01 µg/L). The minimum for 2018 chlorophyll a concentration recorded was 0.55 µg/L, recorded in December at NZ068, slightly lower than the 2017 value (0.65 µg/L).

The mean pheophytin a concentration for all samples in 2018 was 1.40 µg/L, similar to the 2017 value (1.48 µg/L), and the median value was 0.95 µg/L, which was lower than the 2017 value (1.21 µg/L). The maximum pheophytin a concentration was 15.4 µg/L, recorded at D19 in November, compared to 5.01 µg/L in 2017. The minimum pheophytin a concentration was 0.50 µg/L, which is equivalent to the reporting limit; this was observed three times, at D19 (October), NZ068 (July), and NZ325 (December). Several sites had pheophytin a levels below the reporting limit, primarily in the fall/winter.

Northern Interior Delta

Chlorophyll a average concentrations were higher in early spring and mid-summer (Figure 3). The highest concentration was recorded at C3A in May (5.59 µg/L) and the lowest was recorded at NZ068 in December (0.55 µg/L). The mean and median values were 2.15 µg/L and 1.71 µg/L, respectively.

Pheophytin a average concentrations were highest in the winter and spring; values were low compared to chlorophyll a (Figure 3). The maximum (3.16 µg/L) was recorded at C3A in July and the minimum (0.50 µg/L) was recorded at NZ068 in July, although October and November included concentrations below the detection limit. The mean and median were 1.23 µg/L and 1.02 µg/L, respectively.

Phytoplankton average concentrations were highest in February-April, with cyanobacteria dominating throughout the year (Figure 4; "other" encompasses chrysophytes and euglenoids). Green algae concentrations were relatively high in February and March.

Southern Interior Delta

Chlorophyll a average concentrations were highest in the summer (Figure 5). The maximum recorded was at C10A in July (71.87 µg/L); the minimum was at P8 in December (0.76 µg/L). The mean and median were 7.82 µg/L and 3.06 µg/L, respectively.

Pheophytin a average concentrations were fairly constant throughout the year, with slight spikes in the summer months (Figure 5). The maximum pheophytin a value was recorded at C10A in September (12.12 µg/L); the minimum occurred at C9 in February (0.61 µg/L). The mean and median values were 2.39 µg/L and 1.41 µg/L, respectively.

Phytoplankton average concentrations were highest in the spring and summer months, with the highest concentrations occurring in April (Figure 6; "other" encompasses chrysophytes, dinoflagellates, and euglenoids). Cyanobacteria dominated throughout the year and centric diatom concentrations were relatively high in the summer months.

Figure 3. Average chlorophyll a and pheophytin a densities in the Northern Interior Delta. Pheophytin a was below the reporting limit (0.50 µg/L) in October and November.

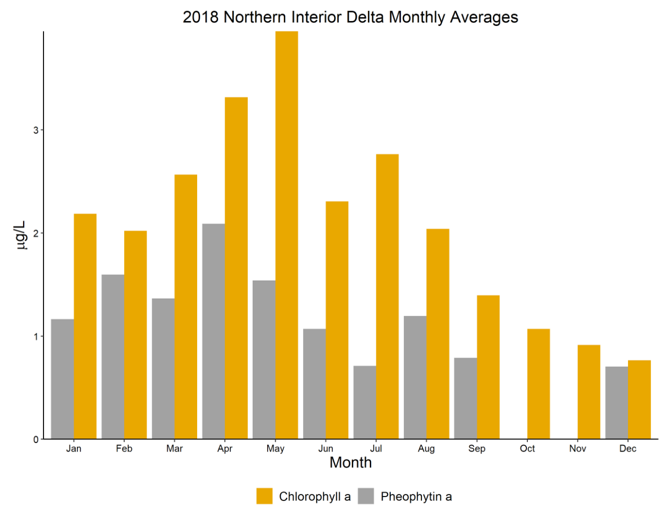


Figure 4. Average organism density in the Northern Interior Delta; note secondary Y-axis for cyanobacteria. "Other" consists of chrysophytes and euglenoids.

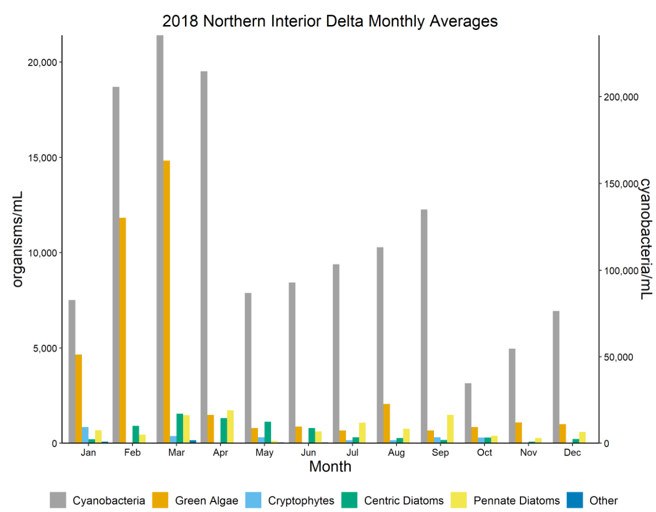


Figure 5. Average chlorophyll a and pheophytin a densities in the Southern Interior Delta.

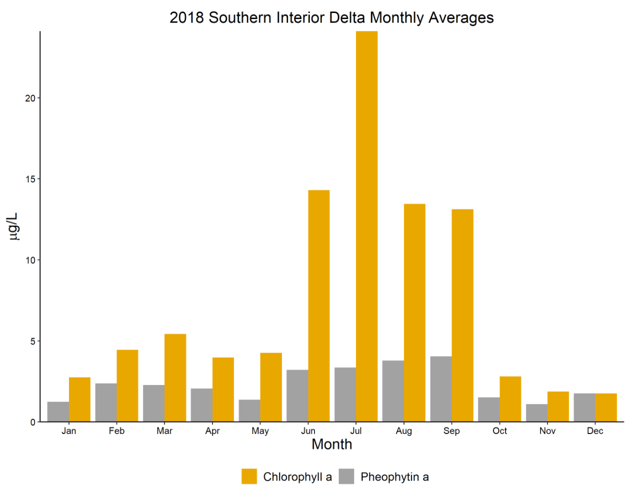
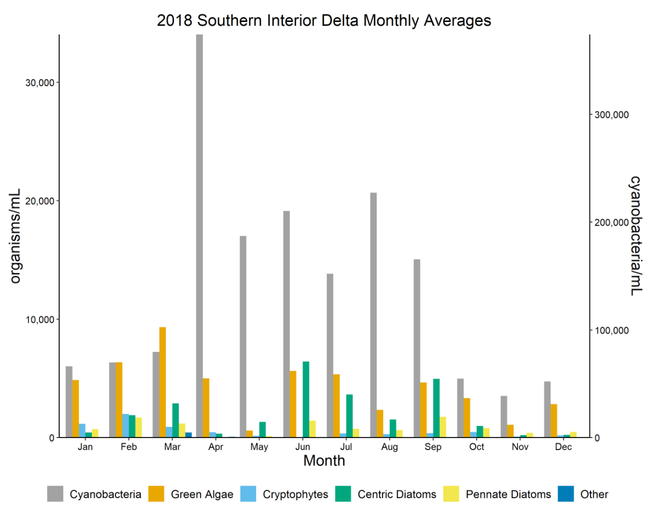


Figure 6. Average organism density in the Southern Interior Delta; note secondary Y-axis for cyanobacteria. "Other" consists of chrysophytes, dinoflagellates, and euglenoids.



Central Delta

Chlorophyll a average concentrations were highest in the spring and summer months, excluding the slightly lower concentrations in May (Figure 7). The highest chlorophyll a concentration for this region at occurred at D26 in August (13.80 µg/L); the minimum occurred at D26 in December (0.65 µg/L). The mean and median values were 2.47 µg/L and 1.92 µg/L, respectively.

Pheophytin a average concentrations were relatively consistent throughout the year excluding a large spike in November (Figure 7), when the highest concentration in the region was recorded (15.40 µg/L, station D19). The minimum occurred at D19 in October (0.50 µg/L). The mean and median values were 1.28 µg/L and 0.90 µg/L, respectively.

Phytoplankton average concentrations were highest in the spring and summer months (Figure 8; "other" encompasses chrysophytes and haptophytes). Average concentrations were lower compared to other regions. The highest concentrations were seen in April, and cyanobacteria dominated throughout the year. Higher concentrations of green algae were seen in January-March.

Figure 7. Average chlorophyll a and pheophytin a densities in the Central Delta.

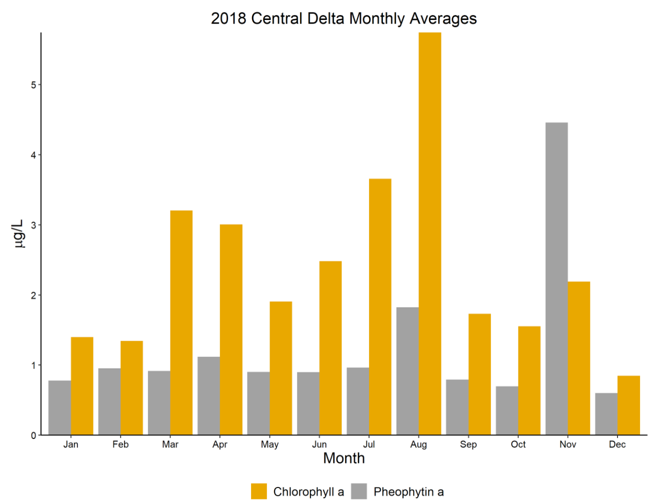
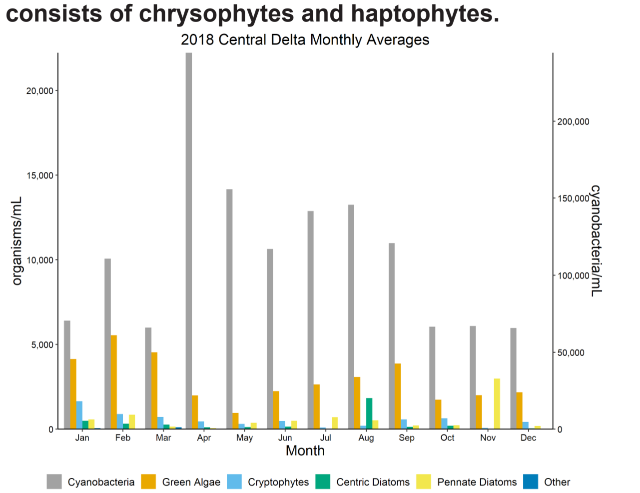


Figure 8. Average organism density in the Central Delta; note secondary Y-axis for cyanobacteria. "Other" consists of chrysophytes and haptophytes.



Confluence

Chlorophyll a average concentrations were highest during the late-spring and summer (Figure 9). The highest concentration occurred at D10 in May (13.00 µg/L); the minimum was recorded at D10 in December (0.68 µg/L). The mean and median values were 2.55 µg/L and 2.05 µg/L, respectively.

Pheophytin a average concentrations were relatively consistent throughout the year. The maximum concentration was recorded at D22 in August (2.99 µg/L) and the minimum at D22 in November (0.51 µg/L) (Figure 9). The mean and median for this region were 1.17 µg/L and 1.04 µg/L, respectively.

Phytoplankton average concentrations were relatively consistent throughout the year, excluding October and November (Figure 10; "other" encompasses chrysophytes). The highest concentrations were seen in April, although average concentrations were lower compared to other regions. Cyanobacteria dominated throughout the year, and green algae concentrations spiked in January-March.

Figure 9. Average chlorophyll a and pheophytin a densities in the Confluence.

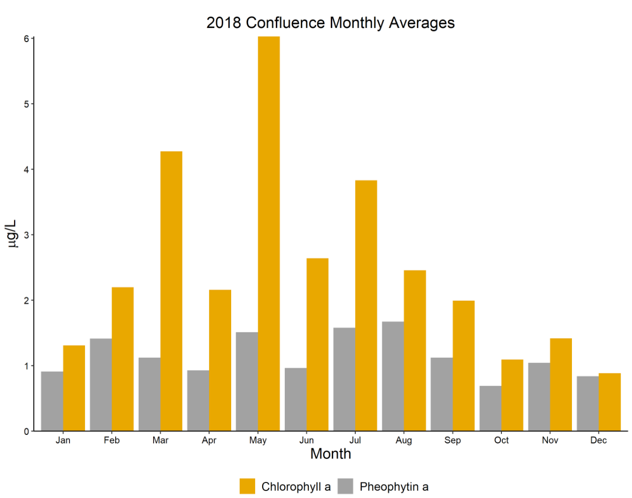
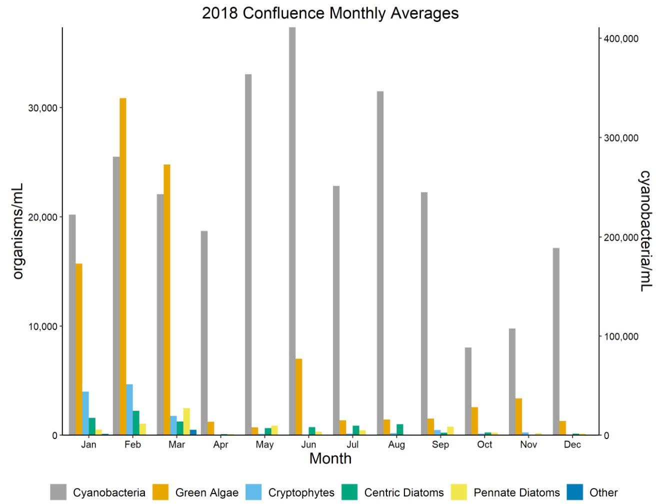


Figure 10. Average organism density in the Confluence; note secondary Y-axis for cyanobacteria. "Other" consists of chrysophytes.



Grizzly Bay and Suisun Bay

Chlorophyll a average concentrations in this region were relatively consistent, excluding a large spike in May (Figure 11), which included the maximum value recorded for this region that year (19.10 µg/L, at NZ032); the minimum was recorded at D8 in January (0.85 µg/L). The mean and median were 3.08 µg/L and 2.27 µg/L, respectively.

Pheophytin a average concentrations were slightly higher in February-May (Figure 11). The maximum concentration was recorded in at NZS42 March (4.31 µg/L) and the minimum at D8 in November (0.56 µg/L). The mean and median were 1.39 µg/L and 1.00 µg/L, respectively.

Phytoplankton average concentrations were relatively consistent in the late winter through early summer months, with lower values in the late fall (Figure 12; "other" encompasses chrysophytes and dinoflagellates). Cyanobacteria was the dominant algal group throughout the year, and green algae concentrations spiked in January-March.

Figure 11. Average chlorophyll a and pheophytin a densities in the Grizzly and Suisun Bays during 2017.

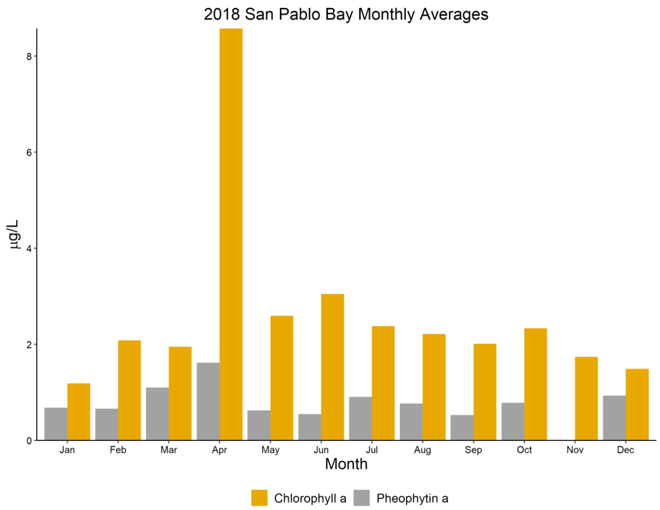
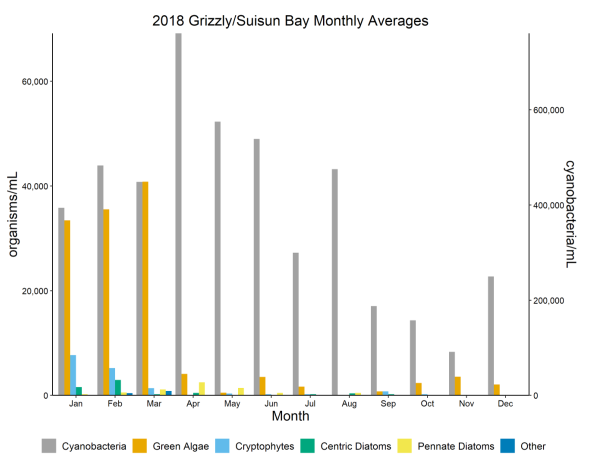


Figure 12. Average organism density in the Grizzly and Suisun Bays; note secondary Y-axis for cyanobacteria. "Other" consists of chrysophytes and dinoflagellates.



San Pablo Bay

Chlorophyll a average concentrations were relatively consistent throughout the year, excluding a large peak in April (Figure 13), where the maximum value for the region was recorded (26.90 µg/L, at NZ002); the minimum concentration was recorded at D6 in January (0.87 µg/L). The mean and median were 2.67 µg/L and 2.10 µg/L, respectively.

Pheophytin a average concentrations were relatively consistent and low (Figure 13). The maximum was recorded at NZ002 in April (2.33 µg/L) and the minimum at NZ325 in December (0.50 µg/L), although November's concentrations were below the reporting limit. The mean and median were 0.89 µg/L and 0.73 µg/L, respectively.

Phytoplankton average concentrations were relatively consistent throughout the year, excluding a large spike in cyanobacteria in April (Figure 14; "other" encompasses chrysophytes, ciliates, dinoflagellates, and euglenoids). Green algae concentrations were highest in January-April.

Figure 13. Average chlorophyll a and pheophytin a densities in the San Pablo Bay. Pheophytin a was below the reporting limit (0.50 µg/L) in November.

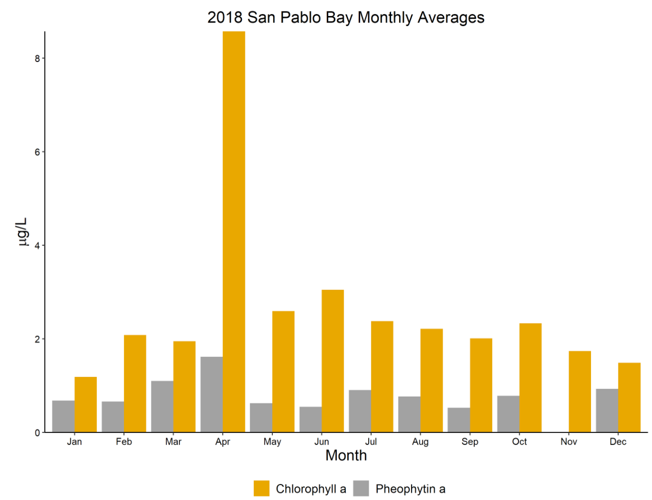
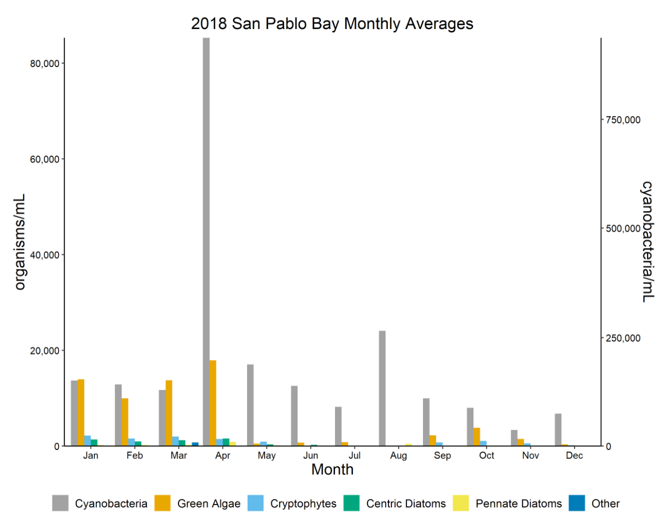


Figure 14. Average organism density in the San Pablo Bay; note secondary Y-axis for cyanobacteria. "Other" consists of chrysophytes, ciliates, dinoflagellates, and euglenoids.



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Benthic Monitoring, 2018

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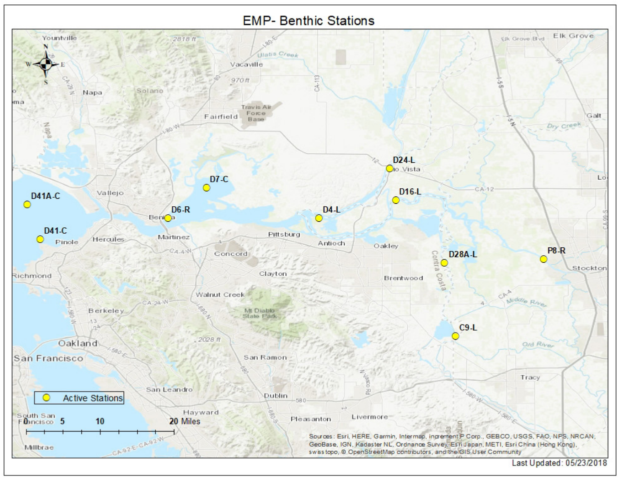
Introduction

Benthic monitoring conducted by the Environmental Monitoring Program (EMP), as part of the Interagency Ecological Program (IEP), has documented changes in the composition, density, and distribution of the macrobenthic biota of the upper San Francisco Estuary since 1975. Benthic species respond to changes in physical factors such as freshwater inflows, salinity, and substrate composition (Peterson and Vayssieres, 2010, Thompson et al. 2013). As a result, benthic community data can provide 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 and Central Valley Project can change the flow characteristics of the estuary and affect the density and distribution of benthic biota. The benthic monitoring data are also used to detect and document the presence of new non-native species in the upper estuary, such as the dramatic 1986 arrival of the overbite clam *Potamocorbula amurensis*. This article summarizes characteristics of benthic communities at the EMP monitoring sites in 2018, and places these results in the context of data from the previous decade.

Methods

Benthic monitoring was conducted monthly at 10 sampling sites distributed throughout the estuary, from San Pablo Bay upstream through the Sacramento-San Joaquin Delta (Figure 1). EMP staff collected five bottom grab samples at each station using a Ponar dredge with a sampling area of 0.052 m^2. Four replicate grab samples were used 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 the Department of Water Resources. All organisms were identified to the lowest taxon possible and enumerated. Sediment composition analysis was conducted at the Department of Water Resources' 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/

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



Prior to analysis, the counts of individual organisms per grab were transformed to individuals/m^2 for each species at each site and sample date. Species were then grouped by phyla, and total densities for individual phyla were then plotted by month to depict seasonal patterns in benthic communities. Rare phyla (fewer than 20 total individuals seen in the entire year) were omitted from the plots.

The 2018 water year was designated as below normal for both the Sacramento Valley and the San Joaquin Valley according to the Department of Water Resources' Water Year Hydrologic Classification Indices. Benthic communities in 2018 were expected be similar to previous years below normal, such as 2010, 2012 and 2016, and to differ in community composition compared to wet years such as 2011 and 2017. Differences between 2018 and wetter years were expected both in species composition and in species abundances.

Results

Several new species were added to the benthic species list in 2018. Two non-biting midges, *Parakiefferiella sp. A* and *Einfeldia sp. A* (Order Dipetera, Family Chironomidae), were collected for the first time by the EMP benthic survey in May, as were the oligochaete worm Ripistes parasita (Order Tubificida, Family Naididae) and an unidentified Cardiidae clam (Order Veneroida, Family Cardiidae). A new polychate worm, *Scoletoma erecta* (Order Eunicida, Family Lubrinerida) was collected for the first time in June, and a new amphipod, *Stenula modosa* (Order Amphipoda, Family Steonthoidae), was collected in October 2018.

Nine phyla were represented in the benthic fauna collected in 2018: Cnidaria (jellyfish, corals, sea anemones, and hydrozoans), Platyhelminthes (flatworms), Nermertea (ribbon worms), Nematoda (roundworms), Annelida (segmented worms, leeches), Arthropoda (crabs, shrimp, insects, mites, amphipods, isopods), Mollusca (snails, univalve mollusks, bivalves), Phoronida (horseshoe worms), and Chordata (tunicates and sea squirts). Annelida, Arthropoda, and Mollusca accounted for over 99% of all individuals collected in 2018.

Of the 190 benthic species collected in 2018, the ten most abundant species represented 85% of all individuals collected throughout the year. These include four species of amphipod, two clams, two oligochaete worms, a sabellid polychaete worm, and an ostracod (Table 1). Refer to Fields and Messer (1999) for descriptions of the habitat requirements, physical attributes, and feeding methods of these species.

In the site descriptions that follow, many species densities are reported as the annual average densities of individuals per m^2, sometimes with a note on any moderately sized seasonal peaks. Some species, especially arthropods, display strongly marked seasonal variability with peak densities several times their annual averages; in these cases, reporting the timing and magnitude of the peaks was more informative than the annual averages for readers interested in how the sites varied throughout the year. Readers who wish to see the full dataset can access it at: https://emp.baydeltalive.com/projects/11280.

The ten most abundant species found in EMP benthic invertebrate monitoring in 2018.

Species	***OrganismType***	***Native/ Introduced Status***	***Station at which species was found*** [a]	***Month(s) in which the species was abundant***	***Total number of individuals***[b]
Potamocorbula amurensis	Asian clam	Introduced	D4, D6, D7, D41A	Every month	58,244
Ampelisca abdita	Amphipod	Introduced	D4, D6, D7, D41, D41A	June - December	34,795
Varichaetadrilus angustipenis	Tubificidae worm	Introduced	D24, D16, D28A, P8, C9, D4, D7	March, April, June, July, August, September	17,796
Corbicula fluminea	Asian clam	Introduced	D24, D16, D28A, P8, C9, D4, D7	Every month, especially July and December	14,391
Corophium alienense	Amphipod	Introduced	D6, D7, D41A	July, November	13,835
Americorophium spinicorne	Amphipod	Native	D24, D16, D28A, P8, C9, D4, D6, D7	March, May, November	9,644
Gammarus daiberi	Amphipod	Introduced	D24, D16, D28A, P8, C9, D4, D6, D7	April, May, June, October, December	8,123
Cyprideis sp. A	Ostracod	Unknown	D28A, P8, C9, D4	October, November, December	6,715
Manayunkia speciosa	Sabellidae polychaete worm	Introduced	D16, D28A, P8, C9, D4	February, April, November, December	5,178
Limnodrilus hoffmeisteri	Tubificidae worm	Unknown; cosmopolitan	D24, D16, D28A, P8, C9, D4, D7	November, December	4,934

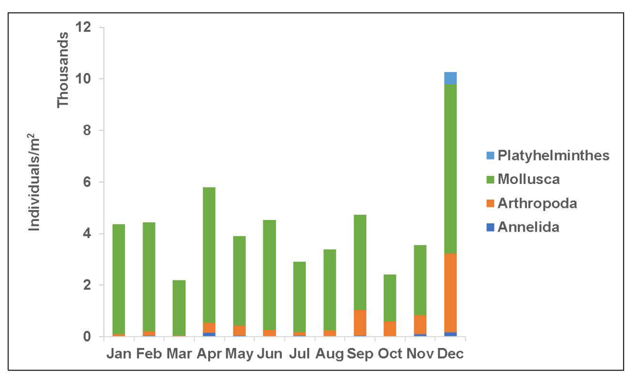
[a]For each species, stations are listed in order from highest to lowest total annual abundance.

[b] Total number of individuals was the sum of individuals at all sites at all months in 2018.

North Delta (D24)

D24 is located on the Sacramento River, just south of the Rio Vista Bridge (Figure 1). The sediment at this station was almost entirely sand with shells throughout 2018, and there were a total of 31 species in five phyla at D24. Mollusca was the most abundant phylum for much of the year and made up 84% of all organisms collected (Figure 2). Virtually all (97%) of the mollusks found at D24 in 2018 were *Corbicula fluminea*, which was consistent through much of the year before reaching a high of 5,697 individuals/m^2 in December. Arthropoda accounted for 13% of all individual organisms collected. *Gammarus daiberi* made up 78% of all arthropods at D24, with an annual average density of 455 individuals/m^2. The oligochaete worm *Varichaetadrilus angustipenis* was the most abundant annelid, with a peak average density of 149 individuals/m^2 in December. Over the last several years, *C. fluminea* density decreased from annual densities of 2,329 individuals/m^2 in 2012 to 540 individuals/m^2 in 2016, with a significant increase in density at the end of 2018. Additionally, there was a significant increase in the most abundant arthropod, *G. daiberi*, from 2017 to 2018. Otherwise, the benthic community found at D24 in 2018 was similar in species composition to other years over the last decade.

Figure 2. Density of benthic organisms, grouped by phylum, collected at station D24 (Sacramento River at Rio Vista) by month in 2018. Very rare phyla (defined fewer than 20 individuals total for the year) were omitted from this figure.

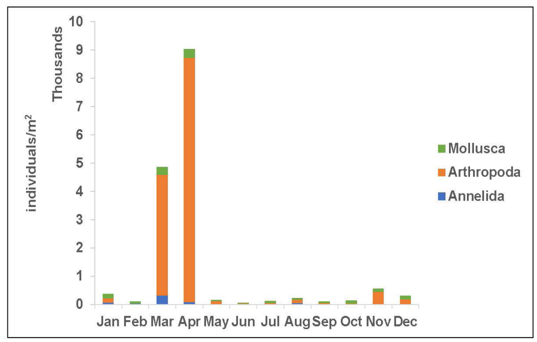


Central Delta (D16, D28A)

The benthic monitoring program sampled at two stations in the central Delta. D16 is located in the lower San Joaquin River near Twitchell Island (Figure 1). In 2018, the substrate composition of D16 was mostly sand, with the addition of shells and shell hash from September to December. There were 31 species in six phyla at D16 in 2018. Arthropoda was the most abundant phylum, especially in March and April, and made up 87% of all organisms collected through the year (Figure 3). The most abundant arthropods at D16 in 2018 were *Americorophium spinicorne* (peaking in April at 6,486 individuals/m^2, over eight times its annual average density), *Gammarus daiberi* (with peaks in April at 1,553 individuals/m^2, six times its annual average density, and in November at 423 individuals/m^2), and *Americorophium stimpsoni* (peaking in April at 591 individuals/m^2, six times its annual average density). Mollusks made up 8% of all organisms collected and *Corbicula fluminea* was by far the most abundant, making up 93% of mollusks collected at D16 and peaking at an average density of 288 individuals/m^2 in April, just over three times its annual average density. Except for dramatic peaks in *A. spinicorne* in 2016 and 2018, the community composition at D16 has remained largely consistent through the last decade.

D28A is located in Old River near Rancho Del Rio (Figure 1). The substrate at this station generally consisted of fine sand with clay or silt, and large quantities of vegetative material in some months. In 2018, there were 128 species in six phyla at D28A, and the most abundant phyla were Arthropoda (46% of all individual organisms) and Annelida (43% of all individual organisms) (Figure 4). The most abundant arthropod was the ostracod *Cyprideis sp. A*, with an annual average density of 2,580 individuals/m^2 and a peak density in December at 15,317 individuals/ m^2, six times its annual average density. The amphipod *G. daiberi* was the second most abundant arthropod with an annual average density of 784 individuals/m^2 with a peak density of 4,255 individuals/m^2 in September, five times its annual average density. The most abundant annelids were the polychaete worm *Manayunkia speciosa*, which had an annual average density of 1,399 individuals/m^2 and a notable peak average density in December at 9,413 individuals/m^2, and the oligochaete worm *Varichaetadrilus angustipenis*, with an annual average density of 1,392 individuals/m^2 and a peak density in April at 6,168 individuals/m^2 and in September at 4,101 individuals/m^2. Between 2012 and 2014, there were increases in the densities of *Cyprideis* sp. A, the amphipods *A. spinicorne* and *G. daiberi*, *V. angustipenis*, and *M. speciosa*, with decreases afterwards in all of these. There was no clear pattern of community composition at D28A according to wet or dry years.

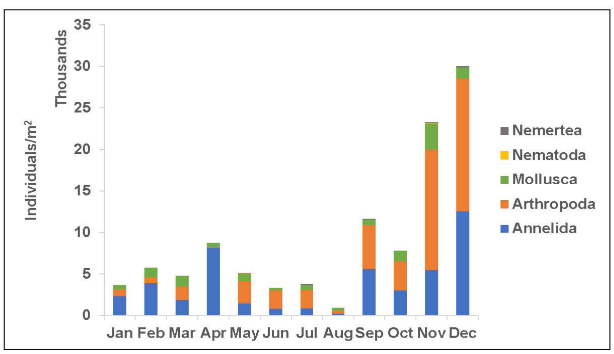
Figure 3. Density of benthic organisms, grouped by phylum, collected at station D16 (San Joaquin River at Twitchell Island) by month in 2018. Very rare phyla (defined as fewer than 20 individuals total for the year) were omitted from this figure.



South Delta (P8, C9)

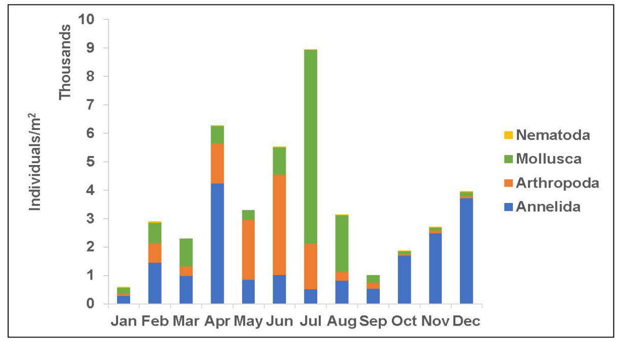
The benthic monitoring program sampled at two stations in the southern Delta. P8 is located on the San Joaquin River at Buckley Cove (Figure 1). The substrate was generally made up of clayey sand or sandy clay with some organic material. P8 had a total of 55 species in six phyla, and Annelida was the most abundant phyla at this station in 2018, accounting for 44% of all organisms collected (Figure 5). The dominant annelids were *M. speciosa*, which made up 42% of all annelids in 2018 and peaked in April with an average density of 3,563 individuals/m^2 (5 times its annual average density), and *Limnodrilus hoffmeisteri*, which peaked in December with an average density of 1,202 individuals/m^2. Mollusca made up 31% of all organisms collected at P8. *Corbicula fluminea* was by far the most abundant, making up 85% of mollusks collected and peaking at 6,380 individuals/m^2 in July, over seven times its annual average density. Arthropoda made up 25% of all organisms collected at P8. The most abundant arthropods were *Americorophium stimpsoni* (peaking in June with 2,322 individuals/m^2, over four times its annual average density), and *Americorophium spinicorne* (also peaking in June with 635 individuals/m^2, over four times its annual average density). Over the last decade, *Manayunkia speciosa* experienced a dramatic increase in density between 2012 and 2015 before declining sharply between 2016 and 2018. *Corbicula fluminea* in 2018 reached the highest density it has seen at this station since 2008.

Figure 4. Density of benthic organisms, grouped by phylum, collected at station D28A (Old River) by month in 2018. Very rare phyla (defined as fewer than 20 individuals total for the year) were omitted from this figure.



C9 is located at the Clifton Court Forebay intake (Figure 1). The substrate was primarily varying proportions of sand and clay throughout the year. There were 78 species in seven phyla at C9 in 2018. Annelida was the dominant phylum throughout the year, accounting for 67% of all organisms collected in 2018 (Figure 6). The most abundant annelids were *V. angustipenis* (annual average of 2,206 individuals/m^2 with a peak of 3,740 individuals/m^2 in September), *L. hoffmeisteri* (annual average of 1,062 individuals/m^2), and *Ilyodrilus frantzi* (annual average of 935 individuals/m^2). Arthropoda made up 23% of all

Figure 5. Density of benthic organisms, grouped by phylum, collected at station P8 (San Joaquin River at Buckley Cove) by month in 2018. Very rare phyla (defined as fewer than 20 individuals total for the year) were omitted from this figure.



organisms collected. The most abundant arthropod was *Hyalella* sp. A (59% of all arthropods, peak density of 5,433 individuals/m^2 in May, six times the annual average density). Mollusca made up 10% of all organisms collected. The snail Physa sp. A was by far the most abundant making up 79% of mollusks collected at C9, peaking at 4,293 individuals/m^2 in April, eight times its annual average density. *Limnodrilus hoffmeisteri* and *V. angustipenis* each had a peak in 2011, with annual average densities about three times their 2018 densities. Several species at C9, notably *L. hoffmeisteri*, *Aulodrilus pigueti*, *M. speciosa*, and *A. spinicorne*, experienced a decline in average densities from 2017 to 2018.

Confluence (D4)

D4 is located near the confluence of the Sacramento and San Joaquin Rivers, just above Point Sacramento (Figure 1). The sediment composition at D4 was primarily clay with sand, with high levels of organic matter found in some months. There were 56 species in six phyla at D4 in 2018. Anthropoda (47% of all individual organisms through the year) was the most abundant phylum, followed by Annelida which made up 43% of all organisms (Figure 7). *Americorophium spinicorne* was the most abundant arthropod at this station (53% of all arthropods, annual

Figure 6. Density of benthic organisms, grouped by phylum, collected at station C9 (Clifton Court) by month in 2018. Very rare phyla (defined as fewer than 20 individuals total for the year) were omitted from this figure. No samples were collected at C9 in March.

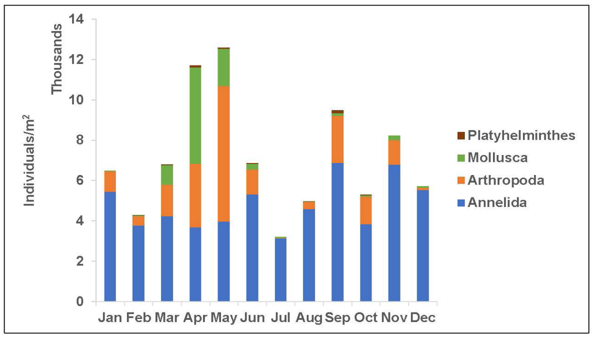
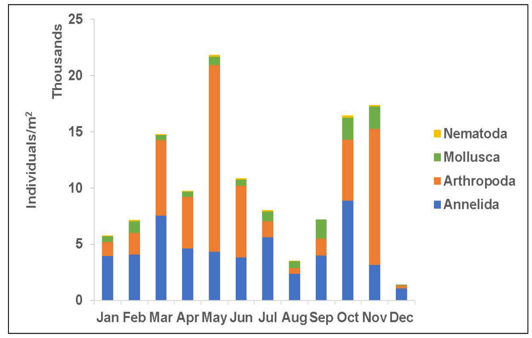


Figure 7. Density of benthic organisms, grouped by phylum, collected at station D4 (Confluence) by month in 2018. Very rare phyla (defined as fewer than 20 individuals total for the year) were omitted from this figure.



average density of 2,584 individuals/m^2), with large peak densities in May of 11,673 individuals/m^2, and in November of 7,966 individuals/m^2. *Gammarus daiberi* was the next most abundant arthropod, with an annual average density of 1,410 individuals/m^2 and a peak in November of 3,913 individuals/m^2 (Figure 7). *Varichaetadrilus angustipenis* was the most abundant annelid (73% of all annelids, annual average density of 3,287 individuals/m^2) followed by *Marenzelleria neglecta* (annual average density of 366 individuals/m^2). *Corbicula fluminea* made up 86% of all mollusks collected, with a peak density in October of 1,798 individuals/m^2. *Americorophium spinicorne* experienced a sharp decline in density at D4 from a decade high of 7,871 individuals/m^2 in 2013 to a decade low of 159 individuals/m^2 in 2015, but returned to higher counts by 2017.

Suisun Bay (D6 and D7)

The benthic monitoring program sampled at two stations in the Suisun Bay area. D6 is located in Suisun Bay near the I-680 bridge (Figure 1). The substrate at D6 was consistently clay with shells, and D6 had 23 species in four phyla in 2018. Mollusca was by far the dominant phylum in all months at this station (Figure 8), accounting for 99% of all organisms collected. The invasive Asian clam *Potamocorbula amurensis* made up >99.9% of all mollusks collected with an annual average density of 17,341 individuals/m^2, reaching a peak density of 35,769 individuals/m^2 in January. Most of the remaining organisms were species of arthropods, the isopod *Synidotea laevidorsalis* being the most abundant with an annual average density of 81 individuals/m^2, reaching peak density in December at 351 individuals/m^2. The cumacean crustacean *Nippoleucon hinumensis* experienced a peak density of 529 individuals/m^2 in April. *Potamocorbula amurensis* experienced a two-fold increase from 2017 to 2018 and reached the highest density recorded at this site in the last decade. D6 has the highest average density of invasive clams among all of our sites. Densities of both *P. amurensis* and *N. hinumensis* densities dropped during the wet years 2011 and 2017 while the spionid worm *Marenzelleria neglecta* and *G. daiberi* densities increased during these wet years.

Figure 8. Density of benthic organisms, grouped by phylum, collected at station D6 (Suisun Bay) by month in 2018. Very rare phyla (defined as fewer than 20 individuals total for the year) were omitted from this figure.

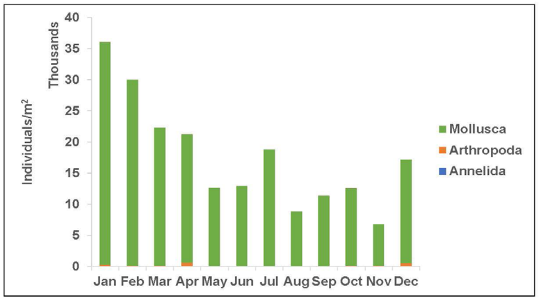
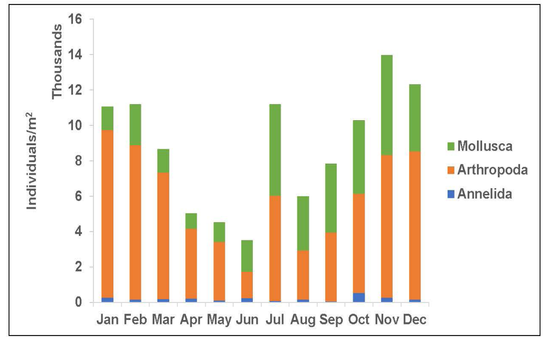


Figure 9. Density of benthic organisms, grouped by phylum, collected at station D7 (Grizzly Bay) by month in 2018. Very rare phyla (defined as fewer than 20 individuals total for the year) were omitted from this figure.



D7 is located in Grizzly Bay, near Suisun Slough (Figure 1). The substrate at D7 contained some organic matter and was uniformly clay or clay with shells. There were 28 species in five phyla in 2018. Arthropods made up 65% of all organisms counted at D7 and mollusks made up 32%. *Corophium alienense* made up 96% of all arthropods with an annual average density of 5,526 individuals/m^2 and a peak density of 9,452 individuals/m^2 in January. *Potamocorbula amurensis* made up 99% of all mollusks found at D7, with an annual average density of 2,830 individuals/m^2, with peaks in July and November of 5,135 individuals/m^2 and 5,601 individuals/m^2 respectively. *Potamocorbula* density generally increased through 2018 (Figure 9). Similar to the pattern seen D6, *P. amurensis* densities declined at D7 in wet years 2011 and 2017 and dramatically peaked in 2014, a critical dry year. In contrast, the amphipods *A. stimpsoni*, *G. daiberi*, and *A. spinicorne* each had notable peaks in wet years but were not found during 2014, a critical dry year.

San Pablo Bay (D41, D41A)

The benthic monitoring program sampled at two stations in San Pablo Bay. D41 is located near Point Pinole (Figure 1) and has a benthic community primarily comprised of marine organisms, especially in drier water years. The substrate at this station primarily consisted of clay with shell debris throughout the year. There were 68 species in eight phyla at D41 in 2018, and Arthropoda was the most abundant phylum at D41, accounting for 92% of all organisms collected (Figure 10). The dominant arthropod at D41 was *Ampelisca abdita* (96% of all arthropods), which had an annual average density of 11,137 individuals/m^2 with a large peak density of 37,990 individuals/m^2 in July. *Ampelisca abdita's* annual average density increased from 83 individuals/m^2 in 2017 to 11,137 individuals/m^2 in 2018. Meanwhile, after having low to zero density over the past decade, the invasive clam *P. amurensis* dramatically peaked in 2017 at 3,762 individuals/m^2 and dropped back to 0 individuals/m^2 in 2018, possibly as a result of the very wet water year in 2017 lowering the salinity in San Pablo Bay enough to make it more habitable by *P. amurensis*.

Figure 10. Density of benthic organisms, grouped by phylum, collected at station D41 (San Pablo Bay) by month in 2018. Very rare phyla (defined as fewer than 20 individuals total for the year) were omitted from this figure.

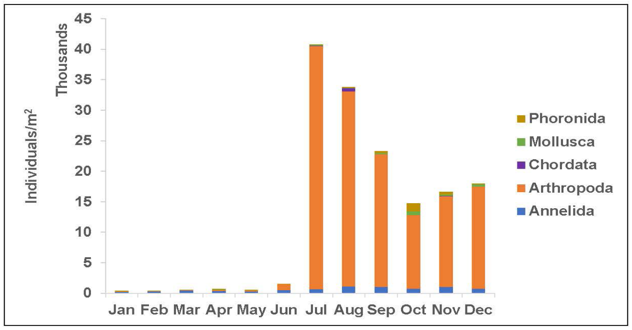
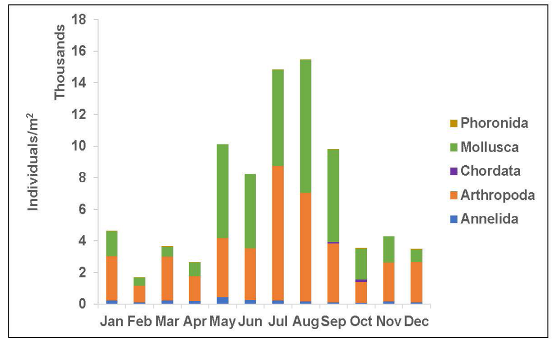


Figure 11. Density of benthic organisms, grouped by phylum, collected at station D41A (San Pablo Bay) by month in 2018. Very rare phyla (defined as fewer than 20 individuals total for the year) were omitted from this figure.



D41A is located in San Pablo Bay near the mouth of the Petaluma River (Figure 1). The substrate at this station was primarily clay with shells and organic debris throughout the year. There were 40 species in five phyla at D41A in 2018, and the most abundant phyla were Arthropoda (49% of all organisms) and Mollusca (47% of all organisms) (Figure 11). The dominant arthropods were *A. abdita* (annual average density of 2,792 individuals/m^2, peak density of 8,284 individuals/m^2 in July) and *N. hinumensis* (annual average density of 480 individuals/m^2, peak density of 1,115 individuals/m^2 in May), which made up 83% and 14% of Arthropoda, respectively. The dominant mollusk was *P. amurensis* which made up 94% of all mollusks collected at D41A, with an annual average density of 3,059 individuals/m^2 and a peak density of 8,005 individuals/m^2 in August. The annual average density of *A. abdita* significantly dropped from 2008 to 2011. In 2017, its density dropped to the lowest recorded during the previous decade, and increased in 2018 back up to levels comparable to 2011-2016.

Conclusions

In summary, 2018 saw increases from 2017 in invasive clams at some locations (*C. fluminea* at D24 and P8, *P. amurensis* at D6) and decreases at others (*C. fluminea* at D16, *P. amurensis* at D41). The changes in *P. amurensis* densities are likely due to the contrast between the wet water year of 2017 with the below normal water year in 2018, but it is not clear why samples from all sites in 2018 had almost twice as many total *C. fluminea* individuals than in 2017. Other notable features of 2018 were the increase in amphipods *A. abdita* at D41 and *A. spinicorne* at D16, and the continued decrease in *M. speciosa* at P8 from its peak in 2015. Our ability to recognize these changes highlight the importance of monitoring benthic invertebrates to a high taxonomic resolution across the entire estuarine salinity gradient, since the benthic invertebrate community provides both a record of the influence of abiotic conditions as well as a key part of the estuarine food web.

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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

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