Interagency Ecological Program for the San Francisco Estuary

IEP NEWSLETTER

VOLUME 29, NUMBER 2, 2016

Of Interest to Managers

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This issue of the Interagency Ecological Program (IEP) Newsletter features one Methods Comparison article and seven Status and Trends articles providing updates on a diverse set of IEP monitoring programs.

In the Methods Comparison article, **Tiffany Brown** (DWR) provides an analysis comparing phytoplankton processing methods from the Environmental Monitoring Program (EMP). In 2008, the EMP changed its enumeration method for phytoplankton samples from counting a minimum number of microscope fields to counting a minimum number of organisms. Results indicate that the new method is succeeding in reducing variability in counts, with differences in counts between the two methods minimally significant. Taxonomic diversity indices also showed no difference between community composition between the two methods, allowing the EMP to retain continuity with the historical data.

In the first Status and Trends article, **Sarah Finstad** (DFW) and **Randy Baxter** (DFW) use data from five of IEP's long-term monitoring programs to present long-term trends in abundance and distribution for six species (American Shad, Threadfin Shad, Delta Smelt, Longfin Smelt, Splittail, and age-0 Striped Bass). Additionally, the article calculates an expanded index for Summer Townet and Fall Midwater Trawl which incorporates data from newer North Sacramento-San Joaquin Delta (Delta) stations. These areas were found to be particularly beneficial for Threadfin and American shad, juvenile Delta Smelt, and age-0 Striped Bass.

In the second Status and Trends article, **Lauren Damon** (DFW) presents a summary of the 2016 Spring Kodiak Trawl (SKT) survey. The 2016 SKT saw the lowest recorded catch of Delta Smelt (n = 59) in its history. The survey also caught 26 young of the year Delta Smelt at the end of the season, a rare event given that the gear targets adult smelt, and a hypothesis is proposed that this observation is a result of early spawning and high growth following warmer water temperatures.

In the third Status and Trends article, **Brian Mahardja** (DWR) and coauthors provide a WY2015 update for the Yolo Bypass Fish Monitoring Program (YBFMP). WY2015 saw record drought in the system, and the Yolo Bypass did not see any floodplain inundation during the reporting period. The drought affected catch such that the YBFMP saw decreased catches of juvenile Chinook Salmon and White Sturgeon. Nevertheless, the YBFMP saw elevated catches of Delta Smelt, continuing a recent trend of increased presence in the Toe Drain of the bypass. Catches of White Catfish are highlighted, as this species was caught in record numbers during WY2015.

In the fourth Status and Trends article, **Trishelle Tempel** (DFW) provides a 2016 annual update on the 20-mm survey, which samples young of the year fishes during the spring. Most Delta Smelt larvae were caught in the North Delta, with 65 percent captured in the Sacramento Deepwater Ship Channel. Potentially a result of slightly improved drought conditions, catches for Delta Smelt increased from the previous year, with the 20-mm index equaling 0.7. Delta Smelt were also collected in the Napa River for the first time since 2012.

In the fifth Status and Trends article, **Trishelle Tempel** (DFW) presents the 2016 update for the Smelt Larva Survey (SLS). The SLS samples larval fishes from January through March, mainly targeting larval Longfin Smelt. In 2016, Longfin Smelt were caught in 47 percent of tows with 739 larvae collected, a record low catch for the survey.

In the sixth Status and Trends article, **Betsy Wells** (DWR) and **Andrew Tran** (DWR) provide an update on the Environmental Monitoring Program's benthic monitoring study for 2015. Possibly a result of drought conditions, the monitoring program found eight new species, primarily in San Pablo Bay. Sampling for 2015 collected specimens from nine phyla and 201 species. The report provides region-specific updates on catch.

In the final Status and Trends article, **Mary Xiong** (DWR) and **Tiffany Brown** (DWR) present data on 2014–2015 phytoplankton community composition. The Environmental Monitoring Program phytoplankton sampling survey collects, identifies, and enumerates phytoplankton from across the estuary. Results show that the phytoplankton community in 2014–2015 was dominated by cyanobacteria and was much less diverse compared to pre-drought years. Changes in biovolume indicate that while cyanobacteria counts were high, the available biomass for the higher trophic levels was low. Cyanobacteria, in general, are poor quality food for zooplankton, relative to other phytoplankton.

Methods Comparison

A Comparison of Different Phytoplankton Counting Methods

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Introduction and Background

Phytoplankton are small, free-floating organisms that occur as unicellular, colonial, or filamentous forms (Horne and Goldman 1994). Phytoplankton can affect water quality parameters, such as acidity (pH); dissolved oxygen; color, taste, and odor; and under certain conditions, some species can develop noxious blooms that result in animal deaths and human illness (Gannon and Stemberger 1978; Carmichael 1981; van den Hoek et al. 1995). In the ocean, phytoplankton occupy the base of the food web and play a vital role in the global carbon cycle and net primary production (Vuorio et al. 2007; Karlson et al. 2010). The short life cycles of phytoplankton allow them to respond quickly to environmental changes (Paerl et al. 2007). This attribute makes phytoplankton community composition a more important indicator for changing water quality conditions than either nutrient or chlorophyll concentrations alone (Willen 2001; Domingues et al. 2008). And so, their standing crop and species composition are indicative of the quality of the water in which they are found (American Public Health Association, American Waterworks, and Water Environmental Federation 2012). Phytoplankton communities are sensitive to human-induced impacts to the environment, such as eutrophication and climate change. As a result, analyses of phytoplankton can serve as an effective approach to understanding and predicting environmental change (Karlson et al. 2010).

Phytoplankton are an important biological component of any water quality monitoring program (Willén 2001), and have a long history of use for assessing water quality (Padisák et al. 2006). They are useful for assessing the status of eutrophication (Chapman 1996; Anderson et al. 2006; Tas et al. 2009), detecting ecological change (Paerl et al. 2007; Domingues et al. 2008; Tas et al. 2009; Nõges et al. 2010), and as biological indicators, particularly diatoms (Reid et al. 1995; Chapman 1996; de la Rey et al. 2004). Because of their fast population responses to changing water quality conditions, phytoplankton are an effective tool for evaluating changes in environmental stressors (Domingues et al. 2008) and short-term impacts (Nõges et al. 2010). They are directly affected by physical and chemical factors (Nõges et al. 2010) and can undergo significant changes during individual years (Padisák et al. 2006).

Because of their high species-richness and sensitivity to environmental factors, phytoplankton are widely used as an important water quality indicator (Nõges et al. 2010). Yet, phytoplankton communities remain underutilized when evaluating long-term ecosystem change and success of restoration efforts (Cairns Jr. et al. 1996). They are good indicators of the trophic state of a system (Anderson et al. 2006; Nõges et al. 2010) and are relatively cost-effective for long-term monitoring of environmental trends (Cairns Jr. et al. 1996). For any water quality monitoring program, appropriate strategies must be selected in relation to its objectives (Chapman 1996), and the monitoring of changes in the phytoplankton community requires a high level of taxonomic expertise (Cairns Jr., et al. 1996). For long-term monitoring programs, certain simplifications in counting and analysis can implemented without much loss of information (Cairns Jr., et al. 1996).

The Utermöhl method (Utermöhl 1958) has become the worldwide standard for quantitative phytoplankton analysis, because it allows phytoplankton to be identified, enumerated, and measured for biovolume (Paxinos and Mitchell 2000; Karlson et al. 2010). It is increasingly useful as phytoplankton abundance decreases, because most organisms will settle out because of the gravitational sedimentation employed by the method (Lund et al. 1958; Willén 1976; Paxinos and Mitchell 2000; Karlson et al. 2010). The Utermöhl method also spares organisms from mechanical damage caused by the centrifuging and filtration used in other methods (Hobro and Willen 1977). Since the Utermöhl method has stayed relatively unmodified since its inception, it allows results from phytoplankton analyses to be compared from different locations (Hobro and Willén 1977; Paxinos and Mitchell

2000). Still, quantitative analyses of phytoplankton remain complicated to perform (Vuorio et al. 2007), and no single method of estimating algal populations is appropriate for all circumstances and purposes (Lund et al. 1958). Deciding how many organisms to count will depend on the purposes of the particular study and what is considered an acceptable error rate at a given level of confidence (Lund et al. 1958; Willén 1976; Hobro and Willén 1977; Karlson et al. 2010). Statistically valid targets for organism counts are still a major subject of standardization, and the required minimum effort per sample for a given precision level is still under discussion (Rott et al. 2007). The precision of counts must also be balanced with the time it takes to analyze a sample; decreasing the error rate from ±20 percent to ±10 percent requires four times as many organisms be counted (Lund et al. 1958; Hobro and Willén 1977; Karlson et al. 2010). Counting too few algae increases the error rate of the counts, and counts below 10 organisms are expected to have a high error rate (Rott 1981).

The California Department of Water Resources (DWR) and the U.S. Bureau of Reclamation are required by Water Right Decision 1641 to collect phytoplankton and chlorophyll-*a* samples in order to monitor algal community composition and biomass at selected sites in the upper San Francisco Estuary. The sampling sites range from San Pablo Bay east to the mouths of the Sacramento, Mokelumne, and San Joaquin rivers, with two "floating" stations located where bottom electrical conductance is 2,000 microSiemens per centimeter (µS/cm) and 6,000 µS/cm, +/-10 percent. These sites represent a variety of aquatic habitats, from narrow, freshwater channels in the Sacramento-San Joaquin Delta (Delta) to broad, estuarine bays. DWR's Environmental Monitoring Program (EMP) has conducted this monitoring since the 1970s.

In order to reduce the error and variability in counting a sample, the EMP modified its phytoplankton enumeration protocol in 2008 to more closely reflect the methods outlined in American Public Health Association (APHA) Standard Methods 2012. The APHA 2012 Standard Methods describe different microscopy techniques for the examination of phytoplankton, but suggests that for the inverted microscope method, natural units should be counted (single cells, filaments, or colonies). It also suggests that microscope counts should be at least 300–400 natural units, 100 of which being the dominant genus or species (American Public Health Association, American Waterworks, and Water Environmental Federation 2012). The goals of this study were to explore and document the differences in counts recorded using these two methods (the historical method from pre-2008 and the current, post-2008 method). For those reasons, we examined:

- How many times the historical method reached the targeted number of organisms (100 of major taxon and 300–400 total).
- Whether any statistical differences could be detected in assemblage between the two methods.
- The relative differences in species diversity or uniformity between the two methods.

Methods

Study Area

The San Francisco Estuary (Estuary) is the largest estuary in the western United States and carries runoff from 40 percent of California's surface area (Nichols et al. 1986). Of the major estuaries in the United States, it is considered the most modified by human activity (Nichols et al. 1986; San Francisco Estuary Institute 2014), and it is also the estuary most invaded by non-native species, worldwide (Cohen and Carlton 1998). 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* (Carlton et al. 1990; Nichols et al. 1990; Alpine and Cloern 1992; Jassby 2008; Greene et al. 2011; Lucas et al. 2016). 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, which has been measured in these western bays since the mid-1980s (Carlton et al. 1990; Nichols et al. 1990; Alpine and Cloern 1992; Jassby 2008; Greene et al. 2011; Lucas et al. 2016).

Historically, phytoplankton samples have been collected once or twice per month at 11–25 stations. The study area currently consists of 15 sites that are sampled monthly (Figure 1); the two floating stations are not shown because of their variable location. Phytoplankton samples are collected with a submersible pump from a water depth of 1 meter (approximately 3 feet) below the water surface. Samples are stored in 60-milliliter glass

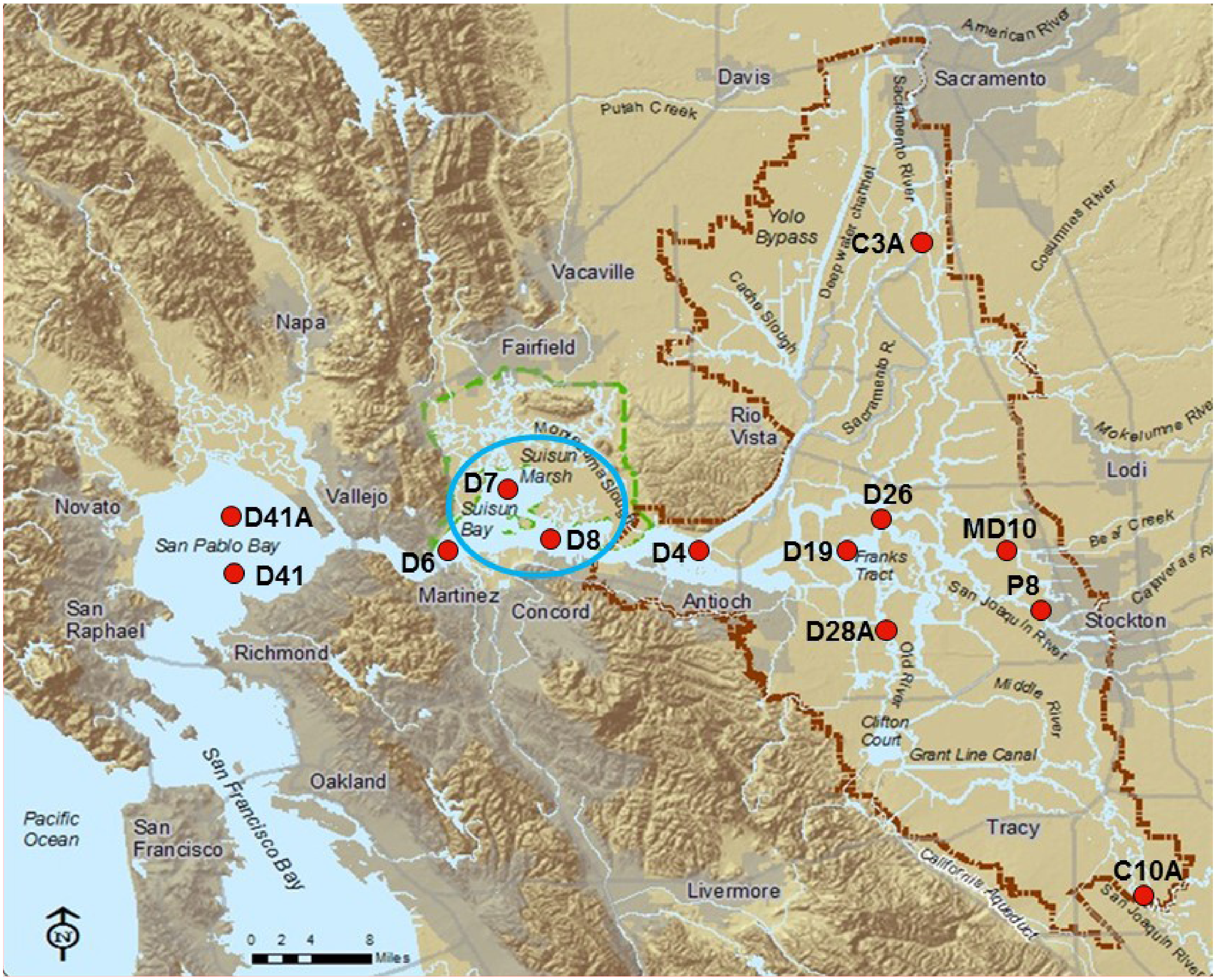

Figure 1. Map of EMP phytoplankton monitoring stations. Stations used for analyses are circled in blue.

bottles. Two milliliters (mL) of Lugol's solution are added to each sample as a stain and preservative. All samples are kept at room temperature and away from direct sunlight until analyzed.

Laboratory Methods

Historical Method (Pre-2008)

Prior to 2008, phytoplankton identification and enumeration were performed at DWR's Bryte Laboratory using the Utermöhl microscopic method (Utermöhl 1958) and modified Standard Methods (American Public Health Association, American Waterworks, and Water Environmental Federation 2012). An aliquot was placed into a counting chamber and allowed to settle for 15 hours, minimum. The aliquot volume, normally 10 mL, was adjusted according to the algal population density and turbidity of the sample. Samples were viewed using a Wilde M-40 inverted microscope, and magnification ranged from 280x to 750x (Lehman 1996). Phytoplankton were enumerated in a Whipple ocular micrometer grid for each settled aliquot. Either 20 random fields, considered the minimum number to count (Rott 1981), were counted, or the number of fields necessary to reach more than 100 units of the dominant taxon were counted, whichever came first (Weber pers. comm.). This modification was deemed necessary because of high turbidity of the samples and extremely low algal numbers.

Current Method (Post-2008)

Beginning in 2008, the enumeration protocol was modified to more closely reflect the methods outlined in APHA 2012 Standard Methods. A minimum of 300–400 algal units are counted, with at least 100 of those units being from the dominant taxon (genus or species). This change is expected to reduce error and variability within a sample when compared with the historical method. The number of fields counted depends on when the target number of counted organisms is reached.

For this comparison, all samples were counted by BSA Environmental Services, Inc., using a Leica DMIL inverted microscope at 800x magnification. The settled aliquot volume, field-of-view, and slide area of the counting chamber were the same for all samples being compared using the two methods; only the number of fields counted would differ between the two methods.

Stations for Analysis and Comparison Protocol

Stations D7 and D8 in Suisun Bay (circled in blue in Figure 1) were selected for this analysis. These stations are considered important because they have been sampled for the entire period of record, and because of Suisun Bay's significance as fish habitat, particularly for Delta Smelt (Moyle 2002). Each station's data was analyzed separately because of differing physical conditions at each site; D7 is a shallow embayment, while D8 is a deep channel with higher flow. From each monthly sample at each station, two subsamples were taken. One subsample was counted using the historical method, counting 20 fields because this was the number of fields most often counted. The other subsample was counted using the current method. For D7, analysis was done for monthly samples from January–November 2014. The December 2014 sample from D7 could not be analyzed because it was frozen during shipment to the phytoplankton contractor. For D8, monthly samples from January–December of 2014 were analyzed.

Statistical Analyses

Count Targets using Historical Method

The primary difference between the methods described in this article is the number of fields counted. As a result, raw count data were used for all statistical analyses. For the historical method, count data were examined to see if the target counts of 100 units of the dominant taxon and 400 units were reached.

Statistical Differences in Taxon Assemblage

To assess if the two methods had significant differences in their taxonomic assemblages, count data for all taxa were compared between the two methods using a 1-way analysis of similarities (ANOSIM) test in the Plymouth Routines In Multivariate Ecological Research (PRIMER) software package (Clarke 1993; Clarke and Warwick 2001). The ANOSIM R statistic is scaled to lie between -1 and 1, with most values between 0 and 1 (Clarke and Warwick 2001). Values near 0 meant that there are no differences between groups, while values near 1 meant the groups are completely separate (Clarke and Warwick 2001). If significant differences were found between the two methods, a similarity percentage (SIMPER) analysis was performed using PRIMER to determine which taxa were responsible. This routine breaks down Bray-Curtis dissimilarities between sample matrices to determine the contribution from each species to the observed differences between the groups of samples.

Relative Differences in Species Diversity and Richness

To assess the relative species richness and diversity between the two methods, three diversity indices were calculated for each method.

1. The total number of species S.
2. The Shannon diversity index as given in the following equation,

$$H' = -\sum_i p_i \log(p_i),$$

where p_i is the proportion of the total count arising from the i^{th} species.

3. Margalef's index as given in the following equation,

$$d = (S - 1)/\log N,$$

where S is the total number of species, and N is the total number of individuals.

These indices are commonly used to assess species community composition and because of their different sensitivities in detecting community structure (Clarke and Warwick 2001; Bandeira et al. 2013). Specifically, the total number of species (S) accounts for all species present, but does not provide any information on the number of individuals per species. Shannon's diversity index accounts for how much an individual species contributes to the total, but is less sensitive when detecting the proportion of rare species (Bandiera et al. 2013). By including the number of individuals per species, Margalef's index is more sensitive to the overall community structure than other indices (Bandeira et al. 2013). After the indices were calculated, a one-way ANOSIM was applied to each pair of indices to see if there were significant differences in community structure between the two counting methods.

Results

Count Method Comparison

D7

All of the subsamples that were counted using the historical 20-field method reached the target counts of 100 organisms of the dominant taxon and 400 total organisms.

D8

Of the 12 subsamples counted using the historical 20-field method, all reached the target goal of 100 organisms of the dominant taxon. Eleven of the 12 subsamples also reached the target count of 400 organisms; the subsample from September 2014 was slightly less than the target goal of 400 organisms, reaching only 384 organisms.

Statistical Differences in Taxon Assemblage

D7

An ANOSIM test showed that the two methods were statistically different, but only weakly, based on the R value ($R = 0.305$, $p = 0.02$). A SIMPER test showed that the main organism responsible was the cyanobacterium *Chroococcus microscopicus* (Table 1, Figure 2), which was the dominant taxon in all the subsamples, regardless of the counting method. The 20-field method had more than double the average abundance of the minimum organism method (Table 1), but also had more variability in the counts compared with the minimum organism method (Figure 2).

D8

Like D7, an ANOSIM test showed weak significant differences between the two methods ($R = 0.340$, $p = 0.01$). Again, the SIMPER test showed that *C. microscopicus* was the primary taxon responsible, with a minor contribution from the cyanobacterium cf. *Synechococcus salinarum* (Table 2, Figures 3 and 4). *C. microscopicus* was again the dominant taxon in all subsamples, regardless of the counting method (Table 2, Figure 3). As at D7, *C. microscopicus* had more than double the average abundance in the 20-field method than the minimum organism method, and also had greater variability (Table 2, Figure 3). Also, cf. *Synechococcus salinarum* appeared more consistently in the 20-field

Table 1. D7 SIMPER results.

Groups Historical Method and Current Method				
Species	***Group Historical Method Average Abund.***	***Group Current Method Average Abund.***	***Average Dissim.***	***% Contrib.***
Chroococcus microscopicus	905.09	433.73	27.69	92.36

Note: Overall average dissimilarity = 29.98. *Average Abund.* is the average abundance of the taxon in that group. *Average Dissim.* is the average dissimilarity between the groups. *% Contrib.* is the percentage contribution of that taxon to the overall dissimilarity between the two groups.

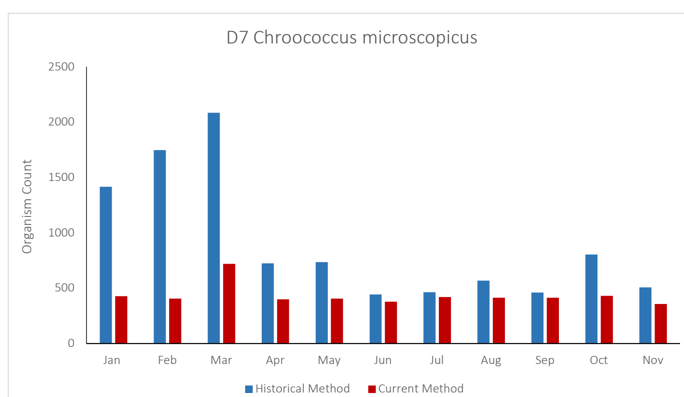

Figure 2. Monthly count totals of *Chroococcus microscopicus* at D7.

method subsamples than in the minimum organism subsamples (Figure 4).

Relative Differences in Species Diversity and Richness

D7

Table 3 lists the diversity indices that were calculated for each method; ANOSIM tests showed no significant differences in each index between the two methods. For species richness, the ANOSIM R was -0.02, p = 0.607. The ANOSIM R value for the Shannon diversity index was 0.008, p = 0.323. For Margalef's index, the ANOSIM R value was -0.009, p = 0.478.

Table 2. D8 SIMPER results.

Groups Historical Method and Current Method				
Species	***Group Historical Method Average Abund.***	***Group Current Method Average Abund.***	***Average Dissim.***	***% Contrib.***
Chroococcus microscopicus	912.33	402.67	29.31	89.11
cf. *Synechococcus salinarum*	25.17	13.75	2.04	6.21

Note: Overall average dissimilarity = 32.90. *Average Abund.* is the average abundance of the taxon in that group. *Average Dissim.* is the average dissimilarity between the groups. *% Contrib.* is the percentage contribution of that taxon to the overall dissimilarity between the two groups.

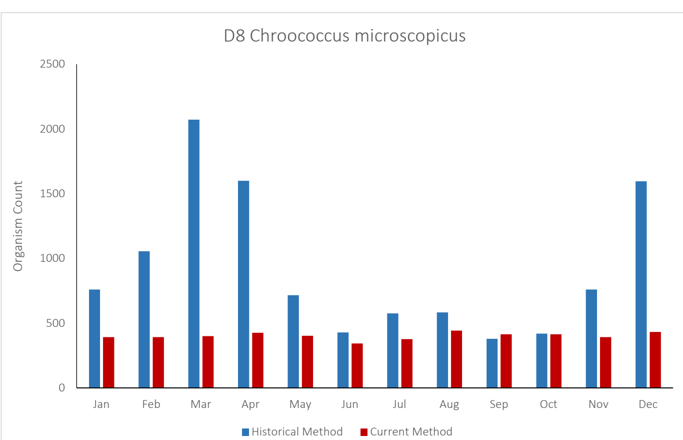

Figure 3. Monthly count totals of *Chroococcus microscopicus* at D8.

D8

Diversity indices for D8 are shown in Table 4; again, the ANOSIM tests showed no significant differences in the indices between the two methods. The ANOSIM R value for species richness was -0.038, p = 0.703. For the Shannon diversity index, the ANOSIM R value was -0.025, p = 0.633; for Margalef's index, the ANOSIM R value was -0.060, p = 0.920.

Discussion

The EMP has monitored the phytoplankton community in the San Francisco Estuary for more than 40 years, and this dataset has proven vital to tracking long-term trends and community changes. The needs and objectives of any long-term monitoring program are likely to change over time because of factors such as introduced species, regime changes, or changing needs of management. In 2008, the EMP modified its phytoplankton counting method to more closely align with APHA Standard Methods (American Public Health Association, American Waterworks, and Water Environmental Federation 2012) and to reduce variability in the counts. This analysis showed that these changes did reduce variability in the counts, especially for major taxa, and further determined significant, but weak, differences between the two counting methods.

The current protocol used by EMP is similar to many other phytoplankton community monitoring programs and studies throughout the world (Fejes et al. 2005; Hunt et al. 2010; Greene et al. 2011), but there is also some variability in protocols based on underlying goals. For

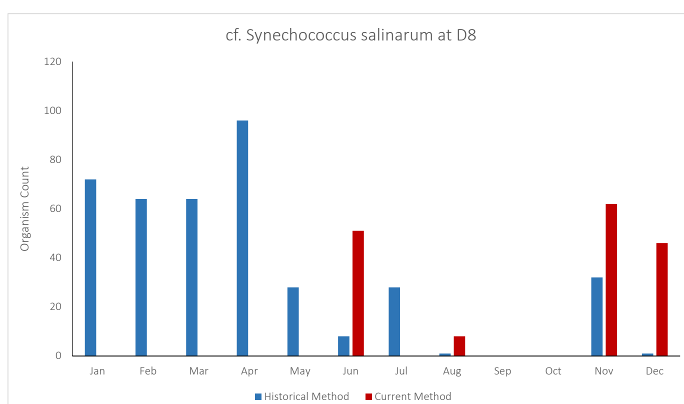

Figure 4. Monthly count totals of cf. *Synechococcus salinarum* at D8.

Table 3. D7 diversity indices.

D7 Diversity Indices					
Species Richness S		*Shannon Diversity Index H'*		*Margalef's Index d*	
S Historical Method	*S Current Method*	*H' Historical Method*	*H' Current Method*	*d Historical Method*	*d Current Method*
12	6	0.195	0.255	1.509	0.819
11	7	0.060	0.176	1.338	0.994
7	3	0.138	0.021	0.782	0.304
6	4	0.193	0.052	0.755	0.500
4	4	0.039	0.091	0.454	0.498
5	4	0.220	0.320	0.651	0.498
3	8	0.031	0.275	0.326	1.148
6	6	0.130	0.181	0.786	0.825
6	6	0.133	0.131	0.813	0.827
4	5	0.029	0.078	0.448	0.658
9	6	0.133	0.432	1.280	0.831

Table 4. D8 diversity indices.

D8 Diversity Indices					
Species Richness S		*Shannon Diversity Index H'*		*Margalef's Index d*	
S Historical Method	*S Current Method*	*H' Historical Method*	*H' Current Method*	*d Historical Method*	*d Current Method*
11	7	0.488	0.214	1.479	0.998
10	5	0.073	0.153	1.291	0.667
7	5	0.174	0.083	0.782	0.666
5	5	0.236	0.114	0.538	0.659
6	4	0.053	0.113	0.760	0.498
4	8	0.136	0.679	0.493	1.156
6	10	0.235	0.334	0.780	1.499
7	6	0.085	0.145	0.940	0.817
4	3	0.054	0.059	0.504	0.331
6	9	0.122	0.229	0.825	1.319
8	6	0.248	0.479	1.047	0.815
8	4	0.072	0.357	0.948	0.486

example, some studies seek to count a minimum number of the dominant taxon, in addition to a minimum number of total units counted (Quinlan et al. 2009; Hunt et al. 2010; Greene et al. 2011; Kimmerer et al. 2012), and other studies count a minimum number of total units with less emphasis on any one dominant taxon (Fejes et al. 2005; Panigrahi et al. 2009; Llebot et al. 2011). In addition, studies can use a combination of both a minimum number of fields and organisms counted (Rocha et al. 2002; Miller et al. 2008), similar to the EMP's historical method of counting either a minimum number of fields or organisms, depending on which goal was reached first. Each individual study or monitoring program is likely to have different protocols based on the questions being asked, and no single method of counting phytoplankton is appropriate for all water quality monitoring programs (Lund et al. 1958).

Documenting changes to a long-term monitoring program is essential (Lehman 1996; Hunt et al. 2010; Cloern and Jassby 2012), and the longer a program continues, the more likely changes will happen because of improvements in sampling, microscope equipment, and general understanding of the ecosystem. The study of temporal change is an important part of ecology, and monitoring programs will need to be "adaptively managed" (Cloern and Jassby 2012). Slow processes or changes, such as El Niño or climate change, cannot be identified without long-term monitoring and ongoing sampling (Cloern and Jassby 2012). The new counting method utilized by the EMP is more accurate and less variable, and will allow the EMP to continue monitoring changes in the phytoplankton community while retaining continuity with the historical data. The dominance of *Chroococcus microscopicus* in 2014 is not fully understood, but this is likely because of ongoing drought conditions. Droughts are likely to increase in both frequency and severity because of climate change (Mosley 2015), and these conditions are generally more favorable to cyanobacteria and other potentially harmful phytoplankton (Lehman et al. 2013; Brown et al. 2016; Dettinger et al. 2016). The EMP plans to repeat this analysis in the future with new samples taken under non-drought conditions.

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Status and Trends

2015 Status and Trends Report for Pelagic Fishes of the Upper San Francisco Estuary

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Introduction

The 2015 Pelagic Fishes Status and Trends Report uses data from five of the Interagency Ecological Program's (IEP) long-term fish monitoring surveys: (1) 20-mm Survey, (2) Summer Townet Survey (STN), (3) Fall Midwater Trawl (FMWT), (4) San Francisco Bay Study (SFBS), and (5) U.S. Fish and Wildlife Service (USFWS) Beach Seine Survey (Honey et al. 2004). Abundance indices, as well as long-term trends in abundance and distributional information, are presented for six species: American Shad (*Alosa sapidissima*), Threadfin Shad (*Dorosoma petenense*), Delta Smelt (*Hypomesus transpacificus*), Longfin Smelt (*Spirinchus thaleichthys*), Splittail (*Pogonichthys macrolepidotus*), and age-0 Striped Bass (*Morone saxatilis*). Four of these species, Threadfin Shad, Delta Smelt, Longfin Smelt, and age-0 Striped Bass, rely on the upper estuary for spawning and rearing, and have recently undergone significant population declines (Sommer et al. 2007). In addition to traditional indices, calculating and reporting "expanded" STN and FMWT indices has begun incorporating data from relatively new sampling stations in Cache Slough and the Sacramento Deepwater Ship Channel regions.

Methods

The California Department of Fish and Wildlife (CDFW) 20-mm Survey monitors distribution and relative abundance of larval and juvenile Delta Smelt throughout its historical spring range (Figure 1). This includes the entire Sacramento-San Joaquin Delta (Delta) and downstream to eastern San Pablo Bay and the lower Napa River. The survey name refers to the size of the Delta Smelt that the survey gear targets, which corresponds to the size at which Delta Smelt are readily identifiable and counted at the State Water Project and Central Valley Project fish salvage facilities. Since 1995, the 20-mm Survey has conducted surveys on alternate weeks from early March through early July, completing nine surveys per year since 2009. Three tows are conducted at each of the 47 stations (Figure 1) using a fixed-mouth, 1,600 micrometer (µm) mesh net (Dege and Brown 2004). The survey added five Napa River stations in 1996. In 2008, two stations each were added in Lindsey Slough, Miner Slough, and the Sacramento River Deep Water Ship Channel (SRDWSC). A < 60 millimeter (mm) fork length (FL) criterion is used to distinguish age-0 Delta Smelt from older fish. Lengths of age-0 fish are then averaged by survey for all stations sampled to determine when mean fork length reaches or surpasses 20 mm. The four surveys whose mean FL bound 20 mm (two surveys above and two below) are used to calculate the annual abundance index. From this subset of surveys, Delta Smelt catch per unit effort (CPUE) is calculated for each of the 41 index stations. CPUE for each tow is calculated by dividing catch by the volume (cubic meters [m^3]) filtered during the sample and then multiplying by 10,000 to obtain a whole number. CPUE is then averaged across tows for each index station. The resulting mean station CPUE values are incremented by one and then $\log_{10}$ transformed (i.e., $\log_{10}(x+1)$). These transformed values are averaged

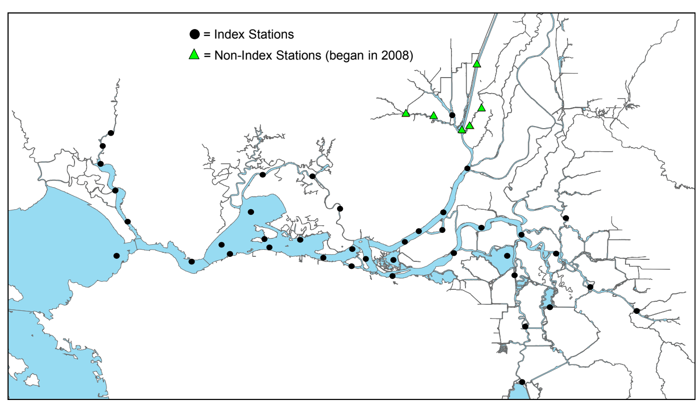


Figure 1. Map of 20-mm Survey stations.

Note: Index stations have been sampled since survey inception in 1995. Data collected at index stations are used to calculate survey and annual abundance indices. Non-Index stations were added to the survey in 2008 to better assess the distribution of Delta Smelt and other pelagic fishes.

within each survey, and then the mean values are back transformed (i.e., 10^x) to return them to their original scale. Finally, one is subtracted from each value and then these values are summed across the four surveys, to obtain the 20-mm Survey annual abundance index.

The STN began in 1959 and its data have been used to calculate age-0 Striped Bass indices for all years since, except 1966, 1983, 1995, and 2002. Delta Smelt indices have also been calculated for the period of record, except for 1966 through 1968. Historically, STN conducted between two to five surveys annually, depending on when the mean FL of age-0 Striped Bass exceeded 38.1 mm, at which time the index could be set and sampling terminated for the year. In 2003, CDFW standardized sampling to six surveys per year, beginning in early June and continuing every other week into late August (Hieb et al. 2005). STN samples 32 historic stations, one of which is located in the Napa River and is excluded from index calculations because of historically infrequent sampling. These "traditional" index stations are distributed from eastern San Pablo Bay to Rio Vista on the Sacramento River, and to Stockton on the San Joaquin River (Figure 2). In 2011, STN added eight supplemental stations in the Cache Slough and SRDWSC regions to increase spatial coverage and better describe Delta Smelt range and habitat (Figure 2). A minimum of two tows are completed at historic stations, and a third is conducted if fish of any species are caught during either of the first two tows. One tow is completed at supplemental stations, with a second conducted only if Delta Smelt catch during the first tow is less than 10.

Catch per tow data from the 31 STN index stations are used to calculate traditional annual abundance indices for age-0 Striped Bass and Delta Smelt. First, catch of a species is summed across the tows at each station. Then, the sum is multiplied by a volume-weighting factor (i.e., the estimated volume in thousand acre-feet represented by each station) (Chadwick 1964). These products are then summed across all 31 index stations within a survey, and then divided by 1000 to produce the survey abundance index. The annual abundance index for age-0 Striped Bass is interpolated using the abundance indices from the two surveys that bound the date when mean FL reached 38.1 mm (Chadwick 1964; Turner and Chadwick 1972). STN did not consistently measure Delta Smelt FL until 1973, so no length criterion is used for the Delta Smelt index calculation. Instead, the annual index for Delta Smelt is the average of the first two survey indices of each year; however, in 1996, the first survey was cut short as a result of equipment malfunction, so the index was calculated as the average of the indices for the second and third surveys.

Expanded STN indices were calculated and reported here for the first time, based on Delta Smelt and age-0 Striped Bass collected in the Cache Slough and SRDWSC regions from 2011 to 2015. Note that only one, or at most two, tows were completed at each of these new Cache Slough and SRDWSC stations (to limit Delta Smelt take), as compared with three tows typical for other traditional sampling stations; thus, sampling for these expanded indices results in a lower detection probability and perhaps a lower abundance calculation for these new regions relative to a calculation using the traditional method of three tows per station. The expanded index for Delta Smelt is calculated in the same manner as the traditional index (i.e., catch per tow summed for each station and multiplied by respective weighting factors), except these weighted station-sums are summed into regional groupings (Cache Slough stations [pink crosses] and Sacramento Deepwater Ship Channel stations [green triangles]) (Figure 2) and added to the traditional indices. These expanded indices are plotted with the Cache Slough and SRDWSC contribution on top of traditional indices in stacked bar graphs. The calculation of the expanded index for age-0 Striped Bass was slightly more involved because of the interpolation step required to calculate the

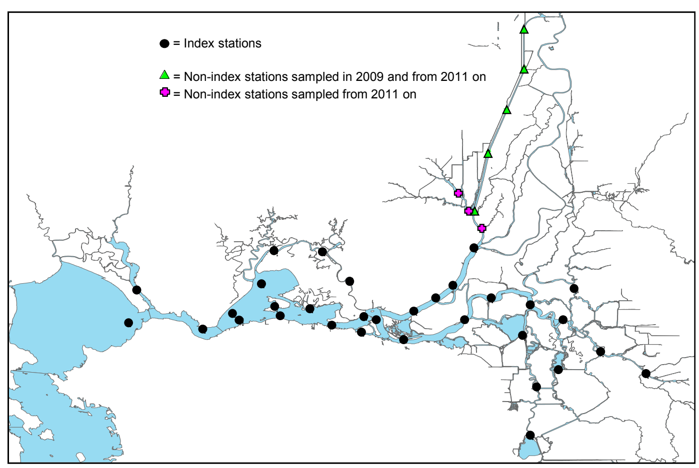


Figure 2. Map of Summer Townet Survey stations.

Note: Index stations have been sampled since survey inception in 1959, and their data are used for calculating survey and annual abundance indices. Non-index stations were added as indicated to better assess the distribution of Delta Smelt and other pelagic fishes.

annual index. Traditional individual survey indices for age-0 Striped Bass were calculated as described above for Delta Smelt. Survey indices for the Cache Slough and SRDWSC regions were calculated the same as for Delta Smelt, and then were summed with the traditional survey index prior to the interpolation step of the age-0 Striped Bass index calculation. The expanded index value for the Cache Slough and SRDWSC regions was derived as the difference, post interpolation, between the traditional (i.e, without Cache Slough and SRDWSC regional contributions) and expanded (i.e., with both Cache Slough and SRDWSC regional contributions) annual indices. When calculating expanded Delta Smelt and Striped Bass indices for the Cache Slough and SRDWSC regions, the following stations were included in the Cache Slough region: 713, 716, 719, 721, 723 (the three pink crosses and the two southernmost green triangles on Figure 2). The SRDWSC region includes these stations: 795, 796, and 797 (the three northernmost green triangles on Figure 2).

The Fall Midwater Trawl Survey (FMWT) began in 1967 and has been conducted in all years except 1974 and 1979. CDFW established the FMWT survey to examine age-0 Striped Bass relative abundance and distribution in the upper estuary (Stevens 1977). Later, FMWT developed abundance and distribution information for other upper-estuary pelagic fishes, including American Shad, Threadfin Shad, Delta Smelt, Longfin Smelt, and Splittail. The FMWT survey currently conducts single tows at 122 stations monthly, from September through December. Trawl sampling ranges from western San Pablo Bay to Hood on the Sacramento River, and from Sherman Lake to Stockton on the San Joaquin River (Figure 3). The traditional annual abundance index calculation uses catch per tow data, one tow per station, from 100 of 122 stations (Stevens 1977). The remaining 22 stations were added in 1990, 1991, 2009, and 2010 to improve understanding of Delta Smelt distribution and habitat use (Figure 3). To calculate traditional survey abundance indices, the 100 index stations are grouped into 17 regions. Monthly indices are calculated by averaging index-station catch-per-tow in each region, multiplying these regional means by their respective weighting factors (Chadwick 1964), and summing these products. Traditional annual abundance indices are the sum of the four (September–December) monthly indices. Expanded abundance indices for non-index stations in the Cache Slough and SRDWSC regions are calculated in the same way as traditional abundance indices, but reported separately for the years 2010–2015, and then plotted on top of traditional indices. When calculating expanded indices for the Cache Slough and SRDWSC regions, the following stations are included in the Cache Slough region: 713, 715, 716, 719, 721, 723 (the two northernmost orange diamonds, the adjacent single red star and pink cross, and the two southernmost green triangles on Figure 3). The SRDWSC region includes these stations: 795, 796, and 797 (the three northernmost triangles on Figure 3). Weighting factors have not yet been developed, and the Sacramento River and Mokelumne River stations (red stars, Figure 3) have not been added to the index calculation because of low detections of smelts and Striped Bass.

The San Francisco Bay Study (Bay Study) began sampling in 1980 to determine the effects of freshwater outflow on the abundance and distribution of fish and mobile crustaceans throughout the San Francisco Estuary. Sampling ranges from south of the Dumbarton Bridge in South San Francisco Bay (South Bay), to just west of Alcatraz Island in Central San Francisco Bay (Central Bay), throughout San Pablo and Suisun bays, north to the confluence of Steamboat and Cache sloughs on the Sacramento River, and east to Old River Flats on the San Joaquin River (Figure 4). The Bay Study samples every station with a single tow using two types of towed nets: an otter trawl (BSOT) to sample the demersal community and a midwater trawl (BSMWT) to sample the pelagic species. There are data gaps in this long-term sampling; most significantly, there was limited midwater trawl

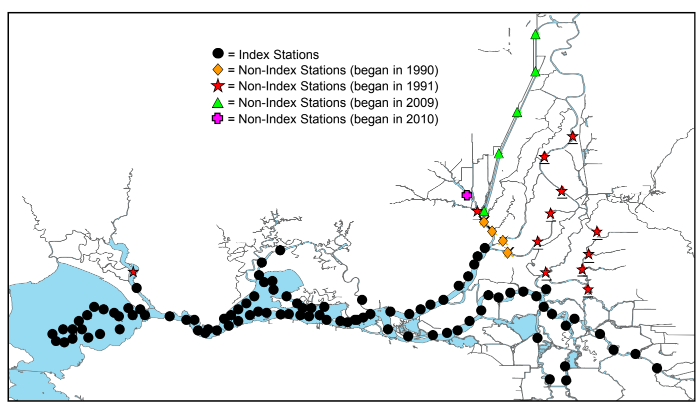


Figure 3. Map of Fall Midwater Trawl Survey stations.

Note: Index stations have been sampled since survey inception in 1967 and their data are used for calculating survey and annual abundance indices. Non-index stations were added as indicated to better assess the distribution of Delta Smelt and other pelagic fishes.

sampling in 1994, no winter sampling (November through January) from 1989 to 1997 to reduce survey costs, and limited sampling at stations in and near the confluence of the Sacramento and San Joaquin rivers in 2007 and 2008 to reduce Delta Smelt take. This most recent data gap resulted in no Bay Study Delta Smelt indices for 2007 and 2008. Of the 52 stations the Bay Study currently samples, 35 core stations (i.e., original stations) (Figure 4) have been consistently sampled since 1980 and are used to calculate the annual abundance indices. Annual abundance indices are calculated as the average of monthly indices over the period for which the life stage was most abundant (typically May through October), and only include data from Bay Study's 35 index stations (Baxter et al. 1999). Monthly indices are calculated as the product of mean CPUE at all index stations within each of the five geographical regions and that region's water volume weighting factor (for the BSMWT) or the region's areal weighting factor (for the BSOT), and then these products are summed across all 5 regions. Additional information about study methods, including index calculation, can be found in IEP Technical Report 63 (Baxter et al. 1999).

Since 1994, USFWS has conducted weekly beach seine sampling at approximately 40 stations in the Delta and in the lower Sacramento and San Joaquin rivers (Brandes and McLain 2001). Data from 33 stations are used to calculate the annual age-0 Splittail abundance index (Figure 5). These stations range from Sherman Lake to Ord Bend on the Sacramento River (not pictured), and to just downstream of the Tuolumne River confluence with the San Joaquin River (Figure 5). Hereafter, we refer to the confluence of the Sacramento and San Joaquin Rivers at Sherman Lake as "the Confluence," and the Tuolumne River confluence with the San Joaquin River as "the Tuolumne confluence." All Splittail < 25 mm FL (measured individuals and proportions resulting from plus counts) are removed from calculations. The 33 index stations are grouped into 10 regions, and the annual index is calculated as the grand average of regional mean catch per m³ for seine hauls conducted in May and June.

FMWT data were used to describe abundance trends and distribution patterns of all six fish species listed in the introduction. Bay Study data were used to describe trends for age-0 American Shad, age-0 Delta Smelt, age-0 Longfin Smelt, age-0 Splittail, and age-0 Striped Bass. STN described trends for Delta Smelt and Striped Bass. Two studies only provided single species information: the 20-mm Survey for the abundance and distribution of larval and juvenile Delta Smelt, and USFWS beach seine data for age-0 Splittail abundance and distribution.

Results

American Shad

The American Shad was introduced into the Sacramento River in 1871 (Dill and Cordone 1997). This anadromous species spawns in the Sacramento, Feather, and American rivers from April through June. Juveniles

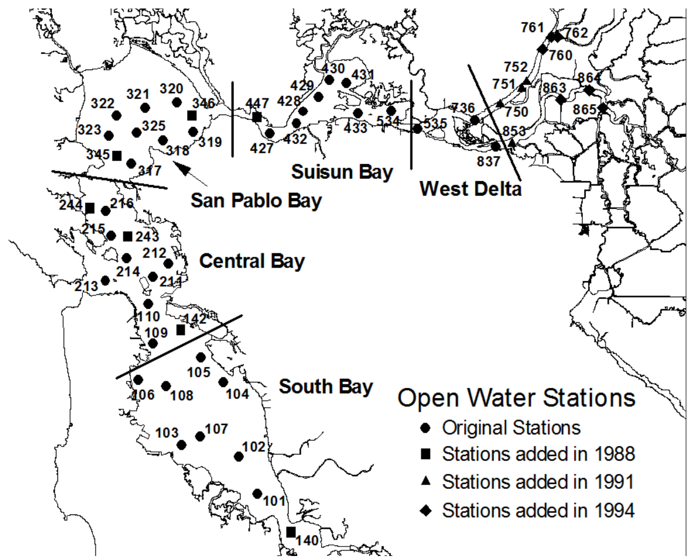


Figure 4. Map of San Francisco Bay Study stations.

Note: Index stations have been sampled since survey inception in 1980 and their data are used for calculating survey and annual abundance indices. Non-index stations were added as indicated to better assess the depth distribution of estuarine organisms (1988), and to assess use of the Delta by brackish water species during the drought (1991 and 1994).

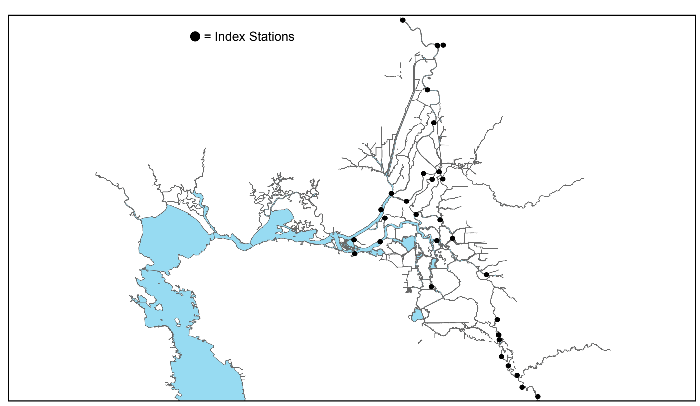


Figure 5. Map of U.S. Fish and Wildlife Service beach seine survey stations.

Note: Data from all pictured and eight non-pictured stations on the Sacramento River are used for Splittail annual abundance indices.

can be found in freshwater areas within the Delta from late May through summer and into fall. From summer through fall, juveniles migrate to the ocean where they mature. Males reach maturity at 3 to 4 years, with females maturing slightly later at 4 to 6 years (Able and Fahay 1998). A large proportion of the spawning population in the Delta succumbs to natural mortality shortly after spawning; however, spent females have been observed downstream of spawning sites, indicating some survival (Stevens 1966). Surveys conducted in the Susquehanna River, in the Northeastern United States, suggest that mortality is higher among females than males (Walburg and Nichols 1967).

The 2015 FMWT index for American Shad was 79, the lowest index on record and a 72 percent decline from the 2014 FMWT index value (Figure 6a). The American Shad FMWT index value peaked at 9360 in 2003. No index after 2003 has exceeded 25 percent of that year's index, and the majority failed to exceed 10 percent of the record high. The 2015 BSMWT index for age-0 American Shad was also the lowest on record, and marks the third year of declining indices (Figure 6b). The number of fish collected over the last few years has been relatively consistent, but only 8.5 percent of the 2015 catch was collected at index stations. In 2015, Bay Study collected 644 American Shad between June and December, and abundance peaked in August (n = 273). All but one fish were collected between San Pablo Bay and the lower Sacramento and San Joaquin rivers; however, 90 percent of the annual catch came from non-index stations in the lower rivers. Distribution widened in late fall, as fish likely emigrated from the estuary.

The 2015 expanded regional index for Cache Slough was six, down from a peak of 432 in 2011, and the lowest on record. The 2015 expanded regional index for SRDWSC was seven, down from a peak of 157 in 2012, and also the lowest on record (Figure 7). In both regions, expanded index trends followed those of traditional indices.

Throughout the 2015 FMWT sampling season, 59 American Shad were collected at traditional index stations from San Pablo Bay through the lower Sacramento and San Joaquin rivers, including the Confluence. No American Shad were collected at traditional index

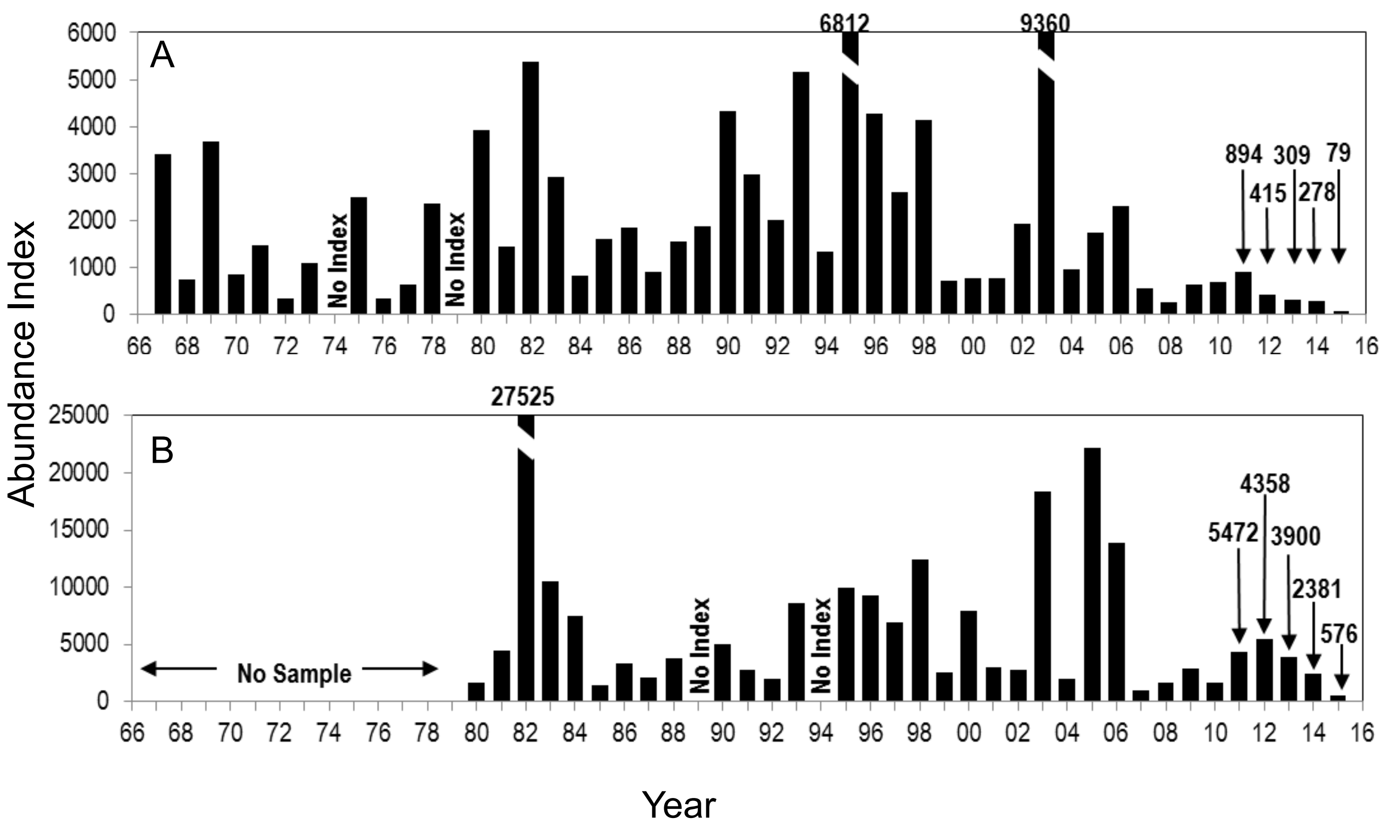


Figure 6. Traditional annual abundance indices of American Shad from: (A) the Fall Midwater Trawl Survey, 1967–2015 (all sizes); (B) San Francisco Bay Study Midwater Trawl, 1980–2015 (age 0).

stations in the South Delta. In September, American Shad were collected from Suisun Bay, the Confluence, the lower Sacramento River, and the lower San Joaquin River (n = 6). In October, they were collected in the Confluence and the lower Sacramento River (n = 10), as well as from a non-index station on the Sacramento River north of Courtland (n = 1). November catches occurred over a broader geographic range, with American Shad collected from Carquinez Strait, Suisun Bay, the Confluence, and the lower Sacramento River (n = 16), as well as from the SRDWSC (n = 5). December had the greatest numbers and widest distribution of American Shad, with individuals collected from San Pablo Bay, Carquinez Strait, Suisun Bay, the Confluence, and the lower Sacramento and San Joaquin rivers (n = 27), as well as from expanded index stations in Cache Slough (n = 2) and the SRDWSC (n = 5). Catches in Suisun Bay and the Sacramento River (n = 30) were substantially lower than previous years, contributing to the record low index value in 2015. Notably, total catch across the Cache Slough and SRDWSC regions (n = 13) was also much lower than in previous years, reflecting the overall trend of decline.

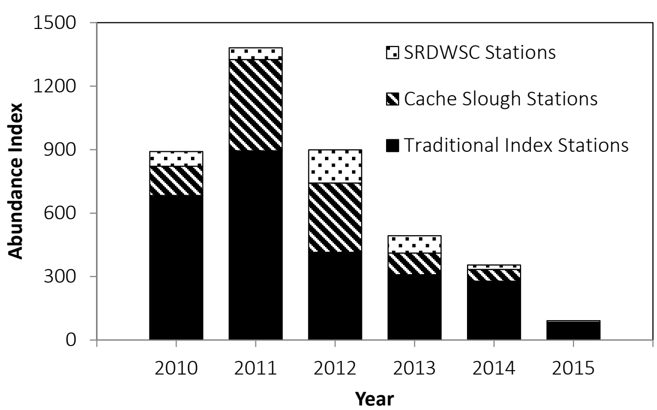


Figure 7. Expanded regional annual abundance indices of American Shad from Fall Midwater Trawl Survey, 2010–2015, for all index stations, Cache Slough stations, and Sacramento River Deep Water Ship Channel (SRDWSC) stations.

Threadfin Shad

The Threadfin Shad was introduced to California reservoirs in the late 1950s, and quickly spread downstream into the Sacramento and San Joaquin rivers (Dill and Cordone 1997). It has become established throughout the Delta and is most common in slow moving, fresh-to-oligohaline water found in dead-end sloughs (Wang 1986). Threadfin Shad are planktivorous throughout life (Holanov and Tash 1978). Spawning occurs from late spring through summer, peaking from May to July (Wang 1986). Individuals can reach maturity in their first year and live up to four years.

The FMWT Threadfin Shad index for 2015 was 806, making it the 10th lowest index on record, but large relative to recent years (Figure 8). Threadfin Shad was the only species to demonstrate an increase in index value from 2014, when the index value was 282. The 2015 index was the highest value seen since 2007, after which values dropped dramatically. Abundance was highest during the late 1990s and early 2000s, with the two highest indices occurring in 1997 (15,267) and 2001 (14,401).

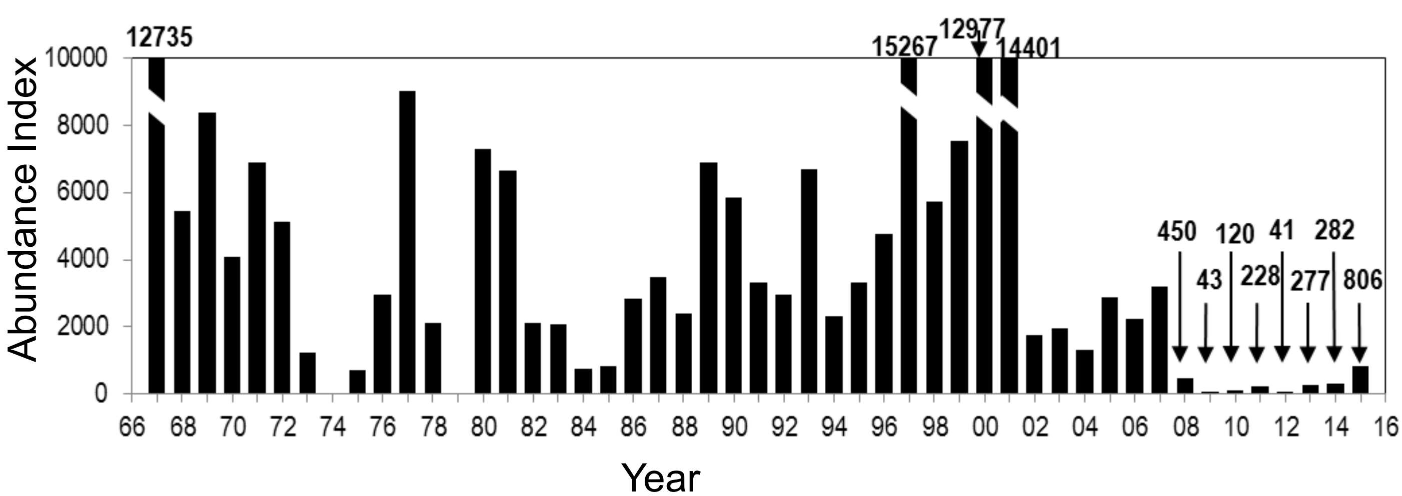


Figure 8. Traditional annual abundance indices of Threadfin Shad (all sizes) from the Fall Midwater Trawl Survey, 1967–2015.

The 2015 expanded regional index for Cache Slough was 57, down from a peak of 1,061 in 2011, and the lowest on record (Figure 9). The 2015 expanded regional index for SRDWSC was 1,595, down from a peak of 3,268 in 2012, but higher than 2013 and 2014 (Figure 9). Although expanded regional abundance indices varied independently of traditional indices, through the period of record one or both of the expanded indices were substantially higher than traditional indices, indicating the current importance of these regions for Threadfin Shad.

During FMWT, 644 Threadfin Shad were collected at traditional index stations across the entire sampling region, from San Pablo Bay to the Sacramento and San Joaquin rivers and the South Delta. In September, the majority of Threadfin Shad collected were from the Sacramento River (n = 160) and expanded index stations in the SRDWSC (220). In October there was a drop in the number of fish collected, but a modest increase in geographic distribution, with fish caught in Suisun Bay (n = 4), the Confluence (n = 5), the lower Sacramento (n = 54) and San Joaquin (n = 6) rivers, and the SRDWSC (n = 95). Catches increased again in November, driven by large numbers once again in the Sacramento River (n = 194) and expanded index stations in the SRDWSC (n = 309). November also had the only instance of catch in the South Delta, with 18 Threadfin Shad caught at station 912 in the Stockton Deep Water Channel. Over half of the Threadfin Shad catches during FMWT occurred during December (n = 1,340), with the vast majority coming from the SRDWSC (n = 1124). Geographic distribution increased during December as well, with fish caught in San Pablo Bay (n = 11), Carquinez Strait (n = 2), Suisun Bay (n = 28), the Confluence (n = 18), Sacramento River (n = 118), Cache Slough (n = 10), and the lower San Joaquin River (n = 36). The increase in the Threadfin Shad index value in 2015 was primarily driven by catch on the Sacramento River, which was the fourth highest on record. The only region to experience a sizeable decrease in catch compared to 2014 was Cache Slough.

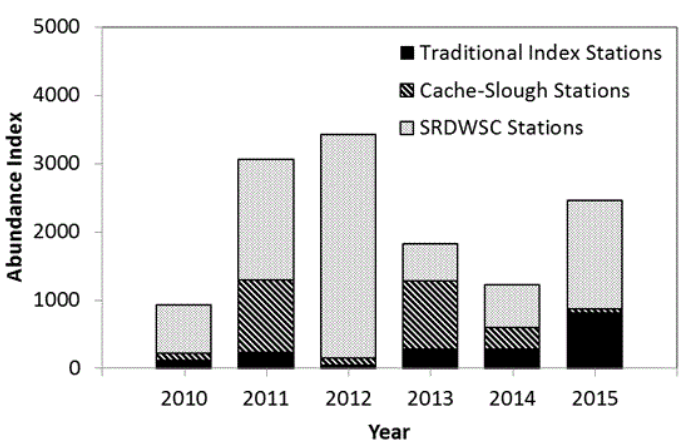


Figure 9. Expanded regional annual abundance indices of Threadfin Shad (all sizes) from the Fall Midwater Trawl Survey, 2010–2015, for all index stations, Cache Slough stations, and Sacramento River Deep Water Ship Channel (SRDWSC) stations.

Delta Smelt

The Delta Smelt is a small (< 90 mm FL) osmerid endemic to the San Francisco Estuary. In the 1980s, Delta Smelt underwent a severe population decline (Figure 10b-d) and in 1993 was listed as a threatened species by State and federal agencies. It is considered environmentally sensitive because of an annual life cycle; dependence on a spatially limited oligohaline-to-freshwater habitat; and low fecundity, averaging 1,200 to 2,600 eggs per female (Moyle et al. 1992). Low fecundity may be partially offset by the ability of females to produce multiple clutches in a single spawning season (Bennett 2005; Damon et al. in prep.).

The 20-mm Delta Smelt index for 2015 was 0.3, the lowest on record (Figure 10a). The 2015 index was calculated from surveys 3–6, during which time only eight Delta Smelt were collected from index stations; another 66 Delta Smelt were caught at non-index stations in the Cache Slough and SRDWSC regions. Through all of the 2015 20-mm surveys, 94 Delta Smelt were collected, with the majority collected at station 719 (n = 76) in the SRDWSC. Catches during late March (survey 1) were comprised of a single Delta Smelt from the lower Sacramento River. Surveys in April (surveys 2–4) had higher catches (n = 34), from the lower Sacramento (n = 4) and San Joaquin rivers (n = 2), the South Delta (n = 1), and non-index stations in the Cache Slough and SRDWSC regions (n = 27). May catches (surveys 5–6) were slightly higher (n = 43), driven by higher catches in the Cache Slough and SRDWSC regions (n = 41). Fish were also collected from the lower Sacramento River (n = 1) and the South Delta (n = 1). Catches dropped in June (surveys 7–8) (n = 15), with fish caught in Suisun Bay (n = 1), the lower Sacramento (n = 2) and San Joaquin (n = 1) rivers, and the Cache Slough and SRDWSC regions (n = 11). A single fish was caught

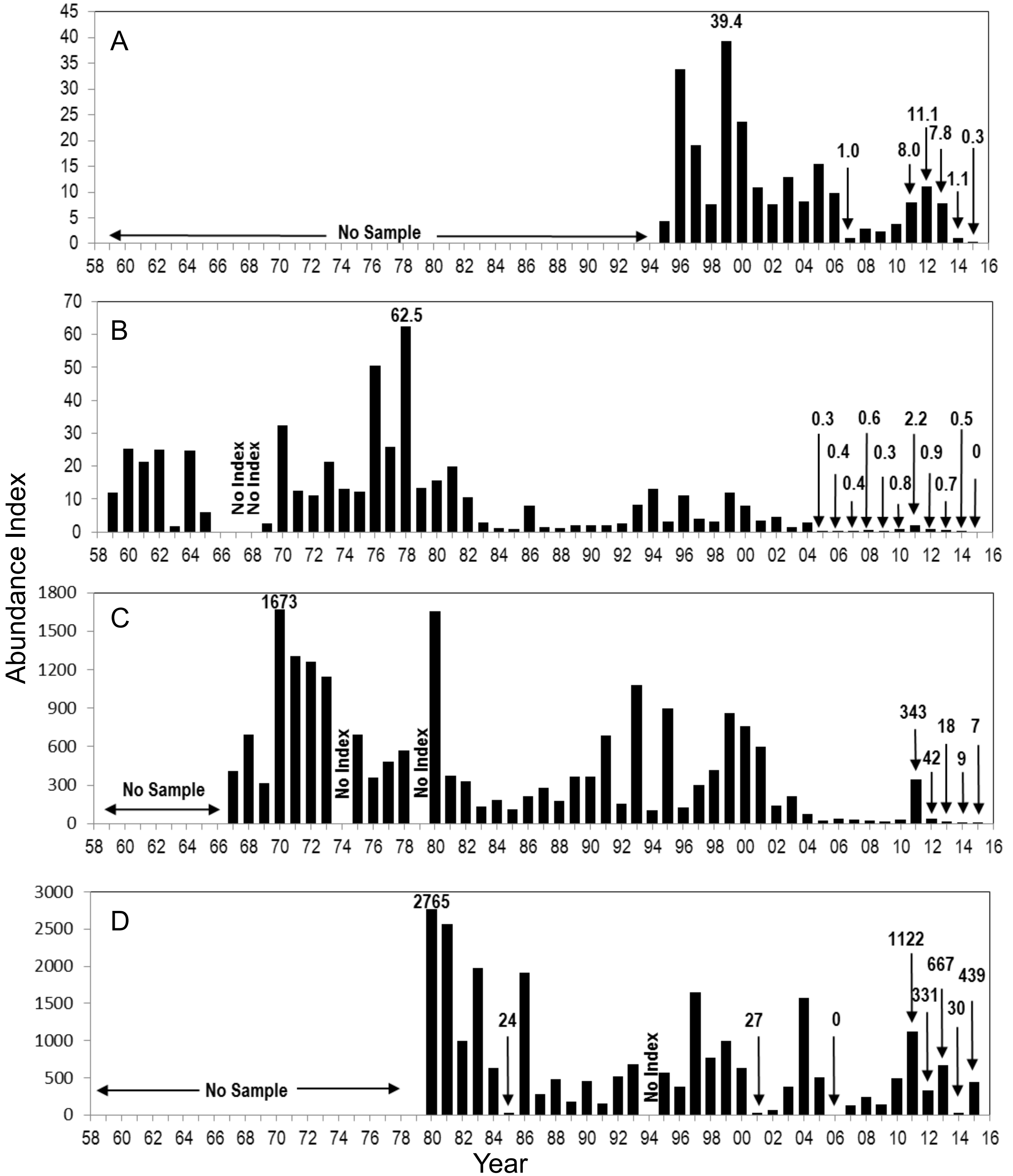
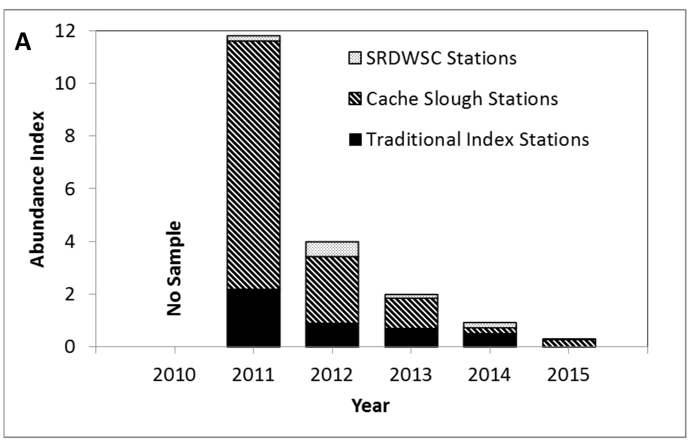


Figure 10. Traditional annual abundance indices of Delta Smelt from: (A) 20mm Survey (larvae and juveniles, 1995–2015); (B) Summer Townet Survey (juveniles, 1959–2015); (C) Fall Midwater Trawl Survey (sub-adults, 1967–2015); (D) San Francisco Bay Study (sub-adults, 1980–2015).

during July (survey 9) in the Cache Slough and SRDWSC regions.

The STN Delta Smelt index for 2015 was zero (Figure 10b). The 2015 expanded regional index for the Cache Slough region was 0.3, up slightly from the low of 0.2 in 2014, but down from a peak of 9.4 in 2011 (Figure 11a). The 2015 expanded regional index for SRDWSC was zero, down from a high of 0.6 in 2012, and the lowest on record. The catch during the two June 2015 surveys used to calculate the index consisted of 10 fish, only one of which was from an index station. The others were collected at expanded index stations in the Cache Slough and SRDWSC regions. A single Delta Smelt was collected in July from Suisun Bay, and none were collected in August.

The FMWT Delta Smelt index for 2015 was seven, resulting in two consecutive years of record low index values (Figure 10c). The 2015 expanded regional index for Cache Slough was zero, down from a peak of 25 in 2011, and tied with 2013 for the lowest on record (Figure 11b). The expanded regional index for SRDWSC was one, down from a peak of nine in 2011 and tied with 2014 for the lowest on record. In 2015, six Delta Smelt were collected at index stations, with catches occurring on the lower Sacramento River (n = 5) in September and December, and Suisun Bay (n = 1) in December. A single Delta Smelt was also collected from the SRDWSC in October of 2015. This year's catch is consistent with the low catches and limited geographic distribution seen in recent years.



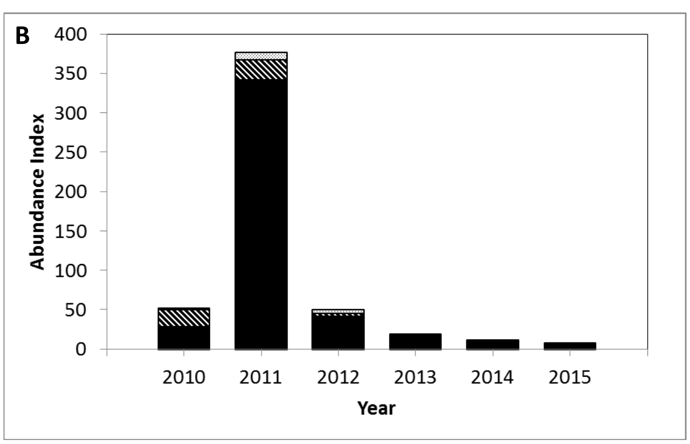


Figure 11. Expanded regional annual abundance indices of Delta Smelt from: (A) Summer Townet (2011–2015); (B) Fall Midwater Trawl, 2010–2015, for all index stations, Cache Slough stations and Sacramento River Deep Water Ship Channel (SRDWSC) stations.

The 2015 BSMWT age-0 Delta Smelt index was 439, nearly 15 times higher than the previous index, but still below the study-period mean (Figure 10d). Fifty-one age-0 Delta Smelt were collected between July and December, with nearly half (n = 24) of the annual catch collected in September. All age-0 fish were collected in the lower Sacramento River between Sherman Island and the Rio Vista Bridge.

Longfin Smelt

The Longfin Smelt is a short-lived, anadromous fish that spawns in freshwater or slightly brackish water in winter and spring. It rears primarily in brackish water, with some young-of-the-year and age-1+ fish migrating to the ocean in summer and fall. Adults typically return to the estuary as water temperatures drop in the late fall and winter. Most reach maturity in their second year, but some individuals appear capable of spawning in their first year and others appear to wait until the end of their third year. A few individuals may survive to spawn a second time (Wang 1986).

The 2015 FMWT Longfin Smelt index was four, the lowest on record and only 25 percent of the 2014 index (Figure 12a). Longfin Smelt abundance was highest in the late 1960s and peaked again in the early 1980s. After a brief increase in the late 1990s, abundance dropped again and has remained relatively low for most recent years. The 2015 expanded regional indices for Cache Slough and the SRDWSC were zero, consistent with previous years of little (expanded index value ≤ 2: 2011, 2012, 2013) or no catch (2010, 2014) of Longfin Smelt at those stations.

The only Longfin Smelt catches during the FMWT survey occurred in December (n = 3). Catches occurred in Carquinez Strait (n = 1), Suisun Bay (n = 1), and the Confluence (n = 1).

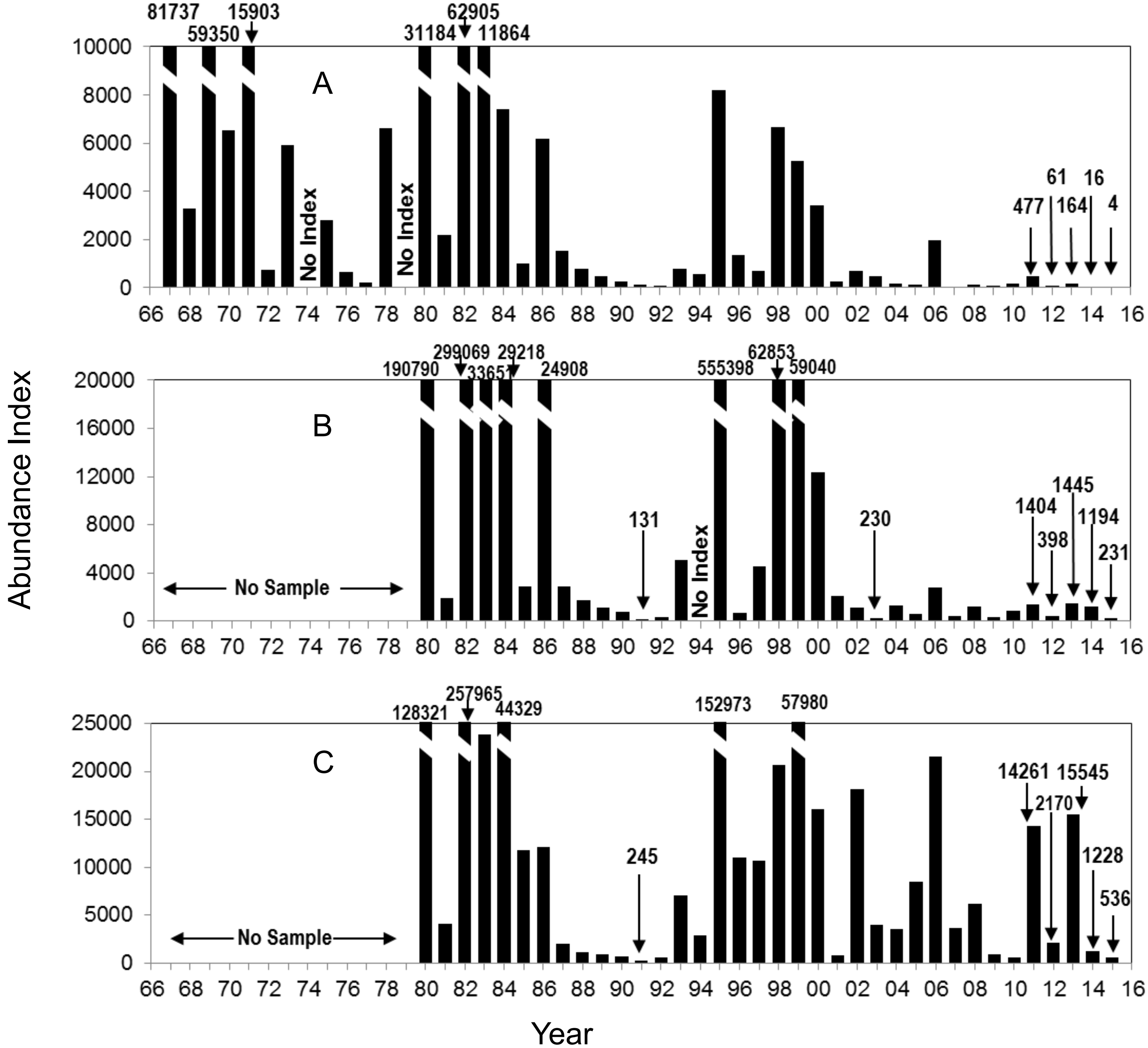


Figure 12. Traditional annual abundance indices of Longfin Smelt from (A) the Fall Midwater Trawl Survey (all sizes, 1967–2015); (B) San Francisco Bay Study Midwater Trawl (age 0, 1980–2015); (C) San Francisco Bay Study Otter Trawl (age 0, 1980–2015).

The 2015 BSMWT index for age-0 Longfin Smelt was 231, only 20 percent of the previous year's index and was the second lowest on record (Figure 12b). Only four age-0 fish were collected in the BSMWT: one fish in May from upper San Pablo Bay (at a non-index station), and three fish in June from Central Bay.

The 2015 BSOT index for age-0 Longfin Smelt was 536, just under half the previous year's index, and the third lowest on record (Figure 12c). Eleven age-0 fish were collected in the BSOT in 2015, all from index stations: eight fish in June just south of Treasure Island in Central Bay, and three fish in October near Oyster Point in South Bay. This was the lowest annual BSOT catch of age-0 Longfin Smelt in the project's history.

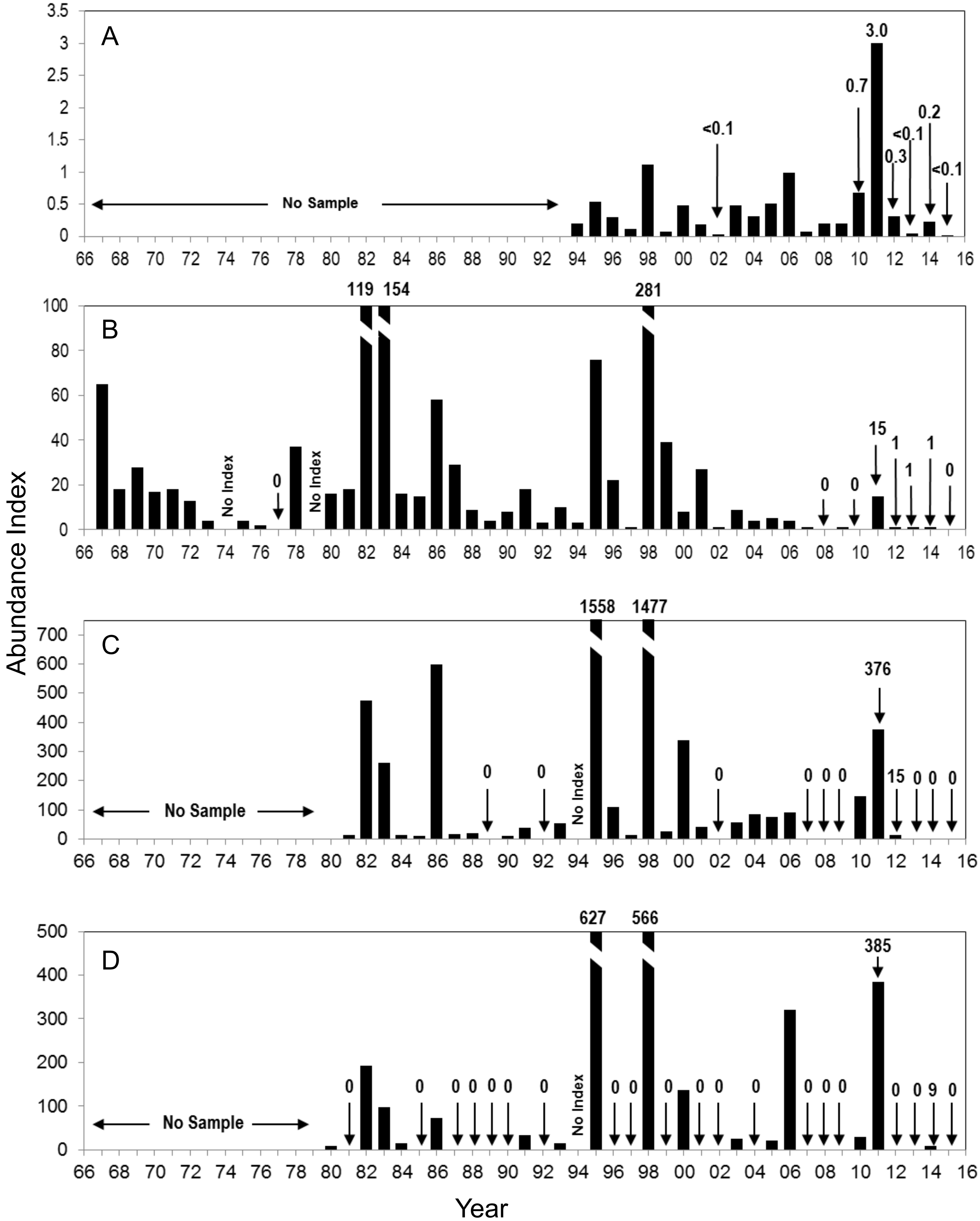


Figure 13. Traditional annual abundance indices of Splittail from: (A) USFWS Beach Seine Survey (juveniles ≥ 25mm), 1994–2015; (B) Fall Midwater Trawl Survey (all sizes), 1967–2015; (C) San Francisco Bay Study Midwater Trawl (age 0, 1980–2015); (D) San Francisco Bay Study Otter Trawl (age 0, 1980–2015).

Splittail

The Splittail is a large cyprinid endemic to the San Francisco Estuary and its watersheds. Adults migrate from brackish to freshwater from late fall to early spring, as river flows increase. During this time, they forage and eventually spawn on inundated floodplains and river margins (Sommer et al. 1997, Moyle et al. 2004). Spawning migrations occur in the Sacramento, San Joaquin, Cosumnes, Napa, and Petaluma rivers, as well as in Butte Creek and other small tributaries (Moyle et al. 2004; Feyrer et al. 2015). The majority of spawning takes place from March through May, and the resulting larvae and small juveniles disperse downstream in late spring and summer. This outmigration coincides with reduced river flows that decrease available backwater and edge-water habitats. Year-class strength is influenced by timing and duration of floodplain inundation. Moderate to strong cohorts are associated with periods of springtime floodplain inundation lasting 30 days or longer.

The 2015 USFWS Beach Seine index for age-0 Splittail was < 0.1, tied with 2002 and 2013 for the lowest index on record (Figure 13a). Regional abundance was highest in the Sacramento River and lowest in the San Joaquin River.

The 2015 FMWT Splittail index for all ages was zero, tied with 1977, 2008, and 2010 for the lowest index on record (Figure 13b). The 2015 expanded regional indices for Cache Slough and the SRDWSC were also zero, consistent with previous years of little (e.g., 2013) or no catch (e.g., 2010) of Splittail at traditional index stations (Figure 14). Expanded indices from Cache Slough in 2012 and 2014 resulted from the collection of single Splittail in each year. FMWT operates in water > 2 meters (m) deep, whereas Splittail, particularly age-0 fish, appear to primarily inhabit water < 2 m deep. Thus, during most years, FMWT data probably does not accurately reflect trends in Splittail abundance. However, FMWT does effectively detect strong year classes that occur in relatively wet years, such as the one in 1998 and the most recent one in 2011.

No age-0 Splittail were collected by the Bay Study in 2015. This marks the fourth consecutive year of zero or very low indices for both the BSMWT and BSOT (Figures 13c and 13d). Similar to FMWT, the Bay Study samples primarily deeper water where age-0 Splittail are uncommon in most years.

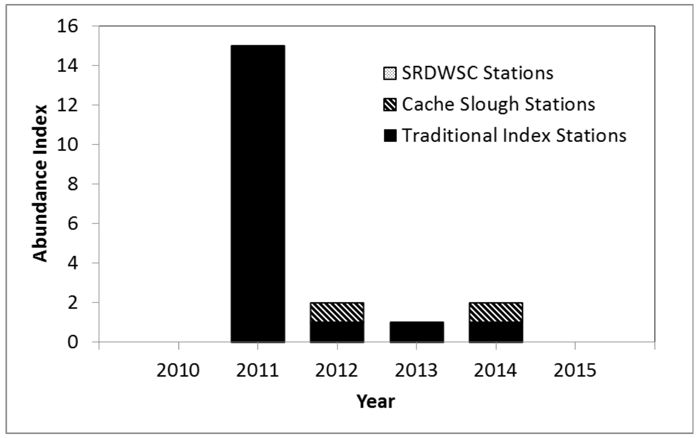


Figure 14. Expanded regional annual abundance indices of Splittail from Fall Midwater Trawl Survey (2010–2015), for all index stations, Cache Slough stations, and Sacramento River Deep Water Ship Channel (SRDWSC) stations.

Age-0 Striped Bass

The Striped Bass is a long-lived anadromous fish first introduced to the San Francisco Estuary in 1897 (Dill and Cordone 1997). Mature individuals forage in near-shore marine habitats, including coastal bays and estuaries. Many adults migrate to the Delta in fall and early winter, where they remain until they migrate upstream in spring to spawn. Spawning takes place in the water column, and both eggs and larvae rely on river and tidal currents to keep them suspended during early development. River currents transport larvae to rearing areas in tidal fresh and brackish waters.

Both STN and FMWT indices showed declines in age-0 Striped Bass abundance in the mid-1970s (Figure 15a-b). Abundance dropped further in the late 1980s and again in the 1990s, and has not approached historic numbers over the last 15 years. Stevens et al. (1985) hypothesized that four factors were responsible for the low abundance: (1) the adult population was too low to maintain adequate egg production; (2) planktonic food production has decreased to a point that is too low to sustain historic population levels; (3) entrainment in water diversions; and (4) pollution in the form of pesticides, petrochemicals, and other toxic substances. More recently, Sommer et al. (2011) argued that age-0 Striped Bass distribution had shifted almost exclusively to shoal and shoreline areas, which are under-sampled by CDFW trawl surveys. While a shift of this nature would reduce catch and thus reduce abundance indices, Sommer et al. (2011)

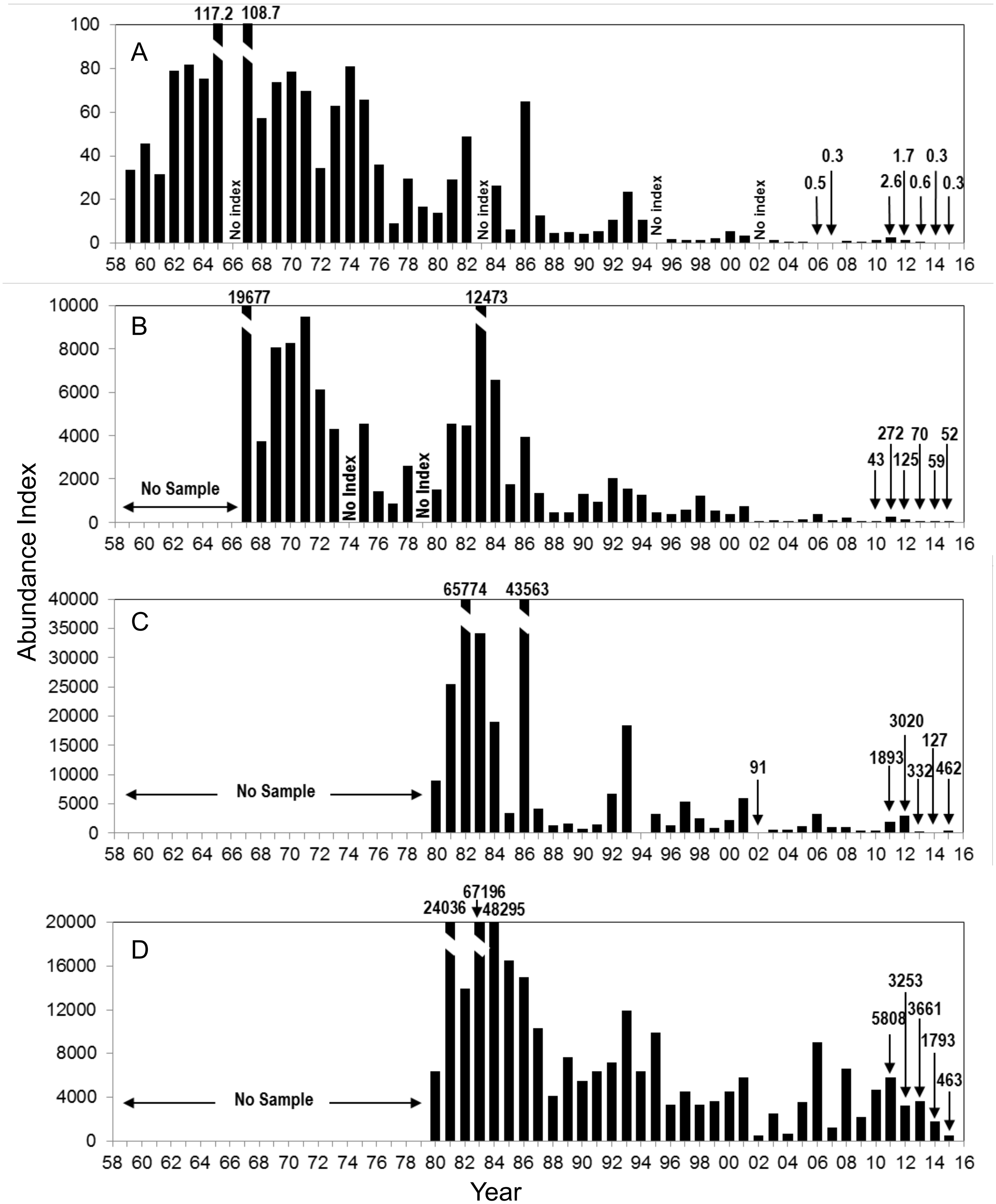


Figure 15. Traditional annual abundance indices of age-0 Striped Bass from: (A) Summer Townet, 1959–2015; (B) Fall Midwater Trawl Survey, 1967–2015; (C) San Francisco Bay Study Midwater Trawl, 1980–2015; (D) San Francisco Bay Study Otter Trawl, 1980–2015.

cautioned against attributing low values solely to a change in habitat use.

The 2015 STN index for age-0 Striped Bass was 0.3, tied with 2014 and 2007 for the lowest index on record (Figure 15a). In 2015, age-0 Striped Bass reached an average fork length of 38.1 mm on June 25, between survey 2 and survey 3. In survey 2, 41 age-0 Striped Bass were collected from traditional index stations, with large proportions coming from the lower Sacramento River (n = 20) and Suisun Bay (n = 15). Fish were also collected from index stations in the Confluence (n = 3) and the lower San Joaquin River (n = 3), as well as from expanded index stations in Cache Slough (n = 1) and the SRDWSC (n = 17). In survey 3, 13 age-0 Striped Bass were collected from index stations, from Suisun Bay (n = 12) and the lower San Joaquin River (n = 1). At expanded index stations in the SRDWSC, an additional 22 age-0 Striped Bass were collected.

The 2015 STN expanded regional index for age-0 Striped Bass was more than double the 2015 traditional index (Table 1). Expanded indices always equaled or exceeded traditional indices. In most years, the date on which the index was set did not vary by much between the traditional and expanded indices. Yet in 2015, age-0 fish from the Cache Slough and SRDWSC regions were so much smaller than those fish from the traditional index sampling area that, when added into the calculation, these small Striped Bass shifted the date when mean FL surpassed 38.1 mm and necessitated the use of later surveys in index calculation. Thus, in 2015 the expanded index was set at a later date than the traditional index (Table 1).

During the entire 2015 STN season, sampling collected 220 age-0 Striped Bass, ranging from the Suisun Bay to the lower Sacramento and San Joaquin rivers, as well as in the SRDWSC and the South Delta. Catches were consistently concentrated in Suisun Bay (n = 49), the lower Sacramento River (n = 64), and the SRDWSC (n = 63), and declined from 97 in survey 1 to seven in survey 6.

Table 1. Traditional and expanded indices of age-0 Striped Bass abundance from Summer Townet Survey, 2011–2015.

Year	*Date Traditional Index Set*	*Traditional Index*	*Date Expanded Index Set*	*Expanded Index*
2011	8/14/2011	2.6	8/16/2011	2.7
2012	7/17/2012	1.7	7/17/2012	2.0
2013	7/11/2013	0.6	7/11/2013	0.7
2014	7/3/2014	0.3	7/3/2014	0.3
2015	6/25/2015	0.3	7/2/2015	0.7

The 2015 FMWT index for age-0 Striped Bass was 52, the second lowest on record, and consistent with the low index values reported since the early 2000s (Figure 15b). Age-0 Striped Bass abundance was highest at the inception of the survey in 1967, peaked again in 1971, and a third time in 1983. In the later 1980s, age-0 Striped bass abundance declined, dropped again in the early 2000s, and has remained low since then. The 2015 expanded regional index for Cache Slough was zero, down from a peak of 56 in 2014 and tied with 2010 for the lowest on record. The expanded regional index for SRDWSC was five, up from one in 2014 and the highest on record (Figure 16).

Forty-two age-0 Striped Bass were collected at FMWT traditional index stations extending from the Carquinez Strait to the lower Sacramento and San Joaquin rivers and the South Delta. In September, age-0 Striped Bass were collected from Suisun Bay (n = 5) and the lower Sacramento River (n = 1). In October, they were collected in the Carquinez Strait (n = 3) and the Confluence (n = 1). In November, age-0 Striped Bass were collected from Suisun Bay (n = 5), the Confluence (n = 3), the lower Sacramento River (n = 1), and the South Delta (n = 1). Also in November, at expanded index stations in the SRDWSC, two age-0 Striped Bass were collected, the only catches in the expanded index regions for the year.

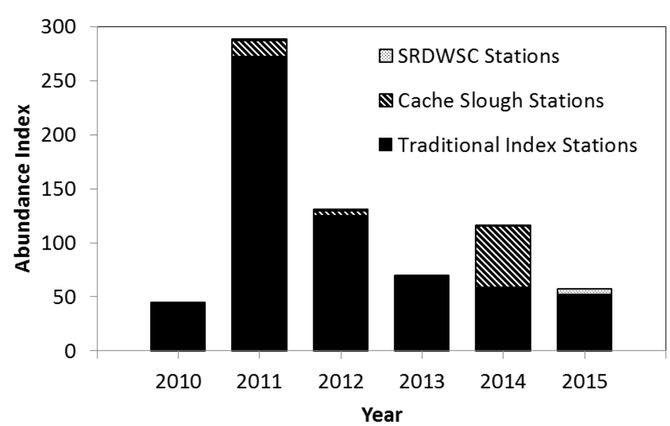


Figure 16. Expanded regional annual abundance indices of age-0 Striped Bass from Fall Midwater Trawl Survey, 2010–2015, for all index stations, Cache Slough stations, and Sacramento River Deep Water Ship Channel (SRDWSC) stations.

Catches at traditional index regions improved modestly in December, with fish caught in the Carquinez Strait (n = 2), Suisun Bay (n = 13), the Confluence (n = 2), and the lower Sacramento (n = 5) and San Joaquin (n = 1) rivers. Age-0 Striped Bass were conspicuously absent from the Cache Slough region, given the high catch there in 2014 (n = 44).

The 2015 BSMWT index for age-0 Striped Bass increased for the first time in three years, but was still the fourth lowest index on record (Figure 15c). Fifty-four fish were collected sporadically between July and December, and abundance peaked in September. Collections ranged from Suisun Bay upstream to the lower Sacramento and San Joaquin rivers, but most occurred in Suisun Bay (n = 33).

The 2015 BSOT age-0 Striped Bass index declined 74 percent from the previous year, and marked the lowest index on record (Figure 15d). Beginning in June, the BSOT collected 228 age-0 Striped Bass total for the year, with peak abundance in September. Similar to the BSMWT, fish were collected between Suisun Bay and the lower rivers, but in the BSOT most came from the lower San Joaquin River (n = 80).

Over the study period, there has been an apparent shift in catch of age-0 Striped Bass, from a balanced distribution of catches between channel stations (> 7 m depth) and shoal stations (< 7 m depth) to predominantly shoal station associated catches, which became especially apparent in the BSOT data (Sommer et al. 2011). This trend of shoal catches dominating total catches of age-0 fish continued with the addition of the 2010 to 2015 data (not shown). The trend is strongest for the BSOT, which samples near the bottom and catches more age-0 Striped Bass than the BSMWT. In all years since 1997, over 90 percent of the age-0 Striped Bass BSOT catch has been at shoal stations. The trend is not as strong for the BSMWT, which samples the water column.

Conclusion

Annual abundance indices in 2015 continued the recent trend of record low or near-record low values observed for these six fish species over the past several years. Even Threadfin Shad, which exhibited a substantial increase in 2015, only achieved a fraction of the abundance exhibited through the 1990s and into the early 2000s. The low catches of Delta Smelt and Longfin Smelt indicate that population levels are near the threshold of detection for most life stages. Given that catches by, or abundance indices from, these studies have specific management implications, index values of "0" have been and will continue to be problematic. Catches of all species in the south Delta also continue to decline. For example, during the entire 2015 FMWT season, only a single south Delta tow yielded fish or invertebrates of any kind (one age-0 Striped Bass and 18 Threadfin Shad).

On a more positive note, the often-sizable abundance contribution of the Cache Slough and SRDWSC expanded index regions to overall index values for STN (2011–2015) and FMWT (2010–2015) suggest that these regions provide important habitat for a number of species in many years. Specifically, Threadfin Shad, American Shad, juvenile Delta Smelt and age-0 Striped Bass inhabit the expanded index regions to varying degrees, frequently in high abundance. Threadfin Shad abundance in these expanded regions recently rivaled historical low abundance for all traditional index regions. For American Shad, Cache Slough and SRDWSC expanded abundance from FMWT sampling equaled a substantial fraction of traditional abundance indices. Delta Smelt and Striped Bass inhabited the Cache Slough and SRDWSC regions in relatively high abundance through summer, but abundance was low by fall in most years. By summer, these regions did not seem to support Longfin Smelt, although the species has been quite dense as larvae and small juveniles in winter and early spring (http://www.dfg.ca.gov/delta/data/sls/CPUE_map.asp; http://www.dfg.ca.gov/delta/data/20mm/CPUE_map.asp). Finally, the trawl gears used did not prove effective for capturing Splittail to assess accurately its use in the Cache Slough and SRDWSC regions; only a couple were detected.

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2016 Spring Kodiak Trawl Summary

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The California Department of Fish and Wildlife (CDFW) conducts the Spring Kodiak Trawl Survey (SKT) annually, from January through May, to (1) determine the distribution and relative abundance of adult Delta Smelt (*Hypomesus transpacificus*) and (2) monitor the gonadal maturation of Delta Smelt as an indicator of when and where spawning is likely occurring. SKT crews conducted a 10-minute surface trawl at 40 stations in the upper San Francisco Estuary (SFE) each month (Figure 1). Each monthly sampling event is called a survey, and they are numbered sequentially, with January being Survey 1. In 2016, stations could not be sampled during Survey 2 (station 724) and Survey 5 (station 340) because of boat breakdown or hazardous weather conditions. For more information on the SKT's equipment, objectives, methods, and prior year summary reports, see previous articles by Souza (2002, 2003) and other articles in the CDFW online bibliography at http://www.dfg.ca.gov/delta/data/skt/bibliography.asp.

Historically, Delta Smelt were among the top three species caught in the SKT, but fell to the ninth most abundant in 2016. This was also the lowest Delta Smelt catch on record (n = 59). Only 13 Delta Smelt were caught under index criteria (see "Index Calculation" below), resulting in an index of 1.8, which was the lowest on record for the SKT (Figure 2). Northern Anchovy and Pacific Herring were the most commonly caught species, and comprised more than 75 percent of the total catch (Table 1). Splittail comprised just more than 1 percent of the total catch (n = 91), the largest on record.

In January (Survey 1), Delta Smelt catches were in the single digits, but their distribution was relatively widespread (n = 7) (Figure 3). They were mostly distributed in the lower Sacramento River, but also extended into western Montezuma Slough and up into the lower reaches of Cache Slough (Table 2). But they were not caught in the Sacramento Deep Water Shipping Channel (SDWSC) in January, a location where they have been consistently detected since it was added to the survey in 2005. Delta Smelt single-digit catches and broad

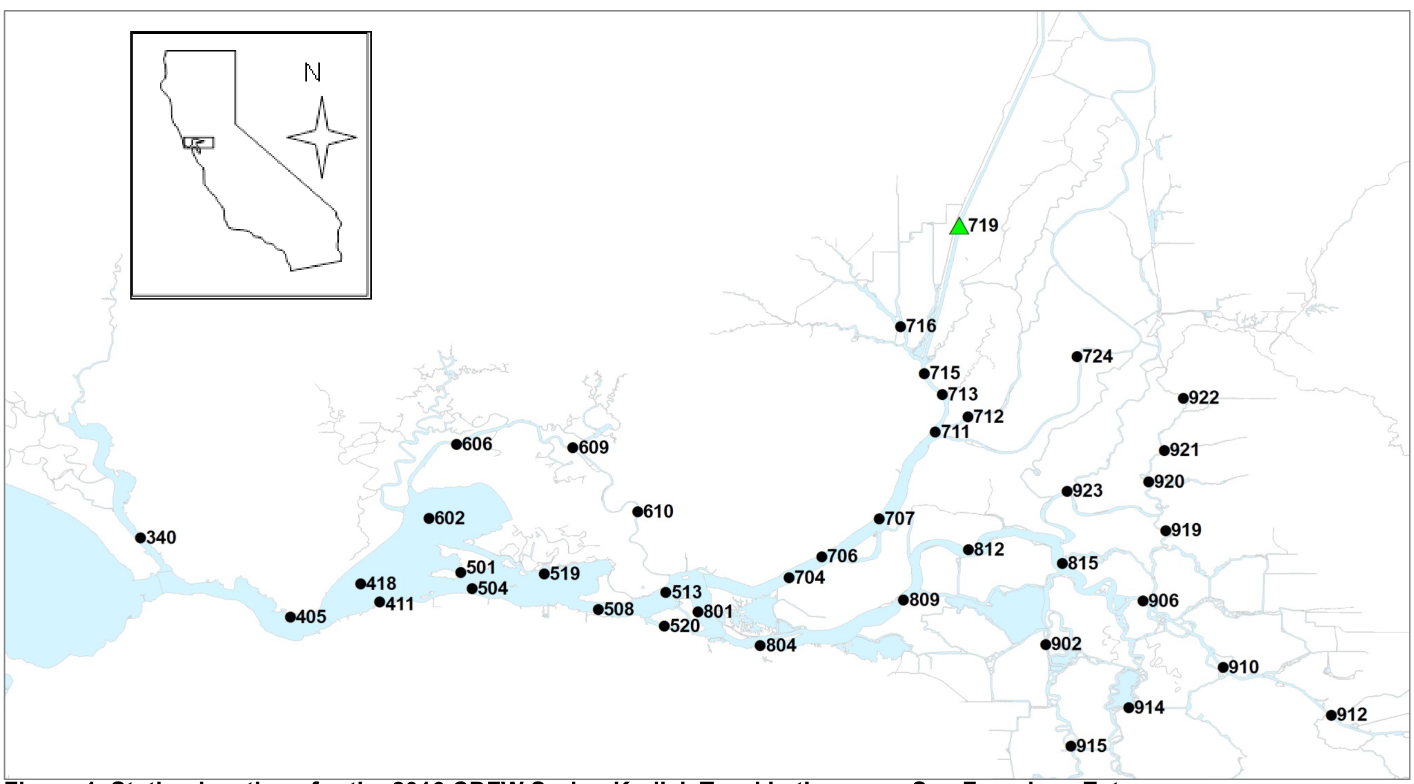

Figure 1. Station locations for the 2016 CDFW Spring Kodiak Trawl in the upper San Francisco Estuary.

Note: The black dots are index stations and the green triangle is a non-index station.

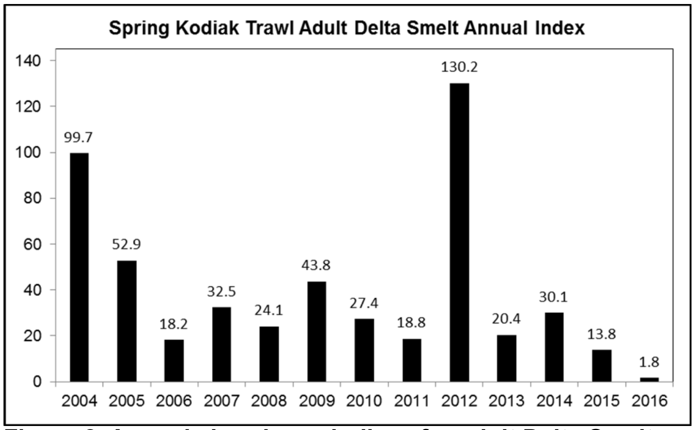

Figure 2. Annual abundance indices for adult Delta Smelt collected from the CDFW Spring Kodiak Trawl, 2004–2016.

Table 1. Total number of organisms caught and their percent of catch in the 2016 CDFW Spring Kodiak Trawl for all stations and surveys combined.

Common Name	*Catch*	*Percent*
Northern Anchovy	4401	53%
Pacific Herring	2027	24%
Threadfin Shad	456	5.5%
Chinook Salmon	347	4.2%
Inland Silverside	319	3.8%
Threespine Stickleback	175	2.1%
Longfin Smelt	126	1.5%
Splittail	91	1.1%
Delta Smelt	59	0.71%
Exopalaemon shrimp	55	0.66%
Steelhead	52	0.63%
American Shad	52	0.63%
Striped Bass	32	0.38%
Topsmelt	19	0.23%
Palaemon shrimp	17	0.20%
Bluegill	17	0.20%
Sacramento Pikeminnow	16	0.19%
Golden Shiner	10	0.12%
Wakasagi	7	0.08%
Shimofuri Goby	6	0.07%
Rainwater Killifish	6	0.07%
Tule Perch	5	0.06%
Pacific Lamprey	4	0.05%
Jacksmelt	3	0.04%
Hitch	2	0.02%
Yellowfin Goby	2	0.02%
Crangon shrimp	2	0.02%
Starry Flounder	2	0.02%
Mosquitofish	1	0.01%
Jellyfish	1	0.01%
Pacific Halibut	1	0.01%
Pacific Staghorn Sculpin	1	0.01%

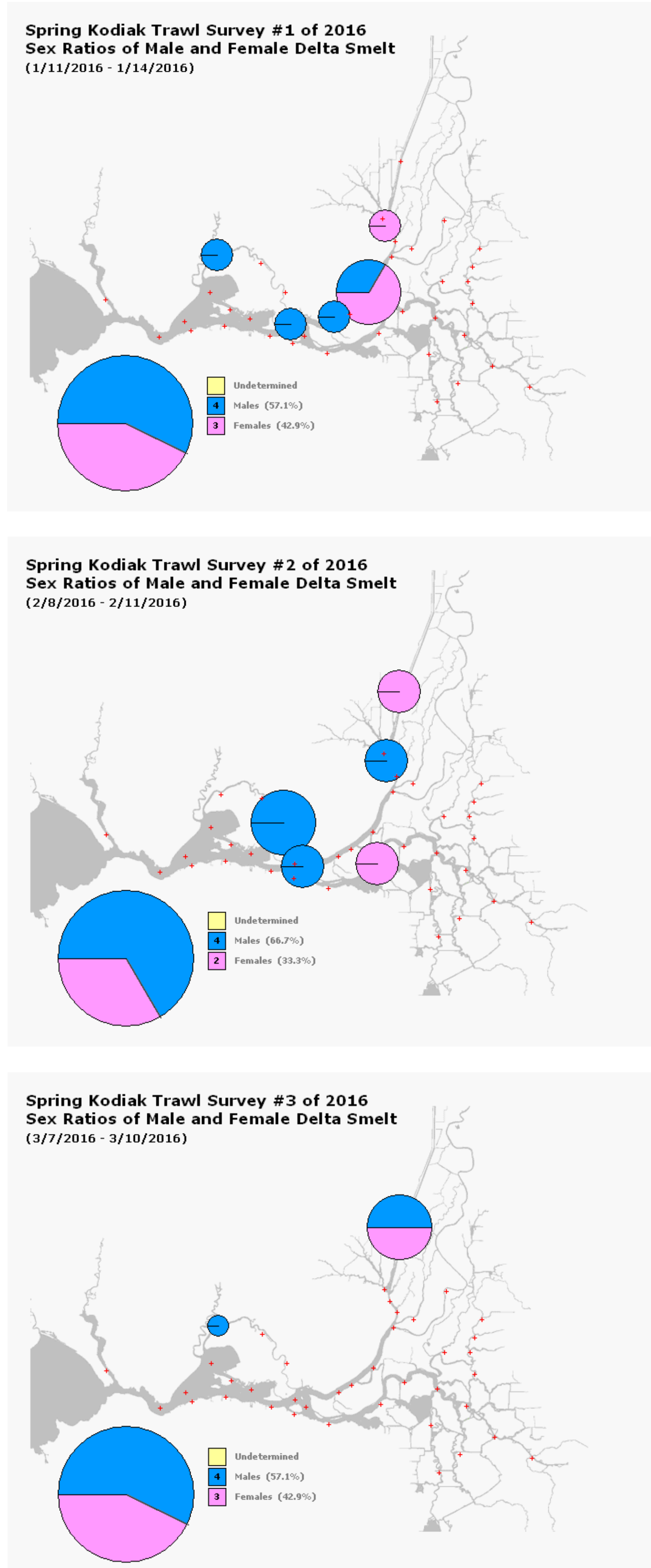

Figure 3. Geographic bubble plot[4] showing the number of Delta Smelt, by gender, caught during each monthly CDFW 2016 Spring Kodiak Trawl **(continued on next page).**

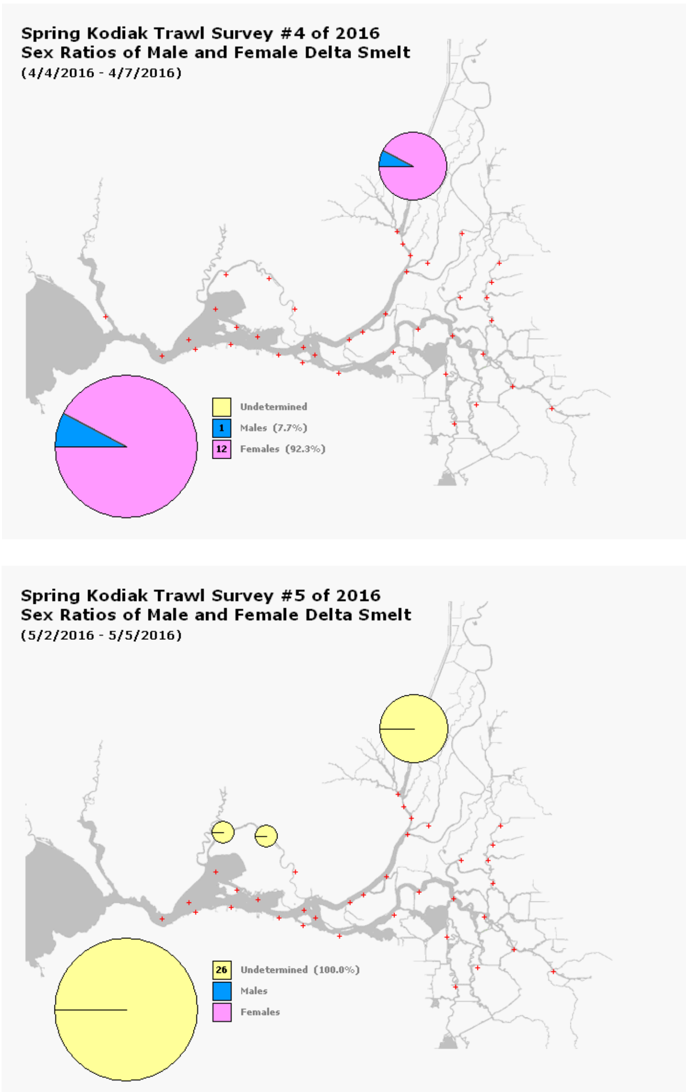

Figure 3. Geographic bubble plot[4] showing the number of Delta Smelt, by gender, caught during each monthly CDFW 2016 Spring Kodiak Trawl, continued.

distribution continued in February (Survey 2) (n = 6), where they were caught around the confluence region, the lower San Joaquin River, Cache Slough, and the SDWSC. By March (Survey 3), nearly all of the Delta Smelt were concentrated in the SDWSC (n = 6), and only one individual was caught in western Montezuma Slough. This upstream distribution continued in April (Survey 4), when Delta Smelt were only caught in the SDWSC (n = 13). By May (Survey 5), adults were no longer detected in the system, but 26 young-of-the-year (YOY) with a fin length as much as 42 millimeters (mm) were captured in the SDWSC (n = 23) and Montezuma Slough (n = 3) (Figure 4). Since the SKT targets spawning adults, the survey timing and net mesh size make YOY

Table 2. Delta Smelt catch per unit effort (10,000 m^3) by station, region, and survey as used to calculate the annual index.

Region	*Station*	*Survey*			
		1	2	3	4
	340	0	0	0	0
	405	0	0	0	0
	411	0	0	0	0
	418	0	0	0	0
	501	0	0	0	0
	504	0	0	0	0
	508	0	0	0	0
	513	1.40	0	0	0
Confluence and West	519	0	0	0	0
	520	0	0	0	0
	602	0	0	0	0
	606	2.02	0	1.40	0
	609	0	0	0	0
	610	0	2.46	0	0
	801	0	1.40	0	0
	Regional Mean:	0.23	0.26	0.09	0
	704	1.09	0	0	0
	706	0	0	0	0
	707	5.05	0	0	0
	711	0	0	0	0
	712	0	0	0	0
Sacramento River System	713	0	0	0	0
	715	1.35	2.03	0	0
	716	0	0	0	0
	724	0		0	0
	Regional Mean:	0.83	0.25	0	0
	804	0	0	0	0
	809	0	1.51	0	0
	812	0	0	0	0
	815	0	0	0	0
	902	0	0	0	0
	906	0	0	0	0
	910	0	0	0	0
	912	0	0	0	0
	914	0	0	0	0
San Joaquin River System	915	0	0	0	0
	919	0	0	0	0
	920	0	0	0	0
	921	0	0	0	0
	922	0	0	0	0
	923	0	0	0	0
Regional Mean:		0	0.10	0	0
Survey Index:		1.06	0.61	0.09	0
Annual Index:		1.8			

Delta Smelt catch rare. In 2016, the most in number and largest in fin length YOY Delta Smelt were caught since the survey started in 2002. YOY have only been caught during routine surveys since 2010, and have been caught in single digits almost every year since then. The two exceptions are 2012, when larval and juvenile Delta Smelt abundance was high (Damon 2013), and 2016 (Figure 4). The increase in 2016 YOY catch may be explained by an increase in water temperature, a result from drought conditions during the past three years. The annual average temperature at Rio Vista has increased 1.8 degrees from the 2002–2015 average. See http://cdec.water.ca.gov/ (Figure 5). 2016 was not included, because the 2015 adult stock produced the 2016-year class. Increased water temperature can result in adult Delta Smelt spawning sooner or YOY growing faster. Additionally, it appears that spawning occurred between February and April this year, based on the presence and absence of mature and spent females throughout the spawning season (Table 3). This is similar to most other years of the SKT survey (2003–2016). Yet, half of the spawning seasons extended into May, whereas the 2016 season did not.

The 2017 SKT began in January and continues through May. Data, metadata, and protocols are available on the CDFW FTP website (ftp://ftp.dfg.ca.gov/Delta%20Smelt/), and interactive geographic distribution maps of Delta Smelt are available on the SKT web page (https://www.wildlife.ca.gov/Conservation/Delta/Spring-Kodiak-Trawl).

Index Calculation

The Delta Smelt Index is calculated using 39 of the 40 routine stations and only Surveys 1–4. These specific stations and surveys are referred to as "index stations" and "index surveys." The index stations include all of the stations in Figure 1 except station 719 (green triangle). For each index survey, the index is calculated by first

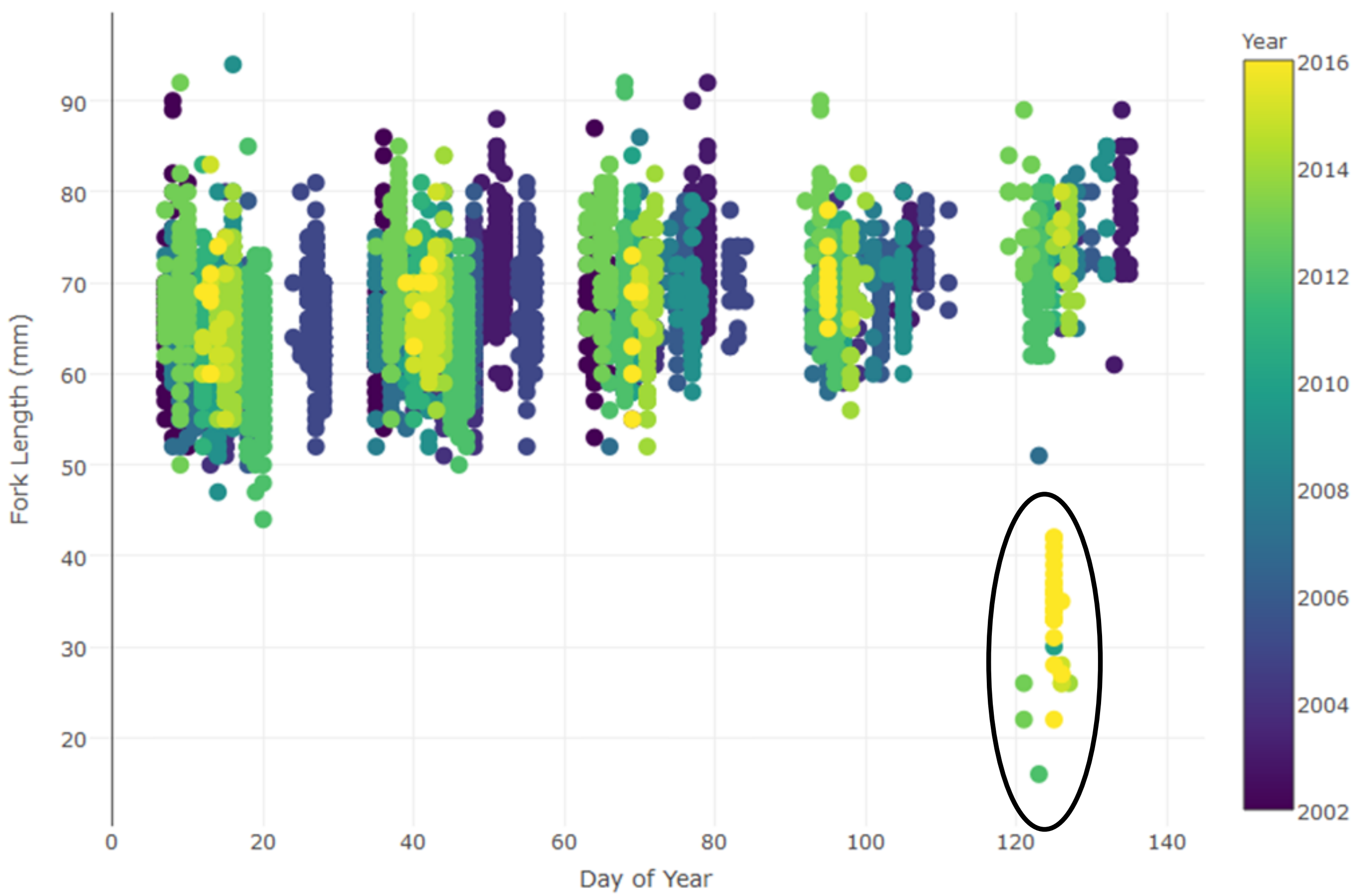

Figure 4. Size distributions of Delta Smelt (mm FL) caught during CDFW's Spring Kodiak Trawl routine surveys from 2002–2016.

Note: Young of the year Delta Smelt are circled and were caught in 2010 and 2012–2016.

Table 3. The numbers of adult Delta Smelt by gonad-stage caught in the 2016 CDFW Spring Kodiak Trawl by survey.

Survey	*1*	*2*	*3*	*4*	*5*
Male					
Developing	4	3	1		
Mature		1	3		
Post-spawn				1	
Female					
Developing	3	1			
Mature		1	2	2	
Post-spawn			1	10	
Total	**7**	**6**	**7**	**13**	**0**
Mean Temp.	9.2	11.5	14.0	17.0	18.5

Note: The table also shows the mean temperature for all stations sampled.

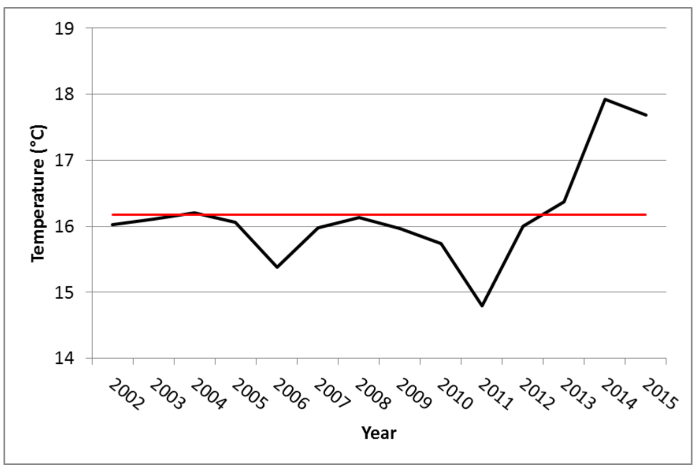

Figure 5. The average Rio Vista (RIV) water temperature (2002–2015) by year in black.

Note: The red line is the average of those years (http://cdec.water.ca.gov/).

calculating the adult catch-per-unit-effort (CPUE, which is the number of fish per 10,000 cubic meters [m^3] of water) at each index station, and then finding the mean CPUE for each region (Table 2). These regional means are summed to produce a survey index, and then the four survey indices are summed to obtain the annual index. CPUE is calculated by dividing the Delta Smelt catch at a station by the volume of water sampled at that station and then multiplying that value by 10,000. Water volume (m^3) is calculated by multiplying the mouth area of the SKT net (13.95 square meters) by the distance traveled by the net (measured in meter counts using a General Oceanics flowmeter) and by the factory conversion factor for the flowmeter (0.02687 meters/count). The SKT index is reported annually via interdepartmental memorandum on the SKT website bibliography (http://www.dfg.ca.gov/delta/data/skt/bibliography.asp).

End Notes

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

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Souza K. 2002. “Revision of California Department of Fish and Game’s Spring Midwater Trawl and Results of the 2002 Spring Kodiak Trawl.” IEP Newsletter 15(3):44-47.

Souza K. 2003. “2003 Spring Kodiak Trawl.” IEP Newsletter 16(4):34-39.

2014–2015 Yolo Bypass Fisheries Monitoring Status and Trends Report

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Introduction

Largely supported by the Interagency Ecological Program (IEP), California Department of Water Resources (DWR) has operated the Yolo Bypass Fish Monitoring Program (YBFMP) since 1998. The YBFMP has provided a wealth of information regarding the significance of seasonal floodplain habitat to native fishes. Basic objectives of the program are to collect baseline data on lower trophic metrics (phytoplankton, zooplankton, and aquatic insects), juvenile and adult fish, hydrology, and water quality conditions. As the largest remnant floodplain of the Sacramento River, the Yolo Bypass has been identified as a high restoration priority by the National Marine Fisheries Service Biological Opinion for winter and spring-run Chinook Salmon (*Oncorhynchus tshawytscha*) and by California EcoRestore; these baseline data are critical for evaluating the success of future restoration projects. Moreover, over the years, data acquired from this monitoring effort have increased our understanding of the crucial role that the Yolo Bypass plays in the San Francisco Estuary ecosystem (Sommer et al. 1997; Sommer et al. 2001; Feyrer et al. 2006; Lehman et al. 2007).

This report describes the fisheries sampling effort for water year (WY) 2015 (October 1, 2014–September 30, 2015), including a summary of the fisheries catch by species and gear type. Our sampling mainly occurred in the Toe Drain, a perennial riparian channel on the eastern edge of the Yolo Bypass (Figure 1). During flooding events, additional sampling occurs in other areas within the Yolo Bypass region, but in WY2015 we did not see any floodplain inundation as a result of the drought conditions. During drier months, the tidally influenced Toe Drain channel is the primary water body in the Yolo Bypass, linking a complex network of tributaries, canals, and ditches. In the WY2015 sampling period, we continued to observe higher numbers of Delta Smelt (*Hypomesus transpacificus*) relative to the previous decade, despite the continuing drought (Ikemiyagi et al. 2015, Mahardja et al. 2015). However, WY2015 saw a reduction in adult and juvenile Chinook Salmon, as well as White Sturgeon (*Acipenser transmontanus*) numbers, compared to recent years (Goertler et al. 2015; Ikemiyagi et al. 2015). The introduced Mississippi Silverside (*Menidia audens*) and White Catfish (*Ameiurus catus*) continued to be highly prevalent in the Toe Drain throughout the drought period.

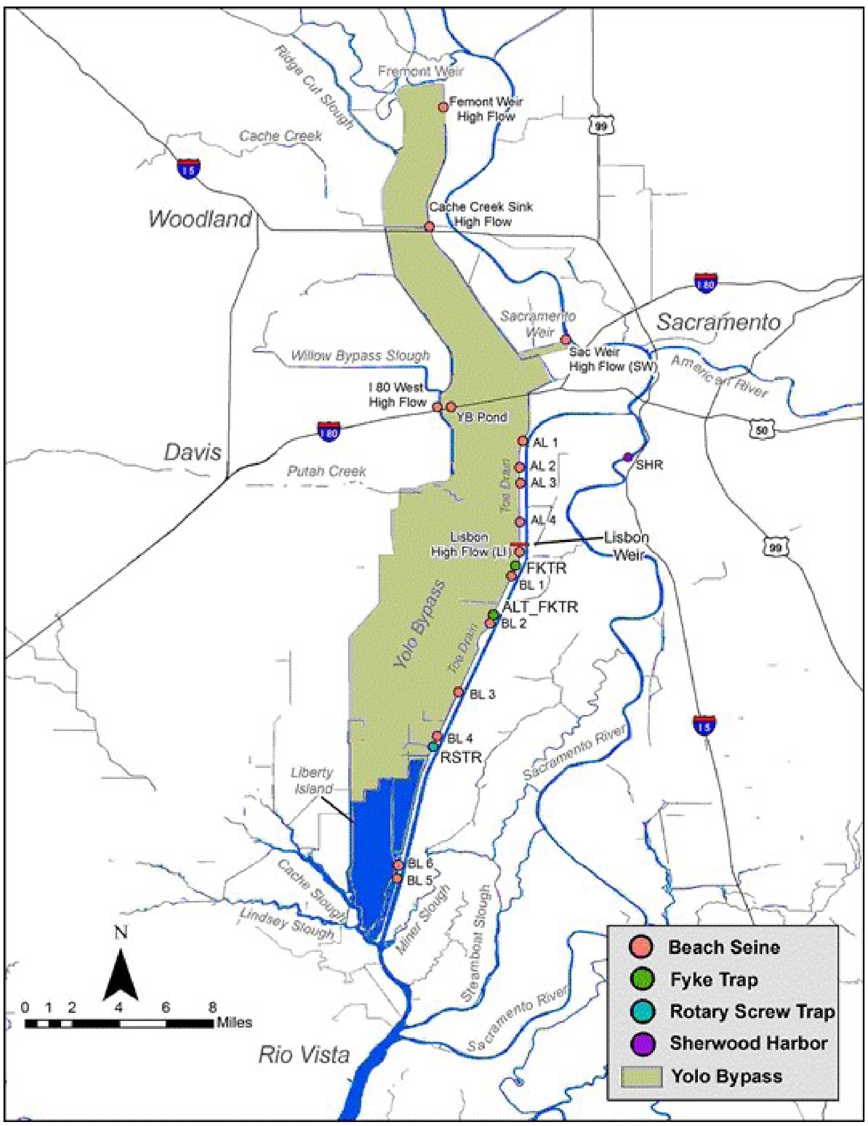

Figure 1. Map of Yolo Bypass showing the various sampling locations of the YBFMP.

Methods

Since 1998, small adult (e.g., Delta Smelt) and juvenile fish have been sampled with an 8-foot diameter rotary screw trap (RSTR) located in the Toe Drain of the Yolo Bypass, approximately nine miles south of the Lisbon Weir (Figure 1), for up to seven days a week during the months of January–June. In WY2015, the rotary screw trap was consistently operated five days a week for the entire sampling period, without any restrictions from high flows or heavy debris (Figure 2). For the RSTR, the sampling time (total hours based on set and pull times) is used to calculate catch per hour (CPH), as the volume of water sampled is unknown.

Throughout the year, we supplemented the collection of small adult and juvenile fish in the Yolo Bypass by conducting biweekly beach seine surveys at various locations along the Toe Drain and in a perennial pond on the west side of the Yolo Bypass (Figure 1 and Figure 2). Sampling consists of one seine haul parallel to the shore for every site, with the exception of BL5. A 25-feet wide and 4-feet high seine net with 1/8 inch mesh was used. During inundation events (such as in WY2011), weekly sampling is also conducted at four distinct site locations accessible only during flood conditions (Figure 1); however, none of these sites were sampled in WY2015 because of the lack of a substantial inundation event. The spread of Water Hyacinth (*Eichhornia crassipes*) in the Toe Drain has precluded beach seine sampling at station BL5 since August 2013, with only a brief respite during spring of 2014 (Ikemiyagi et al. 2015). As such, no beach seine sampling was conducted at BL5 throughout WY2015. To compensate for the loss of the BL5 site from our continuous beach seine survey, the alternate site of BL6 was added in March of 2015.

To monitor upstream-migrating large-adult fish in the Toe Drain, a 10-foot diameter steel-framed fyke trap has been used since 1999. The fyke trap is operated up to five days a week during the months of October–June (Figure 2) and is typically serviced once every 24 hours. The trap is normally located three-quarters of a mile below Lisbon Weir and thirteen miles north of the terminus of the Toe Drain. Because of the excessive growth of Water Hyacinth around Lisbon Weir in WY2015, no fyke trap sampling was conducted from October 11 through November 30 of 2014, and an alternate site further downstream was used in its place for 10 days, from December 1 to December 10 of 2014 (Figure 1).

A survey for the general composition and timing of larval fishes in the Toe Drain has also been conducted since 1999. Sampling is carried out by towing a 2-meter (m) long, 500-micrometer mesh net with a 0.65-meter diameter opening for 10 minutes. Historically (1999–2014), sampling consisted of a single tow taken every other week between January and June at the RSTR and

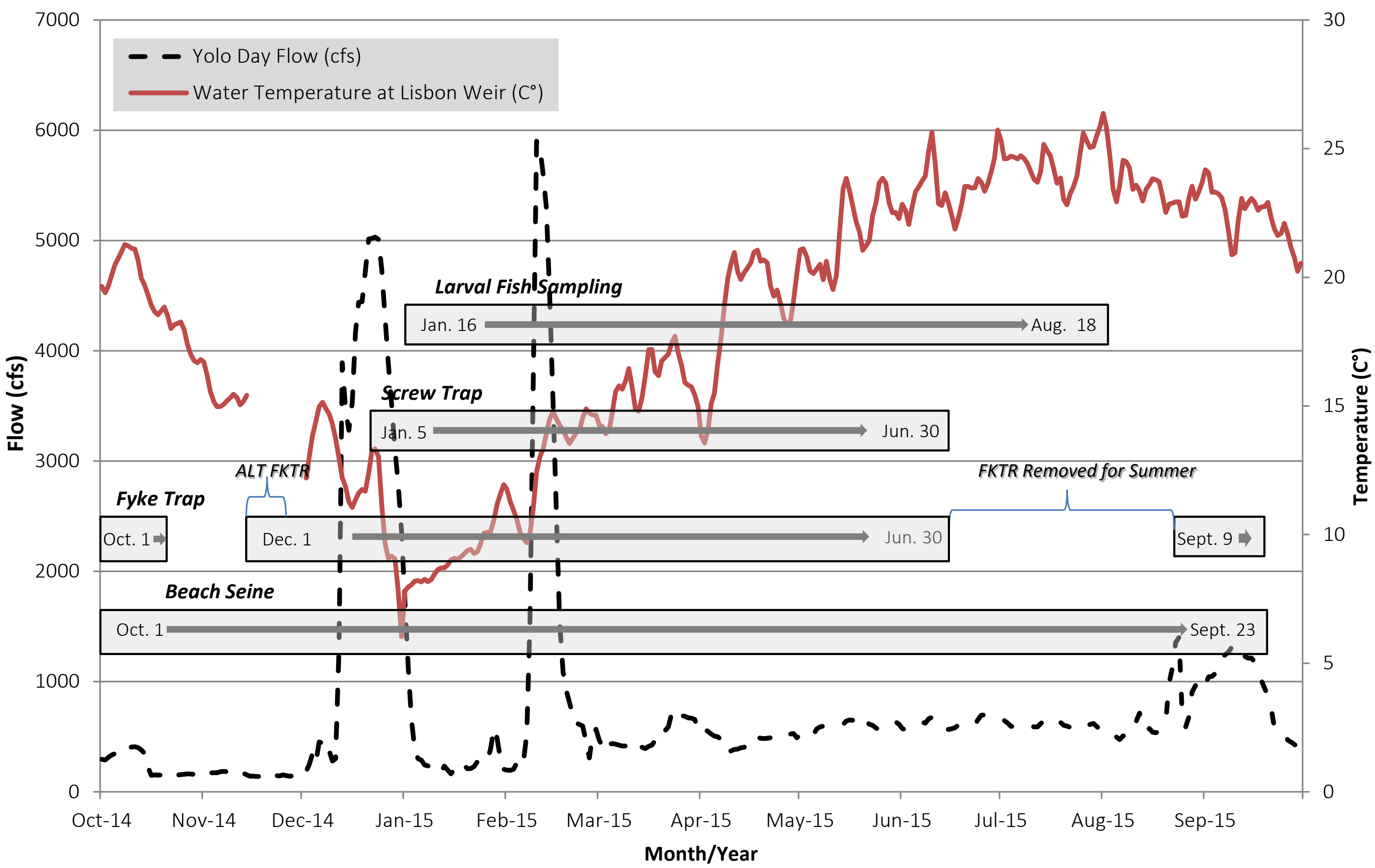

Figure 2. Fishing effort for every gear type summarized against average daily flow from Dayflow and water temperature at Lisbon Weir.

Sherwood Harbor on the Sacramento River (SHR) (Figure 1). But in WY2015, three replicate tows were added for each sampling event at the RSTR (totaling four tows per sampling event) between March and July to evaluate gear efficiency and to identify its limitations. Of the four replicate tows, two tows were conducted mid-channel, as had been done in previous years, while the other two tows were conducted near the shore (approximately one meter away from the bank). Replicate tows were not added to the Sacramento River at Sherwood Harbor site.

To provide data on ambient water quality conditions, field crews concurrently collected data on several water quality parameters during all sampling, including water temperature, electrical conductivity, dissolved oxygen, acidity (pH), turbidity, and Secchi depth. Data loggers (Onset Corporation) also recorded water temperature at 15-minute intervals at RSTR (January–June only) and below Lisbon Weir (year-round) in the Toe Drain, and for comparison purposes, at SHR (year-round). In addition, to monitor lower trophic parameters in the Yolo Bypass, chlorophyll-*a* (chl-*a*) grab samples (to estimate phytoplankton biomass), zooplankton, and drift invertebrate samples are collected on a bi-weekly basis (weekly during inundation) at the RSTR site with paired sampling at SHR, though these data are not presented in this report.

Results and Discussion

Drought Effects

WY2015 constituted the third consecutive drought year in the Sacramento Valley. The Yolo Bypass Toe Drain saw reduced flows and floodplain habitat availability as a result of these lingering drought conditions. Similar to the previous two dry years, the low precipitation and flow seemed to promote higher levels of floating aquatic vegetation in the Toe Drain. High densities of floating, matted Water Hyacinth completely occluded entire portions of the Toe Drain above and below Lisbon Weir and downstream to our fyke trap location during the summer and fall months. Elevated densities of Water Primrose (*Ludwigia* spp.) also resulted in the partial blockage of some beach seine sites above Lisbon Weir and in the perennial pond site (YB Pond).

Hydrology

The Sacramento Valley experienced a critically dry WY in 2015 (California Department of Water Resources 2016a). Based on Dayflow estimates (California Department of Water Resources 2016b), the Yolo Bypass average daily flow in WY2015 was higher than WY2014 at 795 cubic feet per second (cfs), with a high of 5,901cfs (February 10th) and a low of 139 cfs (November 19th). In comparison, the previous dry WY of 2014 had less than half the average daily flow at 327 cfs (Ikemiyagi et al. 2015). Fremont Weir did not overtop in WY2015, as the Sacramento River only reached a maximum stage of 33.29 feet on December 15th, 2014 (Fremont Weir overtops at 33.5 ft.) (California Department of Water Resources 2016a).

Water Quality

Water Temperature

In WY2015, water temperatures at SHR and RSTR followed typical seasonal trends, with the highest temperatures occurring in the summer, and the lowest temperatures in the late fall and winter (Table 1). When compared to WY2014 (Ikemiyagi et al. 2015), average water temperatures in the Yolo Bypass were slightly higher in the fall and winter, but were within similar range for spring and summer. Characteristic of most years, the Yolo Bypass experienced greater variation in water temperatures when compared with the adjacent Sacramento River, though this pattern was less pronounced because of the lack of flooding. Higher temperature variation in the Yolo Bypass can be attributed to the occasional presence of shallow inundated floodplain in the region, lower average water velocity, and the shallower channel bathymetry of the Toe Drain relative to the Sacramento River.

Conductivity

Variation in conductivity within the Toe Drain is highly interrelated to upstream tributary inputs during both floodplain drainage events in the winter and spring (Schemel et al. 2004) and agricultural discharge flows in the summer and fall (Frantzich et al 2015). Conductivity measurements in WY2015 followed a pattern typical

Table 1. Summary statistics of water temperature, conductivity, and Secchi depth for Yolo Bypass at the RSTR station and Sacramento River at Sherwood Harbor.

Water Temperature °C								
Month	Avg.		Min.		Max.		Std. Dev.	
	Sac	Yolo	Sac	Yolo	Sac	Yolo	Sac	Yolo
Oct	19.08	19.12	16.01	16.44	21.82	21.83	1.66	1.42
Nov	14.20	15.40	12.17	13.91	16.25	17.46	1.41	0.57
Dec	12.01	12.03	7.67	5.67	14.05	15.34	1.51	2.22
Jan	15.47	9.69	10.47	5.21	20.65	12.53	4.72	2.05
Feb	12.98	13.96	11.88	11.73	14.48	16.34	0.65	1.20
Mar	16.47	17.55	12.87	13.57	20.01	20.79	1.86	1.94
Apr	18.59	18.16	14.55	14.67	22.42	24.48	2.04	1.83
May	20.43	20.24	18.60	18.34	22.66	25.43	1.05	1.14
Jun	23.75	23.95	21.08	19.70	25.79	29.52	1.02	1.51
Jul	24.13	24.27	22.15	21.49	25.77	27.97	0.81	1.30
Aug	23.96	23.82	22.68	21.58	25.43	27.85	0.52	0.94
Sept	21.44	22.06	18.68	19.67	24.07	24.61	1.20	0.92
Conductivity µS/cm								
Oct	127	519	119	287	135	824	11	268
Nov	127	405	122	381	132	428	7	33
Dec	132	290	107	257	145	311	22	18
Jan	149	515	146	385	151	591	4	70
Feb	166	533	158	326	174	664	11	133
Mar	164	771	156	691	172	877	11	63
Apr	152	634	130	580	165	700	19	33
May	114	588	114	383	114	798	N/A	161
Jun	128	367	126	300	129	545	2	61
Jul	120	295	118	295	121	295	2	
Aug	148	488	121	296	176	680	28	272
Sept	139	620	127	591	150	681	16	28
Turbidity NTU (Secchi Depth m.)								
Oct	3.2 (1.99)	133.6 (0.17)	2.6 (1.99)	37.6 (0.1)	3.8 (1.99)	388.6 (0.27)	0.9 ()	139.8 (0.05)
Nov	6.64 (1.55)	70.7 (0.22)	4.8 (1.40)	52.3 (0.21)	8.5 (1.7)	89.1 (0.23)	2.6 (0.21)	26.0 (0.01)
Dec	57.9 (0.41)	182.9 (0.13)	17.2 (0.13)	86.4 (0.05)	117.3 (0.8)	350 (0.24)	52.6 (0.35)	99.9 (0.06)
Jan	22.05 (0.95)	49.0 (0.23)	9.6 (0.95)	38.2 (0.18)	34.5 (1.1)	74.6 (0.3)	17.6 (0.21)	10.3 (0.04)
Feb	24.6 (0.95)	119.2 (0.18)	6.8 (0.40)	40.8 (0.06)	42.4 (1.5)	490.6 (0.27)	25.2 (0.78)	134.8 (0.07)
Mar	6.65 (1.05)	52.5 (0.22)	5.0 (0.90)	35.4 (0.19)	8.3 (1.2)	85.2 (0.26)	2.3 (0.21)	12.3 (0.02)
Apr	7.6 (1.46)	56.5 (0.21)	5.7 (1.00)	38.4 (0.15)	9.3 (2.19)	102 (0.26)	1.8 (0.64)	17.4 (0.04)
May	7.7 (0.2)	84.7 (0.18)	7.7 (0.20)	39.6 (0.09)	7.7 (0.2)	131.6 (0.28)	N/A	30.6 (0.05)
Jun	5.7 (1.6)	70.0 (0.20)	3.9 (1.20)	43.5 (0.15)	7.5 (2.0)	117 (0.28)	2.6 (0.57)	17.2 (0.03)
Jul	4.6(1.93)	56.1 (0.24)	3.7 (1.3)	53.6 (0.23)	6 (2.8)	58.6 (0.25)	1.2 (0.78)	3.5 (0.01)
Aug	3.5 (3.97)	53.5 (0.25)	2.4 (2.60)	23.4 (0.18)	4.9 (5.33)	83.5 (0.32)	1.3 (1.93)	42.5 (0.10)
Sept	3.25 (2.1)	35.4 (0.33)	2.4 (2.1)	23.5 (0.25)	4.1 (2.1)	59.7 (0.04)	1.2 ()	10.2 (0.05)

of dry years (Ikemiyagi et al. 2015). The Yolo Bypass Toe Drain had higher conductivity year-round and was more variable relative to the Sacramento River, with measurements peaking primarily in the spring months (Table 1). The lowest conductivity values occurred in the Toe Drain during both winter and summer months in WY2015, and during periods of the highest net negative Toe Drain flows (periods when the landward tidal movement is stronger than the downstream flows).

Turbidity and Secchi Depth

The annual average water clarity (turbidity, Secchi depth) in the Toe Drain (79.23 Nephelometric Turbidity Units [NTU] at 0.21 meters) was more turbid than the Sacramento River (13.81 NTU at 1.49 m) (Table 1). Higher turbidity is typical of a seasonally dynamic and abiotically-driven environment such as the Yolo Bypass (Nobriga et al. 2005). The seasonal hydrologic variability of the Yolo Bypass, in addition to tidal influence during dry periods, can cause increased turbidity through increased suspended particle concentrations and higher fluctuating temperatures, that in turn can increase algal biomass (Sommer et al. 2004). Higher turbidity has been shown to be beneficial to key Sacramento-San Joaquin Delta (Delta) fish species, such as the Delta Smelt (Nobriga 2008; Sommer and Meija 2013), and may explain the recent increased prevalence of this species in the Toe Drain (Mahardja et al. 2015).

Fish

Thirty-seven fish species were sampled in WY2015; thirteen of which are native to the San Francisco Estuary (Table 2). The total fish catch from the Yolo Bypass continued to be dominated by the non-native Mississippi Silverside (*Menidia audens*), with 7,121 fish sampled for the water year, making up 45.24% and 33.41% of the beach seine and rotary screw trap catch, respectively. The high catch of Mississippi Silversides in the Yolo Bypass is consistent with other studies around the Delta that have demonstrated high prevalence of this invasive species in shallow-water habitats (Nobriga et al. 2005; Mahardja et al. 2016).

In WY2015, we continued to observe higher numbers of Delta Smelt relative to the late 1990s and early 2000s (Mahardja et al. 2015). We captured a total of 51 Delta Smelt (10 adults and 41 juveniles) for the year, and

Table 2. Species catch summarized by gear type for WY 2015.

Species	***Screw Trap***	***Fyke Trap***	***Beach Seine***	***Total Catch***
Mississippi Silverside	1,997 (33.41%)	1 (0.04%)	5,123 (45.24%)	7,121
Western Mosquitofish	285 (4.77%)	0	2,509 (22.15%)	2,794
Threadfin Shad	734 (12.28%)	35 (1.33%)	1,295 (11.43%)	2,064
Striped Bass	1,743 (29.16%)	100 (3.79%)	163 (1.44%)	2,006
White Catfish	38 (0.64%)	1856 (70.28%)	3 (0.03%)	1,897
American Shad	761 (12.73%)	72 (2.73%)	38 (0.34%)	871
Bigscale Logperch	0	0	670 (5.92%)	670
Bluegill	14 (0.23%)	10 (0.38%)	432 (3.81%)	456
Shimofuri Goby	55 (0.92%)	0	385 (3.40%)	440
Sacramento Splittail	172 (2.88%)	170 (6.44%)	22 (0.19%)	364
Largemouth Bass	10 (0.17%)	5 (0.19%)	283 (2.50%)	298
Black Crappie	22 (0.37%)	164 (6.21%)	53 (0.47%)	239
Black Bullhead	0	14 (0.53%)	113 (1.00%)	127
Channel Catfish	0	85 (3.22%)	0	85
Delta Smelt	51 (0.85%)	0	0	51
Common Carp	0	42 (1.59%)	3 (0.03%)	45
Chinook Salmon	37 (0.62%)	3 (0.11%)	3 (0.03%)	43
Redear Sunfish	1 (0.02%)	1 (0.04%)	41 (0.36%)	43
Yellowfin Goby	6 (0.10%)	0	34 (0.30%)	40
White Crappie	0	27 (1.02%)	9 (0.08%)	36
Tule Perch	2 (0.03%)	0	29 (0.26%)	31
Prickly Sculpin	2 (0.03%)	0	24 (0.21%)	26
Golden Shiner	4 (0.07%)	1 (0.04%)	18 (0.16%)	23
Threespine Stickleback	22 (0.37%)	0	0	22
Sacramento Blackfish	0	19 (0.72%)	2 (0.04%)	21
Sacramento Pikeminnow	0	5 (0.19%)	16 (0.14%)	21
Sacramento Sucker	0	14 (0.53%)	6 (0.05%)	20
Fathead Minnow	3 (0.05%)	0	15 (0.13%)	18
Warmouth	0	0	18 (0.16%)	18
Wakasagi	16 (0.27%)	0	4 (0.04%)	20
White Sturgeon	0	14 (0.53%)	0	14
Green Sunfish	1 (0.02%)	0	11 (0.10%)	12
Goldfish	0	2 (0.08%)	0	2
Pacific Lamprey	1 (0.02%)	1 (0.04%)	0	2
Starry Flounder	0	0	2 (0.02%)	2
Rainwater Killifish	1 (0.02%)	0	0	1
Spotted Bass	0	0	1 (0.01%)	1
Grand Total	**5,978**	**2,641**	**11,325**	**19,944**

Note: Sorted by descending order of abundance.

all fish were collected at the RSTR site. Our catch per hour (CPH) of Delta Smelt for WY2015 was 0.023 fish per hour, which was higher than the 1998–2015 mean of 0.014 fish per hour. Juvenile Chinook Salmon catch from the rotary screw trap and beach seine sampling for 2015 was our lowest since 2011 (Goertler et al. 2015). In WY2015, a total of 37 juvenile Chinook Salmon were collected at the rotary screw trap, and three were captured by beach seine (Table 2).

Larval Fishes

Similar to WY2014 (Ikemiyagi et al. 2015), the three species with the highest larval catch in the Toe Drain for WY2015 were Threadfin Shad (*Dorosoma petenense*), Prickly Sculpin (*Cottus asper*), and *Tridentiger* spp. (Table 3). Catch of larval Prickly Sculpin, Threadfin Shad, and *Tridentiger* spp. peaked in early April, late April, and mid-May, respectively. Unlike 2014, DWR saw a higher proportion of larval Mississippi Silverside in the total catch, with peak catch occurring in mid-May. As expected for a dry year (Moyle 2002; Moyle et al. 2004), catch of native larval fish (e.g., Splittail and Sacramento Sucker) was low for 2015.

Table 3. Summary of total catch from the 2015 expanded larval fish sampling at the Yolo Bypass RSTR site, by date.

Species	3/4	3/24	4/2	4/16	4/30	5/18	6/3	6/17	6/30	7/15	7/28
American Shad	0	0	0	0	0	0	1	3	0	0	0
Bigscale Logperch	0	0	41	12	7	0	1	0	0	0	0
Common Carp	0	0	0	0	2	8	9	4	9	0	0
Golden Shiner	0	0	0	1	0	0	1	0	0	0	0
Mississippi Silverside	0	0	0	11	47	54	9	4	0	1	0
Prickly Sculpin	53	89	98	92	47	7	2	1	1	0	0
Sacramento Sucker	0	0	0	1	0	0	0	0	0	0	0
Splittail	0	0	4	0	0	0	0	0	0	0	0
Striped Bass	0	0	0	0	0	1	0	0	0	0	0
Threadfin Shad	0	0	10	3	67	123	109	251	82	34	42
Tridentiger spp.	0	0	0	9	234	32	2	2	0	0	0

Note: Each sample consists of four replicate net tows: two nearshore and two mid-channel.

White Catfish

In WY2015, DWR observed the highest fyke trap CPH of adult White Catfish (*Ameiurus catus*) on record since the YBFMP began operating the trap in 1999. To evaluate the interannual variation of White Catfish catch numbers and investigate if there is any temporal pattern over the 16-year period, White Catfish CPH from the fyke trap from October to May for each water year since 1999 was examined. Annual CPH of White Catfish was calculated by taking the average of the monthly mean CPH for each water year (Figure 3). In a similar manner, the proportion of fyke trap CPH comprised of White Catfish for each water year was also calculated (Figure 4).

White Catfish have consistently dominated the adult fish catch from the fyke trap in the Yolo Bypass (Frantzich et al. 2013; Ikemiyagi et al. 2014; Ikemiyagi et al. 2015), comprising at least 20 percent of total annual CPH for each of the past 16 years. When examining annual catch, DWR found that not only was there particularly high CPH of White Catfish in WY2013 and WY2015, but that the CPH and proportion of total CPH have increased over time (Figures 3 and 4). Using a Mann-Kendall trend test (Mann 1945), the annual CPH of White Catfish in the fyke trap was found to be increasing over time over the study

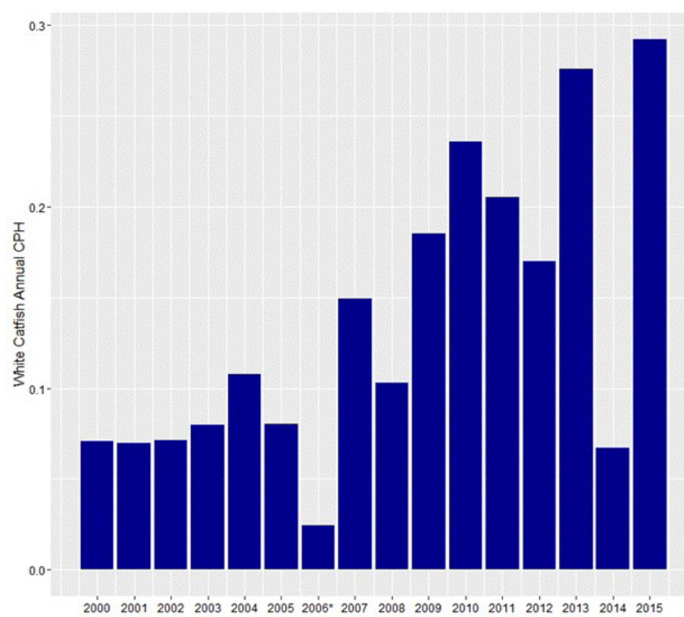

Figure 3. Annual CPH (from October to May) of White Catfish from the fyke trap showing a general pattern of increase over time.

*Limited sampling in water year 2006 as a result of extended high flow periods in the Yolo Bypass.

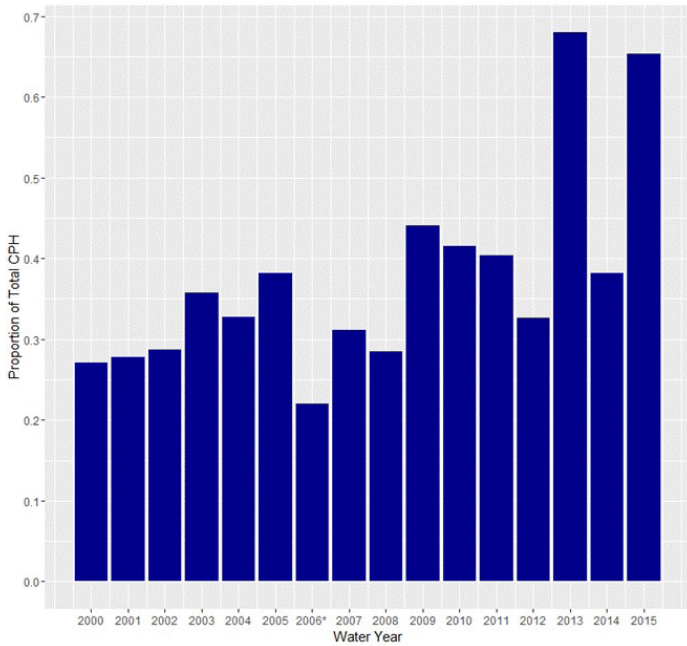

Figure 4. Proportion of fish CPH per year from the fyke trap that is comprised of White Catfish.

*Limited sampling in water year 2006 as a result of extended high flow periods in the Yolo Bypass.

period (1998–2015; $p < 0.01$). The proportion of White Catfish annual CPH to total annual CPH was also found to be increasing over time ($p < 0.01$).

Both the increase in CPH and the increase in proportion of White Catfish in the total fyke trap catch indicate that the species is likely the most abundant large-bodied fish in the Toe Drain during non-inundation periods and will likely be prevalent in the Yolo Bypass for the foreseeable future. It is unknown if catfish species continue to utilize the Yolo Bypass during inundation events, as the fyke trap often cannot be operated during such high flows. An introduced species, White Catfish are generally omnivorous in their diet, though they have the potential to become more piscivorous upon reaching adulthood (Turner 1966). Channel Catfish (*Ictalurus punctatus*) have also been documented as being piscivorous as adults (Marsh and Brooks 1989; Poe et al. 1991; Vigg et al. 1991; Marsh and Douglas 1997), and they are the second most abundant species caught in the fyke over the entire study period (1998–2015), making up 10.6 percent of the total CPH. Although catfish species have been present in the Delta for decades and have contributed to a successful sport fishery in California (Dill and Cordone 1997), their high (and potentially increasing) abundance suggests that they may have a substantial impact on the ecosystem. As the Yolo Bypass continues to be an important rearing habitat for juvenile native fish species such as Delta Smelt and Chinook Salmon, it may be worth investigating the potential impact of catfish predation on such species in the future.

Acknowledgements

The Yolo Bypass Fish Monitoring Program would not be possible without the support and funding from IEP. We'd like to thank the following WY2015 YBFMP field staff: Angelica Munguia, Mollie Ogaz, Oliver Patton, Lynn Takata, and Pascale Goertler. We'd also like to acknowledge to Ted Sommer for pioneering scientific research in the Yolo Bypass.

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2016 20-mm Survey

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

The 20-mm Survey uses a conical net with 1600-micron nylon mesh for collecting young of the year (YOY) fish. 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 mounted on skis. At each station, the entire water column is sampled using three stepped-oblique tows and a single zooplankton tow. All samples are preserved in 10 percent buffered formalin dyed with rose bengal for later identification and enumeration in the laboratory. Fish are measured to the nearest millimeter (mm) fork length if the caudal fin is forked, or to the nearest mm total length if the caudal fin is not forked. In this article, "length" is

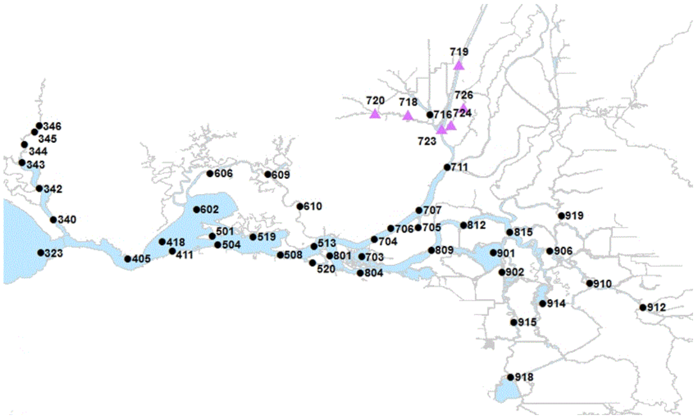

Figure 1. The 2016 CDFW 20-mm Survey station map, showing current sampling locations in the upper San Francisco Estuary.
Note: Stations marked with a black dot are core stations. Stations marked with a purple triangle are non-core stations.

used as a generic term that includes both fork and total length, since the fish captured in the 20-mm fish net may have forked or non-forked caudal fins.

From March 14 to July 7, 2016, nine biweekly surveys were completed. Each survey sampled a total of 47 stations (Figure 1) to measure larval fish and zooplankton densities. As a result of logistical issues, stations were omitted from Surveys 1, 3, and 7. Three stations in Montezuma Slough and one station at the mouth of the Sacramento River were omitted from Survey 1, two stations in Miner Slough were omitted from Survey 3, and one station in the Napa River was omitted from Survey 7.

A total of 72,960 fish representing 42 taxa were caught in 2016 (Table 1). *Tridentiger* spp. (gobies) was the most abundant organism caught, making up about 55 percent of the total catch. Striped Bass (*Morone saxatilis*) was the next most abundant species, making up about 28 percent of the total catch. This year's Striped Bass catch (n = 20,251) showed about a fourfold increase from last year (n = 4,972), and is the second highest catch on record. This year's larval White Sturgeon catch is the highest on record (n = 137). White Sturgeon larvae have only been caught in 14 of the 22 years on record (1995–2016) and the second highest catch occurred in 1998 (n = 81).

Delta Smelt was the 16th most abundant species this year, making up 0.18 percent of the total catch. A total of 128 Delta Smelt were caught, which is a marginal increase from last year (n = 94) (Morris 2016). Larval and juvenile Delta Smelt catch was low in March, but peaked

Table 1. Total species catch for the 2016 CDFW 20-mm Survey.

Common Name	***n***	***% Catch***
Tridentiger Gobies	39,995	54.82
Striped Bass	20,251	27.76
Threadfin Shad	5,382	7.38
Pacific Herring	1,604	2.20
Yellowfin Goby	1,315	1.80
Longfin Smelt	1,113	1.53
Northern Anchovy	775	1.06
Prickly Sculpin	393	0.54
American Shad	278	0.38
Arrow Goby	224	0.31
Centrachids	199	0.27
Threespine Stickleback	170	0.23
Sacramento Sucker	156	0.21
White Catfish	144	0.19
White Sturgeon	137	0.18
Delta Smelt	128	0.14
Longjaw Mudsucker	105	0.13
Inland Silverside	93	0.12
Splittail	90	0.10
Bigscale Logperch	72	0.08
Cyprinids	57	0.07
Topsmelt	50	0.06
Common Carp	44	0.05
Jacksmelt	40	0.05
Wakasagi	34	0.03
Shimofuri Goby	22	0.03
Chinook Salmon	19	0.02
Channel Catfish	17	0.02
Rainwater Killifish	13	0.01
Shokihaze Goby	7	0.01
Bay Goby	7	0.01
Bay Pipefish	6	0.01
White Croaker	5	0.01
Golden Shiner	4	0.01
Plainfin Midshipman	3	< 0.01
Cheekspot Goby	2	< 0.01
Largemouth Bass	1	< 0.01
Bluegill Sunfish	1	< 0.01
Mosquitofish	1	< 0.01
River Lamprey	1	< 0.01
Pacific Lamprey	1	< 0.01
Starry Flounder	1	< 0.01

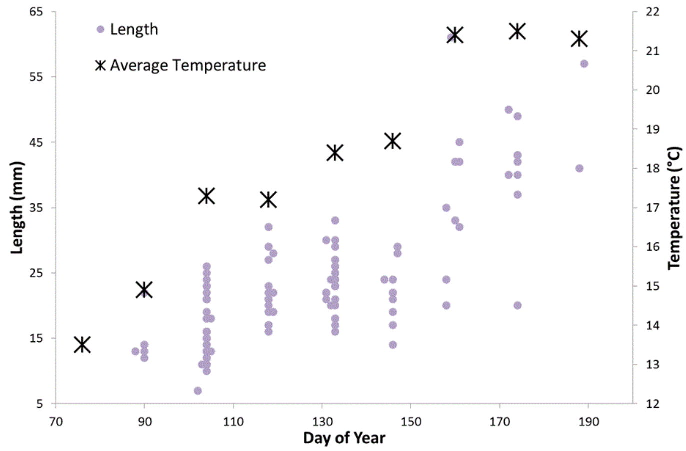

Figure 2. Scatterplot of Delta Smelt lengths (mm) by day of year.

Note: The secondary axis displays mean water temperature by survey, using all stations sampled during the 2016 CDFW 20-mm Survey.

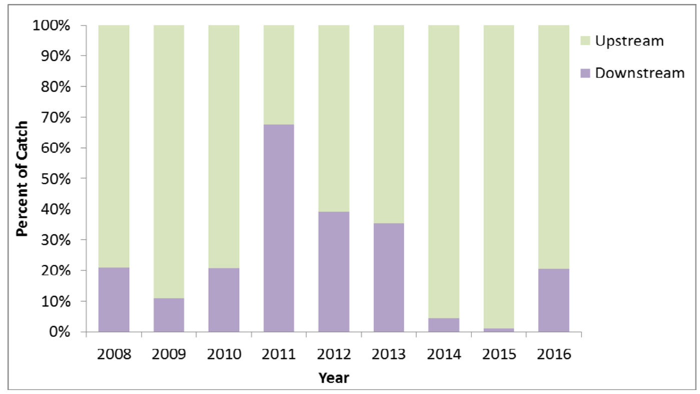

Figure 3. Yearly proportion of young of the year Delta Smelt caught in two geographic regions during the 20-mm Survey, from 2008 to 2016 (not all upstream stations were sampled prior to 2008).

Note: "Upstream" refers to all stations east of the confluence; "Downstream" refers to all stations around and west of the confluence.

in April and May, in which 80 percent of the Delta Smelt were caught for the year (Surveys 3–6, n = 47, 15, 31, and 10, respectively). Catch then decreased for the remainder of the season. Only one adult was caught this year (length = 61 mm), and it was collected during Survey 7. Young of the year Delta Smelt ranged in size from 7–57 mm. Average Delta Smelt length increased 34 mm between March and July (Surveys 2–9). This results in a growth rate of about 0.33 mm/day, which can be calculated by dividing the total growth by the number of days spanning the last 8 surveys. The largest increase in average length was seen between Surveys 6 and 7 (late May–early June, Figure 2). Throughout the Sacramento-San Joaquin Delta (Delta), average temperatures increased almost 3 degrees during this time period, and it is likely that the observed increase in length reflects that new cohorts were no longer being captured as temperatures neared 20 °C, signifying the end of the spawning period (Bennett 2005). In addition, a large phytoplankton bloom was present in the Delta in early May (Brian Bergamaschi, pers. comm. June 1, 2016). If this bloom propagated throughout the food chain, it is possible that it increased food availability to Delta Smelt, and may have played a role in an increased growth rate.

Young of the year Delta Smelt were distributed mostly upstream in 2016, a pattern similar to recent drought years (Damon 2015; Morris 2016). Sixty-five percent of Delta Smelt were caught in the Sacramento Deep Water Ship Channel (SDWSC) at station 719, mostly in April and May (Surveys 3–5). Fourteen percent of Delta Smelt were collected at all other stations upstream of the confluence of the Sacramento and San Joaquin rivers, and 21 percent of Delta Smelt were collected around and downstream of this confluence. The distribution of smelt between upstream and downstream locations was slightly broader this year than in 2014 or 2015 (Figure 3). Delta Smelt were observed in the Napa River for the first time since 2012, and 10 individuals were collected in April and May. Delta Smelt have only been seen in the Napa River when average salinities in the Napa River were less than 10 parts per trillion (ppt) (Figure 4). Their presence in the Napa River is likely a reflection of expanded Delta Smelt distribution resulting from increased outflow and reduced salinity in the Napa River (Bennett 2005). By June, Delta Smelt were no longer detected in the Napa River but were

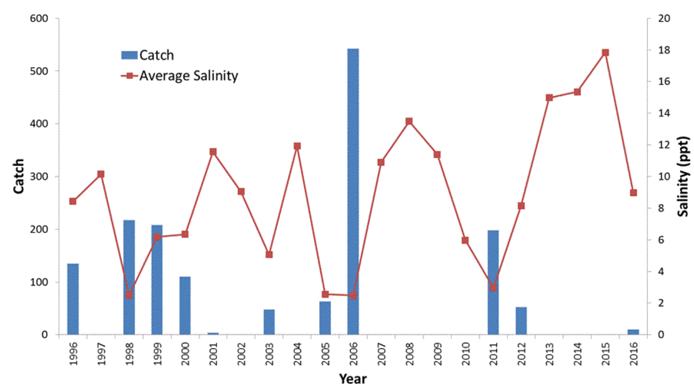

Figure 4. Yearly Delta Smelt catch at Napa River stations and associated average salinity collected during the CDFW 20-mm Survey.

Note: Year is on the X-axis, Delta Smelt catch and average salinity (in parts per trillion) is on the Y-axis.

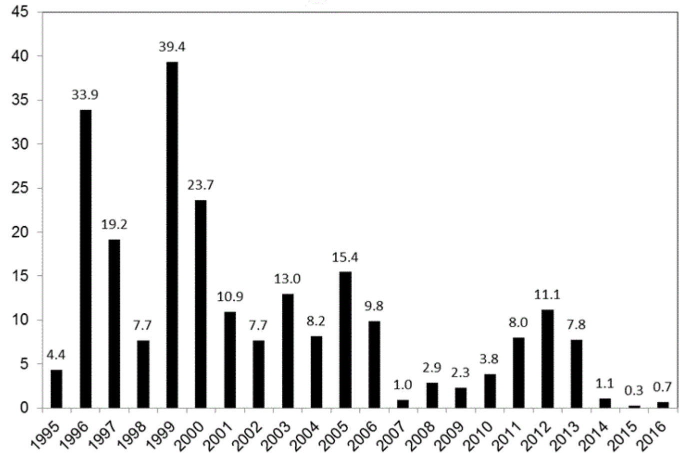

Figure 5. CDFW 20-mm Survey Delta Smelt Index of Relative Abundance (1995–2016).

present in the lower San Joaquin River, where less than 2 percent of the season catch occurred.

The abundance of Delta Smelt increased slightly compared to last year, as indicated by overall catch and the annual index (Morris 2016; Damon and Morris 2016). The 2016 index was 0.7 and was calculated using Surveys 2–5 (March and April) (Figure 5). Surprisingly, the increase in larval production follows a decrease in the spawning stock abundance in 2016 (Damon in press). The increase in larval production may have been influenced by increased flow and increased habitat availability west of the confluence (Bennett 2005).

The 20-mm Survey began collecting jellyfish data in 2015, and a summary of the methods and data is expected to be released in a future edition of this newsletter.

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

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2016 Smelt Larva Survey Summary

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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). SLS provides near real-time catch data to resource managers to aid in assessing the risk of entrainment to Longfin Smelt at water export facilities. The survey also collects data on other larval fishes in the upper SFE.

The SLS samples from January–March, which corresponds to the time period when the highest numbers of larval Longfin Smelt are most likely to be present in the survey area (Baxter 1999). Each year, six biweekly surveys are conducted, and each survey samples 44 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 percent buffered formalin dyed with rose bengal for later identification and enumeration in the laboratory. Fish are measured to the nearest millimeter (mm) forklength if the tail is forked, or nearest mm total length if the tail is not forked. For additional information on SLS methods and sampling design and prior year summary reports, see our online bibliography (http://www.dfg.ca.gov/delta/data/sls/bibliography.asp).

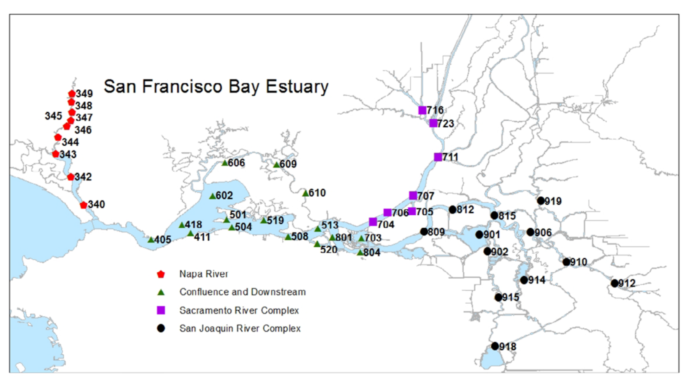

Figure 1. Station locations and geographical regions sampled by the California Department of Fish and Wildlife's (CDFW) Smelt Larva Survey.

The 2016 SLS Survey ran from January 4th to March 17th. All stations were sampled during Surveys 1–5. In Survey 6, nine stations were not sampled in the Napa River owing to boat issues. A total of 129,699 fish representing 26 taxa (Table 1) were collected during the 2016 field season. Pacific Herring (*Clupea pallasii*) was by far the most abundant species caught, comprising about 84 percent of the total catch. Longfin Smelt (*Spirinchus thaleichthys*) was the fourth most abundant species, making up less than 1 percent of the total catch. A total of 739 Longfin Smelt were caught, which is the lowest catch in the history of the survey (2009–2016). Prior to this season, historic annual Longfin Smelt catch has ranged from 966 to 22,727 (average of 10,790). Although their abundance was relatively low, Longfin Smelt were broadly distributed and were collected in 47 percent of all samples taken (for example, see Figure 2). Longfin Smelt were collected in each region of the estuary, but most (71 percent) were collected around and downstream of the confluence (Figure 1).

Table 1. Total species catch from the 2016 CDFW Smelt Larva Survey.

Common Name	*n*	*% of Catch*
Pacific Herring	109,404	84.4%
Yellowfin Goby	15,293	11.8%
Prickly Sculpin	3,941	3.0%
Longfin Smelt	739	0.6%
Northern Anchovy	115	<0.1%
Arrow Goby	79	<0.1%
Sacramento Sucker	33	<0.1%
Shokihaze Goby	18	<0.1%
Bigscale Logperch	9	<0.01%
Delta Smelt	8	<0.01%
Longjaw Mudsucker	8	<0.01%
Threespine Stickleback	8	<0.01%
Shimofuri Goby	7	<0.01%
Jacksmelt	6	<0.01%
White Catfish	5	<0.01%
Pacific Staghorn Sculpin	5	<0.01%
Chinook Salmon	4	<0.01%
Inland Silverside	4	<0.01%
White Croaker	3	<0.01%
Rainwater Killifish	3	<0.01%
Cyprinids (Unid)	2	<0.01%
Centrarchids (Unid)	1	<0.01%
Speckled Sanddab	1	<0.01%
Wakasagi	1	<0.01%
Spotted Bass	1	<0.01%
Bluegill Sunfish	1	<0.01%

Mean fork length of Longfin Smelt increased nearly 6 mm (±4.8 mm) from January to March (Survey 1, n = 47; Survey 6, n = 25), which is the largest increase in the history of the Survey and may indicate high growth rates in 2016 (Figure 3). In February and March (Surveys 3–6), mean fork lengths were consistently highest in the Napa River, and higher around the confluence and downstream than they were in the Sacramento and San Joaquin river complexes (Figure 4). Interestingly, water temperatures were consistently higher in the Napa River than in other regions of the estuary (Figure 5), but the impact these higher temperatures may have had on larval Longfin Smelt growth is unclear. Near and downstream of the confluence, high catch and large individuals were observed, which may indicate downstream transport of larvae from their hatching site to suitable rearing habitat west of the confluence.

Delta Smelt (*Hypomesus transpacificus*) were first collected in mid-March, during the last survey of the year (Survey 6). Eight larval Delta Smelt were collected, and they were broadly distributed throughout the estuary (Figure 6). This suggests that spawning likely began in early March, which is corroborated by the 2016 Spring Kodiak Trawl and 20-mm data (Damon 2016; Tempel 2016).

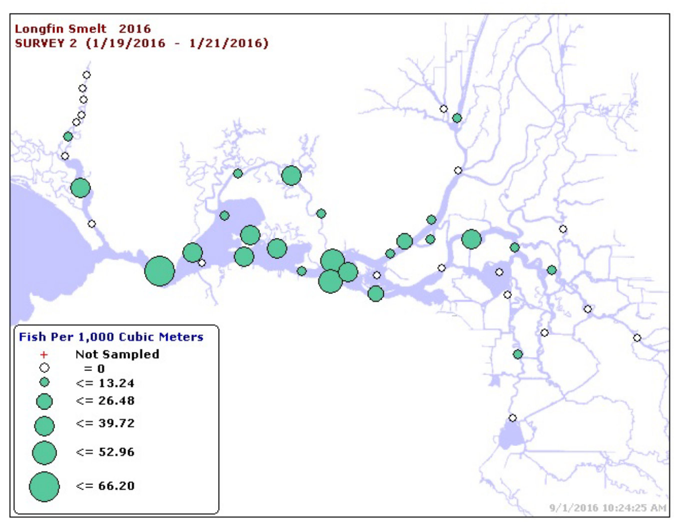

Figure 2. Distribution and catch per unit effort of Longfin Smelt from Survey 2 of the 2016 CDFW Smelt Larva Survey.

Note: Taken from SLS webpage: https://www.wildlife.ca.gov/Conservation/Delta/Smelt-Larva-Survey.

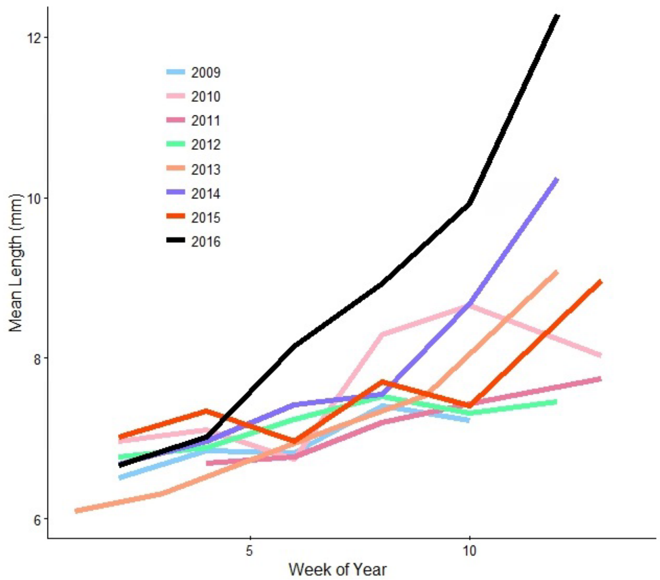

Figure 3. Mean fork lengths of Longfin Smelt collected during the CDFW Smelt Larva Survey, grouped by week of collection and year.

Note: Catch from Napa River stations is not included.

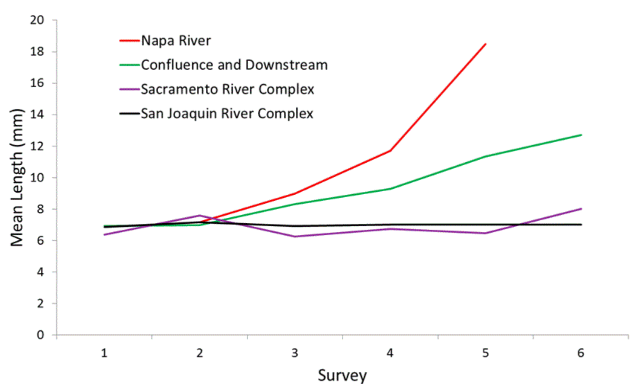

Figure 4. Mean fork lengths of Longfin Smelt collected during the 2016 CDFW Smelt Larva Survey, grouped by survey number and geographic region.

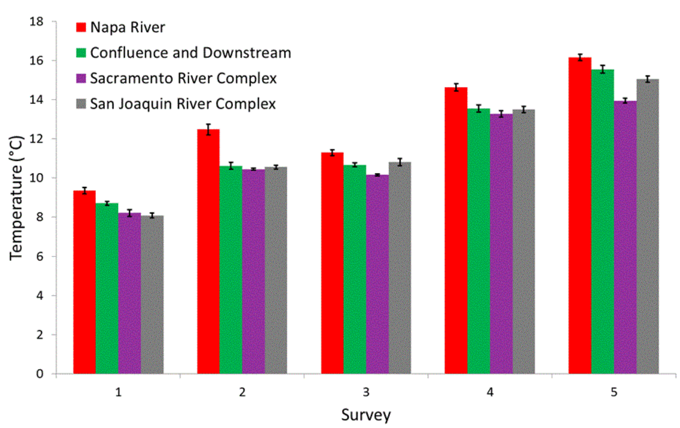

Figure 5. Mean water temperatures (±SE) during the 2016 CDFW Smelt Larva Survey, grouped by survey number and geographic region.

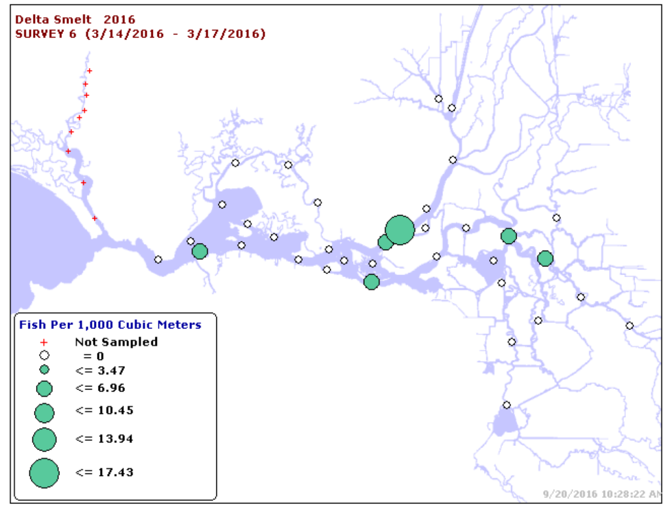

Figure 6. Distribution and catch per unit effort of Delta Smelt from Survey 6 of the 2016 CDFW Smelt Larva Survey.

Note: Taken from SLS webpage: https://www.wildlife.ca.gov/Conservation/Delta/Smelt-Larva-Survey.

For CPUE values, survey data, and data visualization, please see the SLS webpage and FTP site (https://www.wildlife.ca.gov/Conservation/Delta/Smelt-Larva-Survey; ftp://ftp.dfg.ca.gov/Delta%20Smelt/).

References

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2015 Benthic Monitoring

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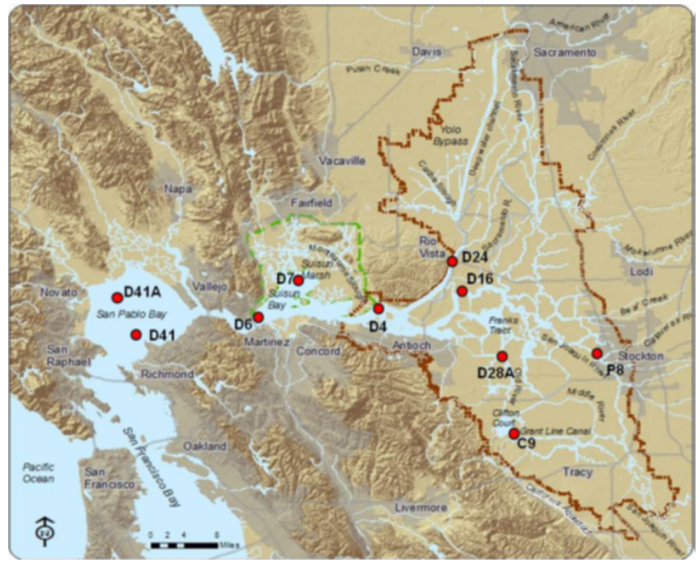

Figure 1. Locations of the Environmental Monitoring Program's (EMP) benthic monitoring stations.

Introduction

The benthic monitoring component of the IEP's Environmental Monitoring Program (EMP) documents changes in the composition, abundance, density, and distribution of the macrobenthic biota of the upper San Francisco Estuary. Benthic species respond to changes in physical factors within the system, such as freshwater inflows, salinity, and substrate composition. As a result, benthic community data can provide an indication of physical changes occurring within the estuary. Because operation of the State Water Project can affect the flow characteristics of the estuary and subsequently influence the density and distribution of benthic biota, benthic monitoring is an important component of the EMP. The benthic monitoring data are also used to detect and document the presence of species that are newly introduced into the upper estuary. This article summarizes the characteristics of benthic communities at the EMP's monitoring sites in 2015, and places these results in the context of results from the previous decade.

Methods

Benthic monitoring was conducted monthly at 10 sampling sites distributed throughout several estuarine regions, from San Pablo Bay upstream through the Sacramento-San Joaquin Delta (Delta) (Figure 1). EMP staff collected five bottom-grab samples at each station using a Ponar dredge with a sampling area of 0.052 square meters (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 California Department of Water Resources. All organisms were identified to the lowest taxon possible and enumerated. Sediment composition analysis was conducted at the California 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 at http://www.water.ca.gov/bdma/meta/benthic.cfm.

Prior to analysis, the counts per grab sample were standardized to individuals per square meter for each species at each site and sample date. Species were then grouped into phyla, and total densities for individual phyla were then plotted month-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 2015 water year was designated as critically dry for both the Sacramento Valley and the San Joaquin Valley. The benthic communities at many of the monitoring sites in 2015 were expected to differ from the communities of the sites in wetter years, such as 2006 and 2011, and to be similar to dry years, such as 2014. Differences between 2015 and wetter years were expected both in species composition and in species abundances, particularly at sites in the low-salinity zone where the regime switches from a freshwater regime to a more salt-tolerant one.

Results

Eight new species were added to the benthic species list in 2015: three species of polychaete worms, an unknown species of Oligochaete worm from genus

Pristina (Order Tubificid, Family Naididae), an unidentified species of nematode, an isopod from genus *Cyathura* (Order Isopoda, Family Anthuridae), and two new species of crabs from genus *Romaleon*. These two species, *R. jordani* and *R. antennarius*, are known to be found in San Francisco Bay, but were found for the first time at EMP survey sites in San Pablo Bay.

Nine phyla were represented in the benthic fauna collected in 2015: 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). Of these phyla, Annelida, Arthropoda, and Mollusca accounted for more than 98 percent of all individuals collected in 2015.

Of the 201 benthic species collected in 2015, the 10 most abundant species represented 78 percent of all individuals collected throughout the year. These included three species of amphipod, an ostracod, an Asian clam, and five worms (Table 1). Refer to the Bay-Delta Monitoring and Analysis Section's Benthic BioGuide (http://www.water.ca.gov/bdma/BioGuide/BenthicBioGuide.cfm) or Fields and Messer (1999) for descriptions of the habitat requirements, physical attributes, and feeding methods of most of these 10 abundant species.

In the site descriptions that follow, species densities are most frequently 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 that are several times larger than their annual averages; in these cases, we decided that reporting the timing and magnitude of the peaks was more informative than reporting the annual averages for readers who are interested in how the sites varied throughout the year. Readers who wish to see the full dataset can access it at http://www.water.ca.gov/bdma/meta/benthic/data.cfm.

North Delta (D24)

D24 is located on the Sacramento River, just south of the Rio Vista Bridge (Figure 1). The substrate at this

Table 1. Ten most abundant species collected by the benthic monitoring component of the EMP in 2015, as determined by total number of individuals collected.

Species	*Organism Type*	*Native/ Introduced Status*	*Stations at which the species was found**	*Month(s) in which the species was abundant*	*Total number of individuals***
Potamocorbula amurensis	Asian clam	Introduced	D6, D7, D4, D41A, D16	May through December	46,924
Manayunkia speciosa	Sabellidae polychaete worm	Introduced	P8, D28A, C9, D24, D16	Abundant all year, peak in July-August	35,866
Ampelisca abdita	Amphipod	Introduced	D41A, D41, D7, D6	May-October	17,815
Limnodrilus hoffmeisteri	Tubificidae worm	Unknown; cosmopolitan	C9, P8, D4, D28A, D24, D16, D7, D6	Abundant all year	13,950
Varichaetadrilus angustipenis	Tubificidae worm	Introduced	D4, D28A, C9, D24, P8, D16	Abundant all year	13,816
Laonome calida	Sabellidae polychaete worm	Introduced	D4, P8, D28A, D16, C9, D7, D24	Abundant all year	12,282
Cyprideis sp. A	Ostracod	Unknown	D28A, C9, P8, D4	January-July	7,299
Gammarus daiberi	Amphipod	Introduced	D28A, C9, D24, D4, P8, D16, D7, D6	May-September	7,256
Aulodrilus pigueti	Tubificidae worm	Unknown; cosmopolitan	C9, P8, D28A, D24, D4	January, July-August	5,969
Corophium aliense	Amphipod	Introduced	D7, D4, D41A, D6, D24	January-May, December	5,914

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

**Total number of individuals was the sum of individuals at all sites at all months in 2014.

station in 2015 was consistently made up of sand in each month of the monitoring. There were 37 species across five phyla at D24. Mollusca was the most abundant phylum, accounting for 43 percent of organisms collected (Figure 2). Nearly all (97 percent) of the mollusks found at D24 in 2015 were *Corbicula fluminea*, which had an average density of 710 individuals/m^2. *Gammarus daiberi* made up 92 percent of all arthropods at D24 in 2015, peaking in May with a density of 2,462 individuals/m^2, which is more than six times its annual average density. The Oligochaete worm *Varichaetadrilus angustipenis* was the most abundant annelid, with an annual average density of 377 individuals/m^2. The benthic community at D24 in 2015 was similar to the community found in past dry years, though *C. fluminea* density continues to decline since 2012, while *V. angustipenis* density increased fourfold in 2015.

Central Delta (D16, D28A)

The benthic monitoring program conducted sampling at two stations in the central Delta. D16 is located in the lower San Joaquin River near Twitchell Island, and D28A is located in Old River near Rancho Del Rio (Figure 1). The substrate at D16 was consistently clay, with varying proportions of sand during the monitoring. There were 24 species across five phyla in D16. Arthropoda was the most abundant phylum, making up 70 percent of all organisms collected (Figure 3). The most abundant arthropods were *Americorophium spinicorne* (peaking in March with 4,654 individuals/m^2, more than 10 times its annual average) and *Gammarus daiberi* (annual average of 146 individuals/m^2).

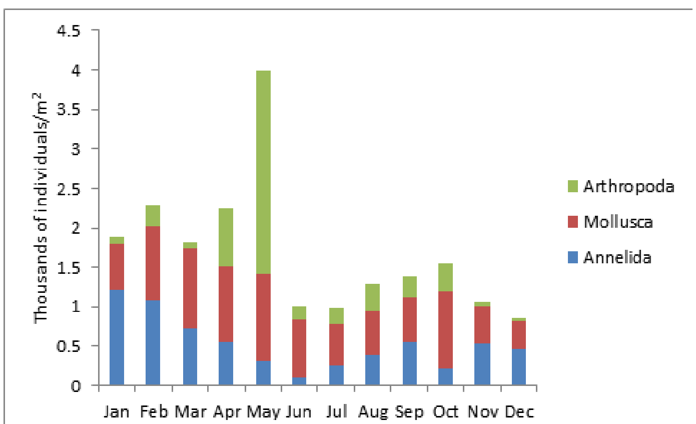

Figure 2. Density of benthic organisms, grouped by phylum, collected at station D24 (Sacramento River at Rio Vista) by month in 2015.

Mollusks made up 14 percent of all organisms collected, and *Corbicula fluminea* was by far the most abundant, with a peak of 384 individuals/m^2 in March. The benthic community at D16 has had relatively stable diversity during the past decade, apart from an increase in *A. spinicorne* density in 2015.

The substrate at Station D28A generally consisted of a high percentage of sand with silt, and some months during monitoring it contained large quantities of vegetable material. D28A had 67 species in seven phyla, and Annelida was the most abundant for almost all months in 2015, accounting for 61 percent of organisms collected (Figure 4). The most abundant annelids were *Manayunkia speciosa*, with an annual average density of 2,990 individuals/m^2 and a peak in February and March, and *Varichaetadrilus angustipenis*, which had an annual average density of 1,790 individuals/m^2. The most

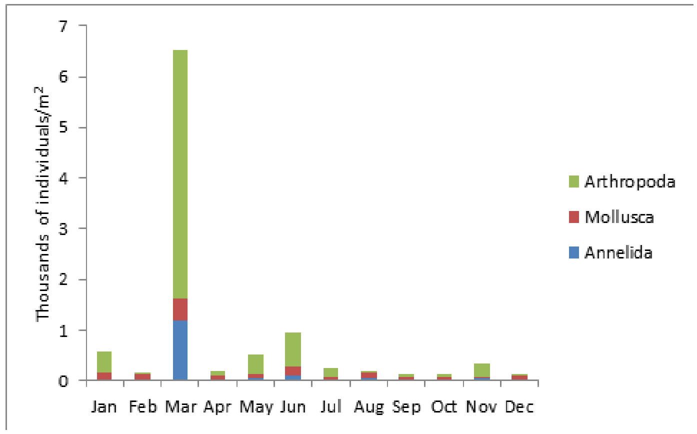

Figure 3. Density of benthic organisms, grouped by phylum, collected at station D16 (San Joaquin River at Twitchell Island) by month in 2015.

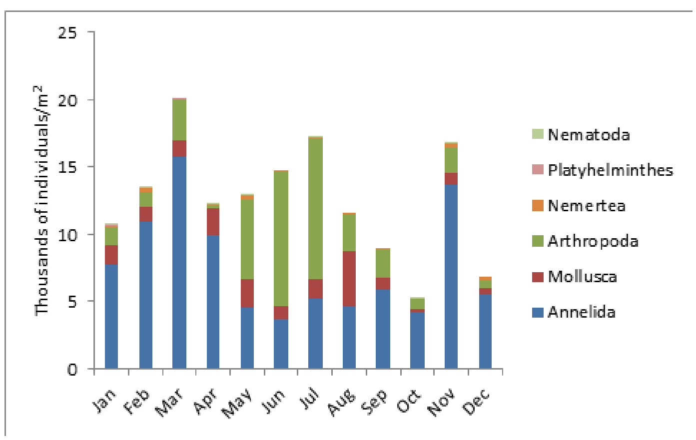

Figure 4 Density of benthic organisms, grouped by phylum, collected at station D28A (Old River) by month in 2015.

abundant arthropods were *Gammarus daiberi* (annual average of 1,223 individuals/m^2, peaking in June at 6,091 individuals/m^2) and *Cyprideis* species *A* (annual average of 1,146 individuals/m^2). Densities of dominant species at D28A have increased dramatically after dropping to very low numbers following the wet winter in 2011, although in 2015 there were half as many arthropods as there were in 2014. Arthropod decreases were especially prevalent for *Cyprideis* species *A*, *G. daiberi*, and *Americorophium spinicorne*.

South Delta (P8, C9)

The benthic monitoring program conducted sampling at two stations in the southern Delta. P8 is located on the San Joaquin River at Buckley Cove, and C9 is located at the Clifton Court Forebay intake (Figure 1). The substrate of station P8 was primarily clay in all months during monitoring. P8 had 48 species in six phyla in 2015. The most abundant phylum in all months was Annelida, accounting for 91 percent of all organisms (Figure 5). The dominant annelid was *Manayunkia speciosa*, peaking in July with 24,288 individuals/m^2 and accounting for 75 percent of all annelids collected at P8. In 2015, P8 showed a large increase in the number of annelids from 2014, driven mostly by *M. speciosa*, which has increased steadily since 2012, but also by *Limnodrilus hoffmeisteri*, which doubled in density during 2014.

The substrate at C9 was silt or clay with varying proportions of sand, peat, and organic debris during monitoring. There were 80 species in seven phyla in 2015. Annelida was the most abundant phylum in all months, and made up 66 percent of all organisms collected (Figure 6). The most abundant annelids were *Limnodrilus hoffmeisteri* (annual average of 2,218 individuals/m^2), *Aulodrilus pigueti* (annual average of 1,462 individuals/m^2, with a peak of 6,529/m^2 in January), and *Varichaetadrilus angustipenis* (annual average of 1,379 individuals/m^2). The most abundant arthropod was *Cyprideis* species *A*, representing 38 percent of all arthropods and peaking in May with 3,764 individuals/m^2. In 2015, the most abundant species in the community declined, notably the annelids *L. hoffmeisteri*, *V. angustipenis*, and *Ilyodrilus frantzi*, which have declined for several years since peaking in 2011. Species that had been increasing since 2011, such as *Manayunkia speciosa*, *A. pigueti*, *Americorophium spinicorne*, and *Cyprideis* sp. *A*, also began to decline in 2015.

Confluence (D4)

D4 is located near the confluence of the Sacramento and San Joaquin rivers, just above Point Sacramento (Figure 1). In most months during monitoring, the substrate was mostly clay and silt with varying levels of organic matter. There were 48 species in six phyla at D4. Annelida was the most abundant phylum year round, accounting for 74 percent of all organisms collected (Figure 7). The most abundant annelid was *Laonome calida,* with an annual average of 3,906 individuals/m^2, peaking in August at 7,221 individuals/m^2 and staying high through December. *Nippoleucon hinumensis* was the most abundant arthropod at D4, with an annual average of 861 individuals/m^2 and peaking in May with a density of

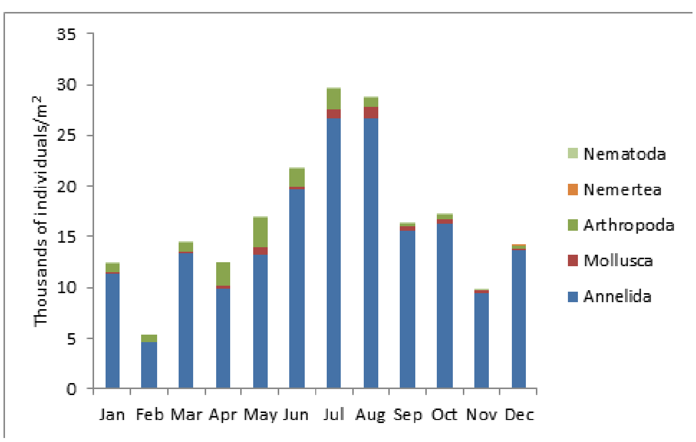

Figure 5. Density of benthic organisms, grouped by phylum, collected at station P8 (San Joaquin River at Buckley Cove) by month in 2015.

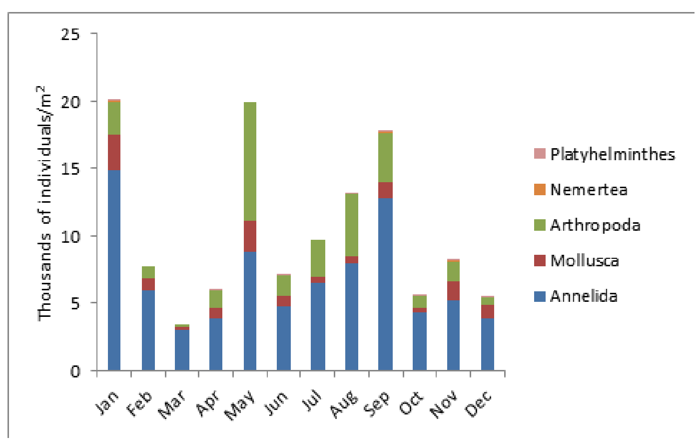

Figure 6. Density of benthic organisms, grouped by phylum, collected at station C9 (Clifton Court) by month in 2015.

4,490 individuals/m^2. *Potamocorbula amurensis* made up 90 percent of all mollusks, with a peak density in August of 4,111 individuals/m^2 and an annual average density of 934 individuals/m^2. In 2015, most species exhibited a continued decline from 2014, especially amphipods *Americorophium spinicorne*, *Gammarus daiberi*, and *Americorophium stimpsoni*. These species formed the majority of the community during the last wet year in 2011. One notable exception to the decline in 2015 was the annelid *L. calida*, which showed a fourfold increase in density from 2014.

Suisun Bay (D6 and D7)

The benthic monitoring program conducted sampling at two stations in the Suisun Bay area. D6 is located in Suisun Bay near Martinez, and D7 is located in Grizzly Bay near Suisun Slough (Figure 1). The substrate at D6 was consistently made up of clay during the monitoring period, with a small proportion of sand. There were 38 species in four phyla at D6 in 2015. Mollusca was by far the dominant phylum in all monitoring months at this station, accounting for 96 percent of all organisms collected (Figure 8). *Potamocorbula amurensis* made up 99.98 percent of all mollusks collected at D6, with an annual average density of 10,466 individuals/m^2, peaking in July and August. Most of the remaining organisms were various species of arthropods. D6 has looked remarkably similar from 2013–2015, with *P. amuerensis* dominating after a decline during the 2011 wet year.

The substrate at D7 was primarily clay throughout the year. In 2015, there were 29 species in four phyla. Mollusks were the most abundant phyla at D7, from May through December, and made up 69 percent of all organisms in 2015 (Figure 9). *Potamocorbula amurensis* accounted for 99 percent of all mollusks and had an annual average density of 7,396 individuals/m^2, with a peak of 17,486 individuals/m^2 in July. The most abundant arthropods were *Corophium alienense* (68 percent of all arthropods), with a peak density of 6,716 individuals/m^2 in May, and the cumacean crustacean *Nippoleucon hinumensis* (23 percent of all arthropods), with an annual average density of 699 individuals/m^2, with peaks in April and October. D7 in 2015 saw a decrease in *P. amurensis*, which had previously been increasing since the last wet year in 2011, while *N. hinumensis* has continued to increase since 2011.

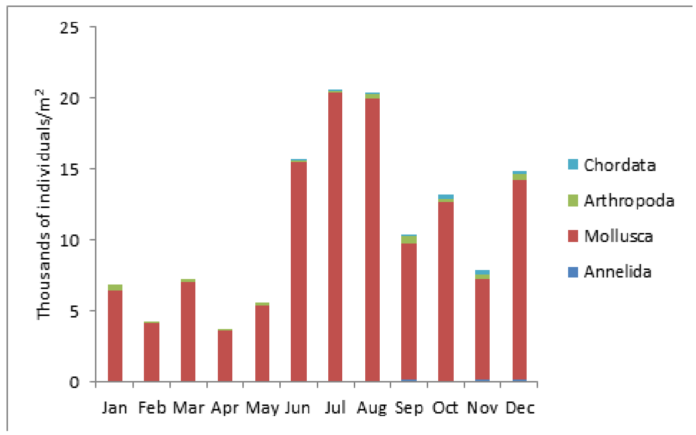

Figure 8. Density of benthic organisms, grouped by phylum, collected at station D6 (Suisun Bay) by month in 2015.

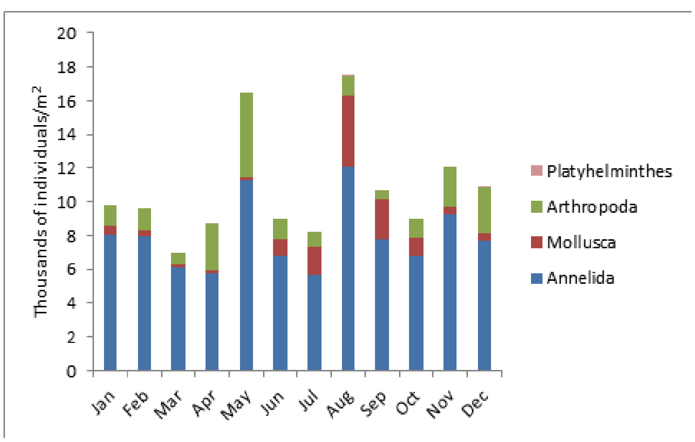

Figure 7. Density of benthic organisms, grouped by phylum, collected at station D4 (Confluence) by month in 2015.

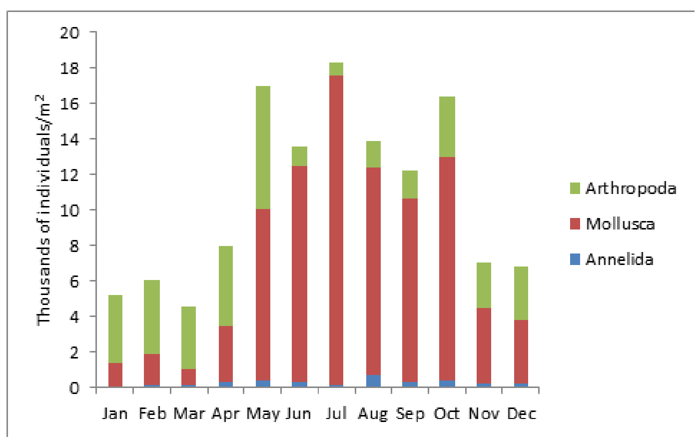

Figure 9. Density of benthic organisms, grouped by phylum, collected at station D7 (Grizzly Bay) by month in 2015.

San Pablo Bay (D41, D41A)

The benthic monitoring program conducted sampling at two stations in San Pablo Bay. D41 is located near Pinole Point, and D41A is located near the mouth of the Petaluma River (Figure 1). D41 has a benthic community primarily comprised of marine organisms, especially in dry water years. The sediment composition at D41 during monitoring was primarily sand or clay mixed with varying proportions of silt and organics (primarily clamshells). In 2015, there were 80 species in nine phyla at D41. Overall, Arthropoda was the most abundant phylum at D41 in 2015 (42 percent of organisms collected) (Figure 10). The amphipod *Ampelisca abdita* was the most abundant arthropod (86 percent of all arthropods), with a peak in October of 11,365 organisms/m^2, almost seven times the annual average. The phylum *Phoronida* accounted for 23 percent of all organisms collected. The sole phoronid, *Phoronopsis harmeri*, had an annual average density of 1,031 individuals/m^2, with two peaks in May and August. At D41 in 2015, *A. abdita* density increased after a massive 2014 decline following a peak in 2013. From 2012-2015, D41 has also seen a large increase in *P. harmeri* density.

The substrate of the D41A station was primarily clay in all months. There were 53 species in six phyla at D41A in 2015. Arthropoda was the most dominant phylum all year, accounting for 87 percent of all organisms collected (Figure 11). The dominant arthropod was *Ampelisca abdita* (92 percent of all arthropods), with an annual average density of 5,443 individuals/m^2, with a peak in August of 10,264 individuals/m^2. The most common annelid was *Euchone limnicola*, with a peak of 1,245 indivduals/m^2, and an annual average density of 369 individuals/m^2. The most common mollusk was *Theora lubrica,* with an annual average density of 201 individuals/m^2. As at D41, there was an increase in *A. abdita* density at D41A in 2015. Also of note was *Potamocorbula amurensis*, which, after a brief boom in the wet year of 2011, declined significantly during the following dry years of 2012–2015.

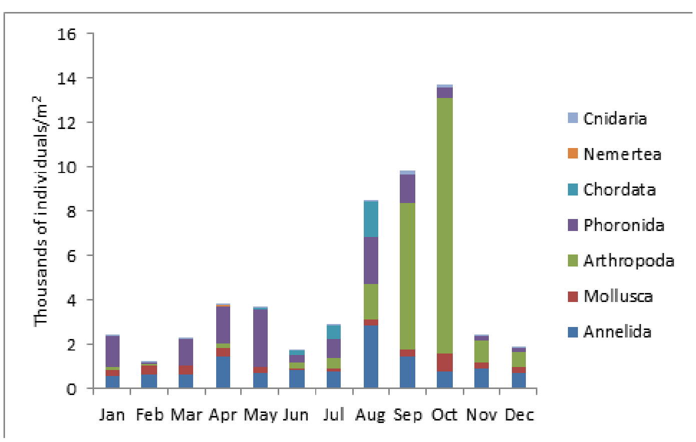

Figure 10. Density of benthic organisms, grouped by phylum, collected at station D41 (San Pablo Bay) by month in 2015.

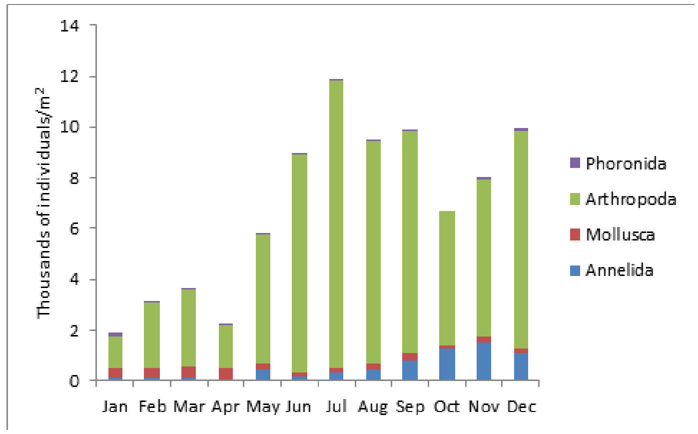

Figure 11. Density of benthic organisms, grouped by phylum, collected at station D41A (San Pablo Bay) by month in 2015.

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2014 and 2015 Phytoplankton Community Composition

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Introduction

The Department of Water Resources and the U.S. Bureau of Reclamation are required by Water Right Decision 1641 (D-1641) to collect phytoplankton samples to monitor algal community composition at selected sites in the upper San Francisco Estuary (Estuary) as part of the Environmental Monitoring Program (EMP). The 13 sampling sites range from San Pablo Bay, moving eastward into the lower Sacramento, Mokelumne, and San Joaquin rivers. These sites represent a variety of aquatic habitats, from narrow, freshwater channels in the Sacramento-San Joaquin Delta (Delta) to broad, estuarine bays. This article describes the results of these monitoring efforts for calendar years 2014 and 2015.

Primary production (carbon fixation through photosynthesis) by phytoplankton is one of the key processes which influence water quality in the Estuary. Phytoplankton are small, free-floating organisms that occur as unicellular, colonial, or filamentous forms (Horne and Goldman 1994). Phytoplankton can affect acidity (pH); dissolved oxygen; color, taste, and odor; and under certain conditions, some species can develop noxious blooms resulting in animal deaths and human illness (Carmichael 1981; Apeldoorn et al. 2007; Paerl et al. 2016). In freshwater, the cyanobacteria, or blue-green algae (class Cyanophyceae), are responsible for producing toxic blooms, particularly in waters that are enriched with phosphates (van den Hoek et al. 1995; Apeldoorn et al. 2007; Paerl et al. 2016).

In addition to being an important food source for zooplankton, invertebrates, and some species of fish, phytoplankton species assemblages can be useful in assessing water quality (Gannon and Stemberger 1978; Rieckenberg, et al. 2015). Because of their short life cycles, phytoplankton respond quickly to environmental changes; hence their standing crop and species composition are indicative of the quality of the water mass in which they are found (American Public Health Association 2012). That being said, 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 physiochemical and other biological data (American Public Health Association 2012).

Methods

Phytoplankton samples were collected monthly at 13 sites throughout the upper Estuary (Figure 1). Samples were collected 1 meter below the water's surface using a submersible pump. The samples were stored in 60-milliliter glass bottles. 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., using the Utermöhl microscopic method (Utermöhl 1958) and modified Standard Methods (American Public Heatlh Association 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 milliliters (mL), was adjusted according to the algal population density and turbidity of the sample. Aliquots are enumerated at a magnification of 800x using a Leica DMIL inverted microscope. For each settled aliquot, phytoplankton in randomly chosen transects were counted. Taxa were enumerated as they appeared along the transects. A minimum of 400 total algal units were counted, and a

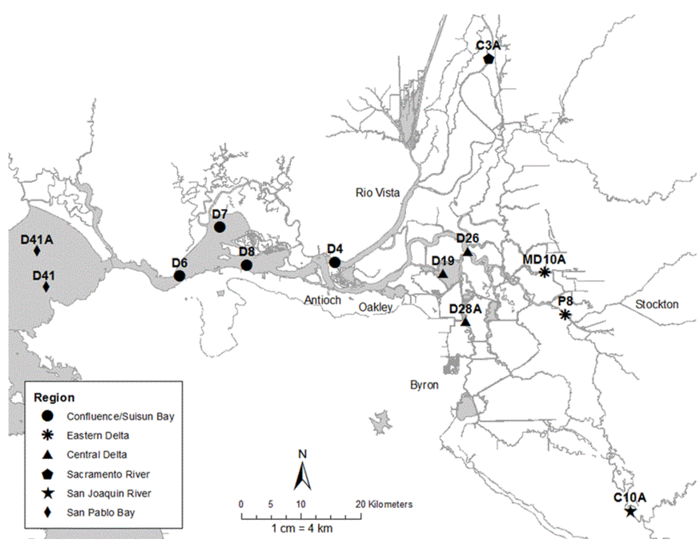

Figure 1. Map of Environmental Monitoring Program discrete phytoplankton stations.

minimum of 100 algal units of the dominant taxon. For taxa that were in filaments or colonies, the number of cells per filament or colony was recorded. Organism counts for each sample were converted to organisms/mL using the following formula:

Organisms = (C x Ac) / (V x Af x 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:

Organisms = C / cV

where:
cV = Counted volume (mL)
(Note: cV = Ac / (V x Af x F))

To show the status and trend on a regional scale in 2014 and 2015, stations were grouped into six regions based on location (Figure 1). One station north of Rio Vista was labeled "Sacramento River," and one station south of Tracy was labeled "San Joaquin River." Three stations east of Antioch but west of Stockton were called "Central Delta." Two stations east of the Central Delta region and west of Stockton were called "Eastern Delta." Four stations west of the confluence but east of Carquinez Strait were labeled as "Confluence/ Suisun Bay," and two stations west of Carquinez Strait were labeled "San Pablo Bay." For each region, the yearly average for each algal group were obtained by averaging the organisms per mL for all stations in that region and year. Monthly averages for each region were obtained by averaging the organisms per mL for all stations in that region for that particular month. Most of the phytoplankton samples for December 2014 were removed from the analyses, as a result of the loss of most of the samples during the shipping process.

Results

Sacramento River (C3A)

This region was heavily dominated by cyanobacteria in 2014 and 2015 (Figures 2 and 3), mainly as a result of the bloom events in the summer and fall of 2014 and spring and winter of 2015 (Figures 4 and 5). Other phytoplankton groups were generally low in number and contributed to less than 5 percent of the yearly average (Figures 2 and 3). Any phytoplankton group that did not have at least one monthly value greater than 5 percent of the total organisms per mL of phytoplankton collected in that month was grouped together as "Other" (Figures 4 and 5). Peaks of pennate diatoms occurred in March and July 2014 and in October 2015 (Figures 4 and 5). There was a peak of green algae in April 2015 (Figure 5). Other groups of phytoplankton were generally low in number throughout both years (Figures 4 and 5).

San Joaquin River (C10A)

The San Joaquin River region was dominated by cyanobacteria in 2014 and 2015 (Figures 6 and 7), though the overall phytoplankton count in 2015 was lower

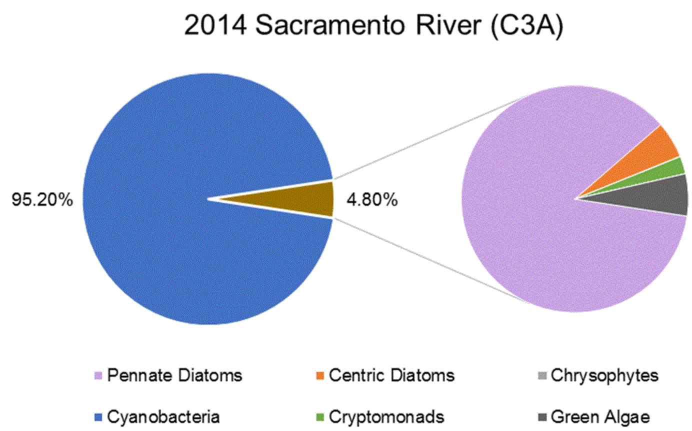

Figure 2. Yearly average of Sacramento River (C3A) phytoplankton groups, 2014.

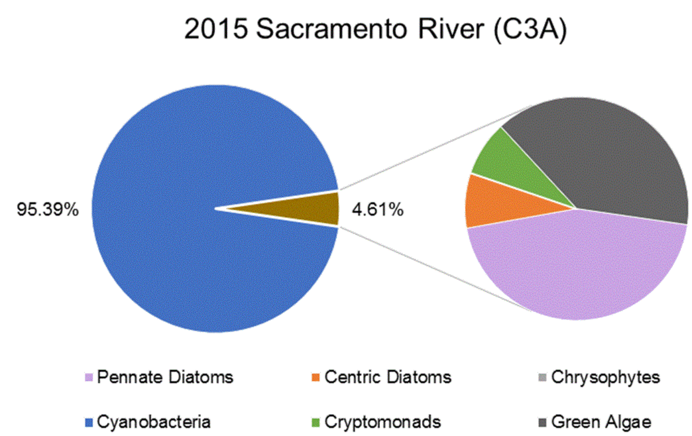

Figure 3. Yearly average of Sacramento River phytoplankton groups, 2015.

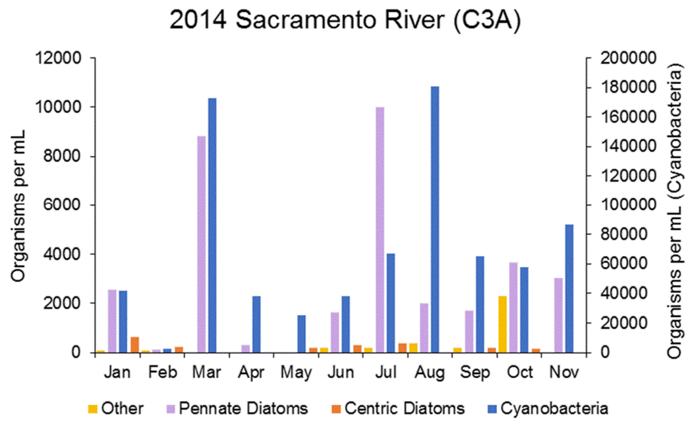

Figure 4. Monthly average of Sacramento River phytoplankton groups, 2014.

Note: Other = chrysophytes, cryptomonads, and green algae. For all graphs, "Other" represents the sum of the monthly average organisms per mL of any phytoplankton groups that did not have a concentration greater than 5 percent of the phytoplankton sample collected in that month.

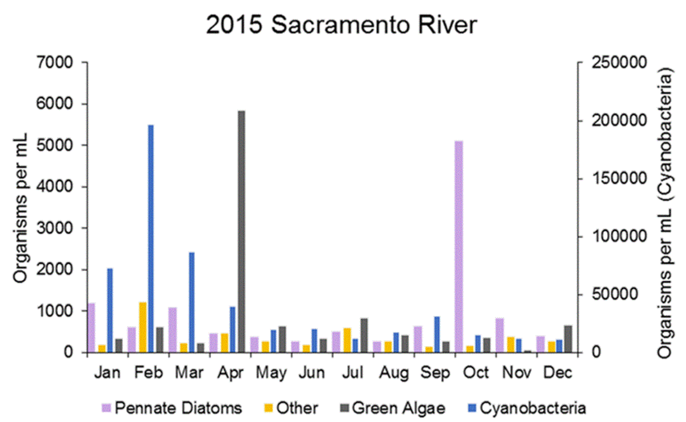

Figure 5. Monthly average of Sacramento River phytoplankton groups, 2015.

Note: Other = centric diatom, chrysophytes, and cryptomonads.

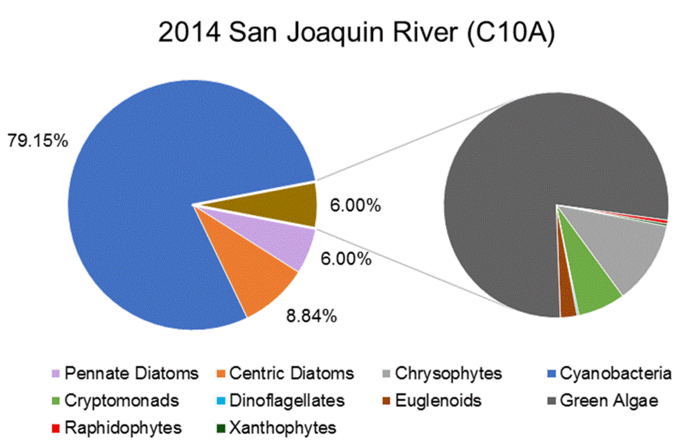

Figure 6. Yearly average of San Joaquin River (C10A) phytoplankton groups, 2014.

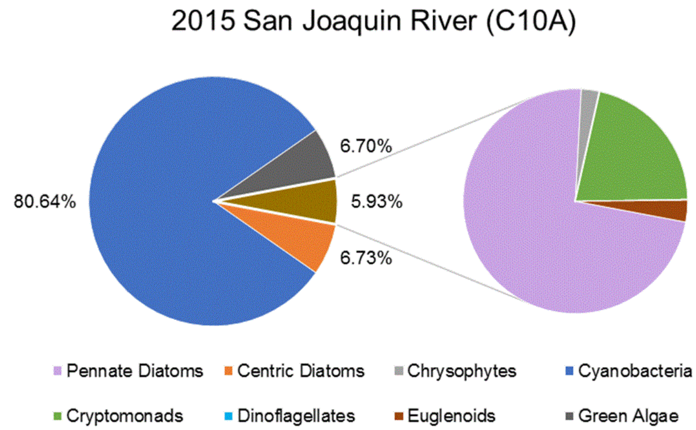

Figure 7. Yearly average of San Joaquin River phytoplankton groups, 2015.

(Figure 9). Green algae had a peak in April of 2014 and occasionally in some months during the winter and through the summer of 2015 (Figures 8 and 9). Pennate diatoms and centric diatoms also made moderate contributions in the spring and summer of 2014 (Figure 8). Centric diatoms had a peak in June 2015 (Figure 9). Although the region had a diverse group of phytoplankton types (Figure 6), aside from cyanobacteria, the rest of the phytoplankton were generally in low numbers (Figures 8).

Central Delta (D19, D26, D28A)

The central Delta was heavily dominated by cyanobacteria both years while the other types of algal groups represented less than 5 percent of the yearly average in both years (Figures 10 and 11). Blooms of cyanobacteria dominated 2014 throughout the year, peaking from spring through fall (Figure 12). Cyanobacteria peaked during the winter months of 2015 and remained high throughout the year (Figure 13). Green algae and centric diatoms also had occasional peaks in 2015 (Figure 13). Other types of phytoplankton were low in concentrations (Figures 12 and 13).

Eastern Delta (MD10A, P8)

The eastern Delta was heavily dominated with cyanobacteria both years (Figures 14 and 15). Blooms of cyanobacteria were highest in the fall months of 2014, with a large peak in November, and in the winter months of 2015, with a large peak in February (Figures 16 and 17). There were small peaks of green algae

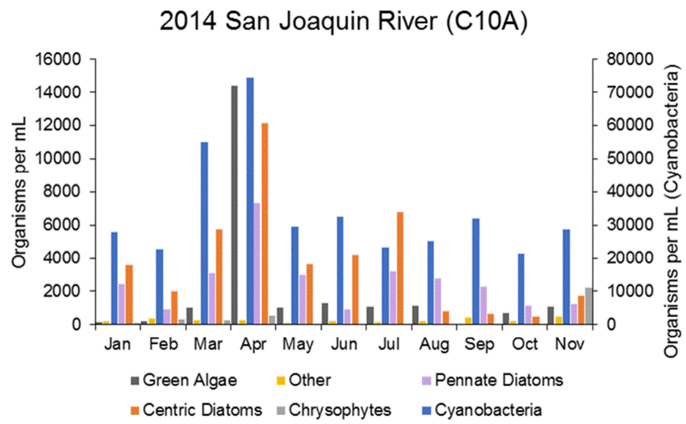

Figure 8. Monthly average of San Joaquin River phytoplankton groups, 2014.

Note: Other = cryptomonads, dinoflagellates, euglenoids, raphidophytes, and xanthophytes.

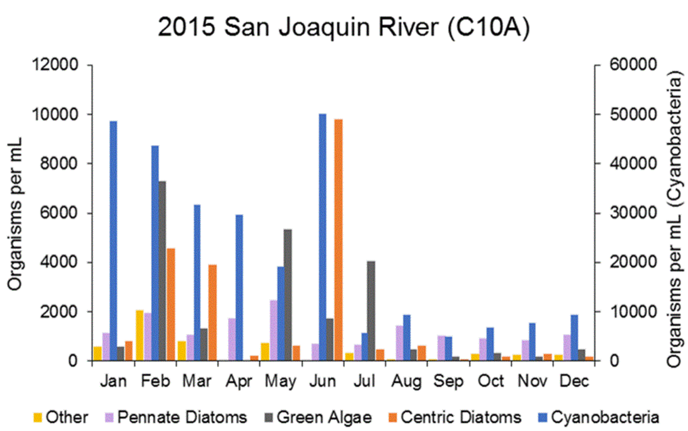

Figure 9. Monthly average of San Joaquin River phytoplankton groups, 2015.

Note: Other = chrysophytes, cryptomonads, dinoflagellates, and euglenoids.

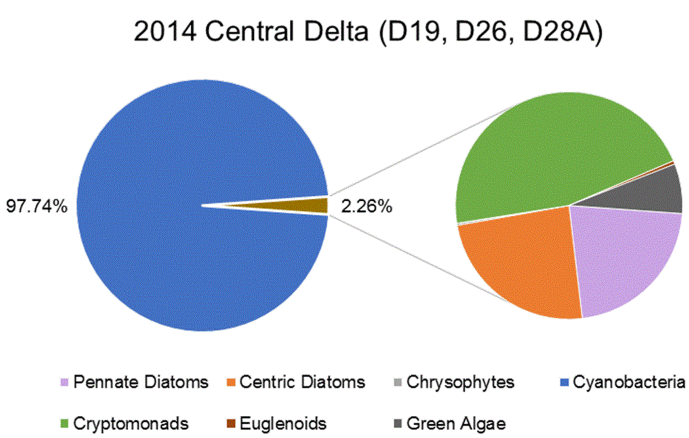

Figure 10. Yearly average of Central Delta (D19, D26, D28A) phytoplankton groups, 2014.

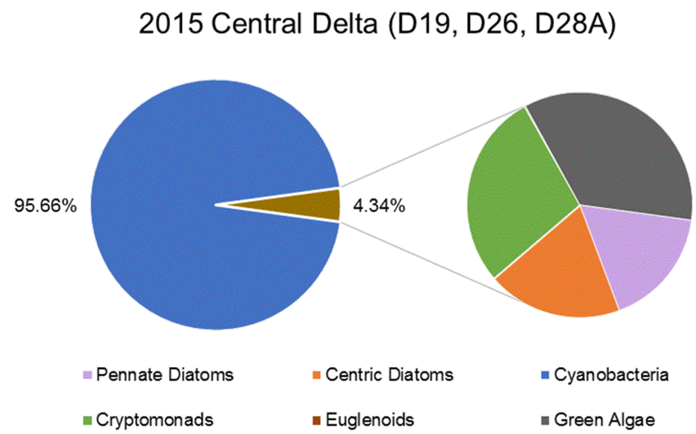

Figure 11. Yearly average of Central Delta phytoplankton groups, 2015.

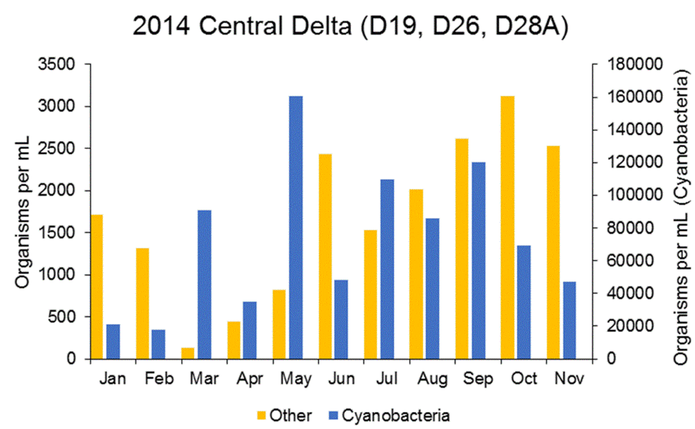

Figure 12. Monthly average of Central Delta phytoplankton groups, 2014.

Note: Other = pennate diatom, centric diatom, chrysophytes, cryptomonads, euglenoids, and green algae.

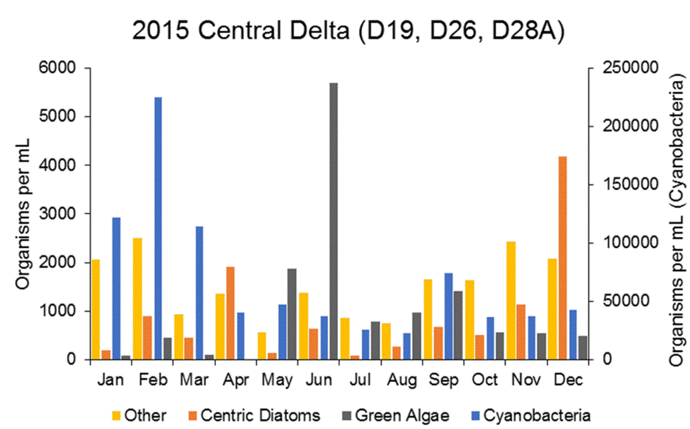

Figure 13. Monthly average of Central Delta phytoplankton groups, 2015.

Note: Other = pennate diatom, cryptomonads, and euglenoids.

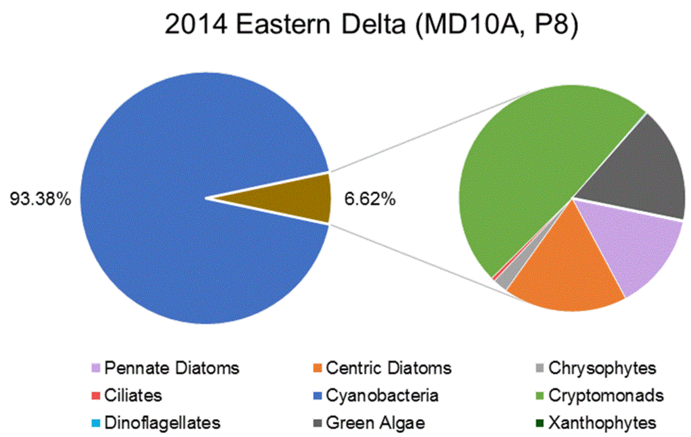

Figure 14. Yearly average of Eastern Delta (MD10A, P8) phytoplankton groups, 2014.

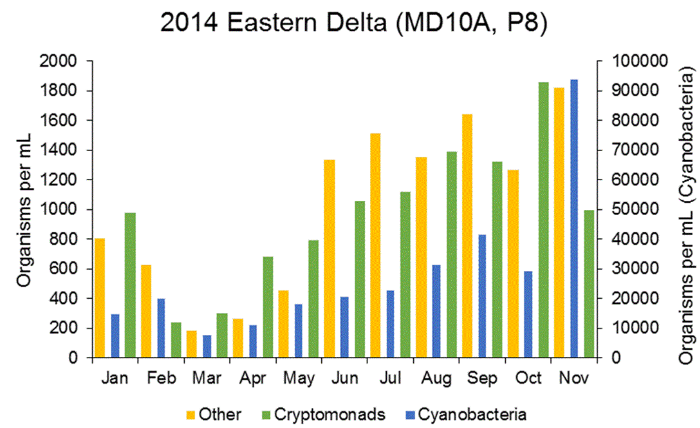

Figure 16. Monthly average of Eastern Delta phytoplankton groups, 2014.

Note: Other = pennate diatom, centric diatom, chrysophytes, ciliates, dinoflagellates, green algae, and xanthophytes.

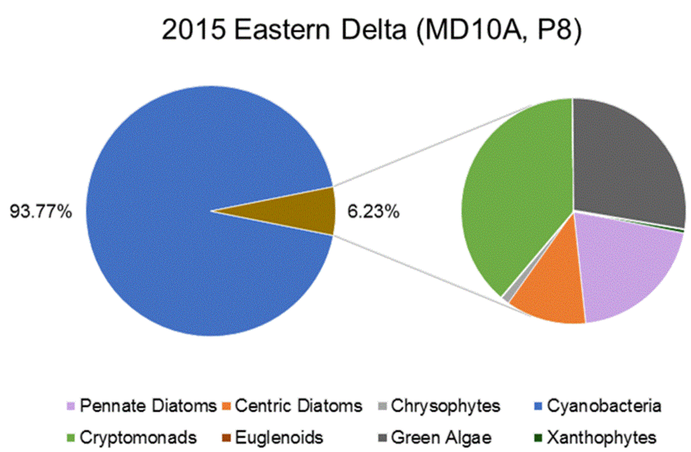

Figure 15. Yearly average of Eastern Delta phytoplankton groups, 2015.

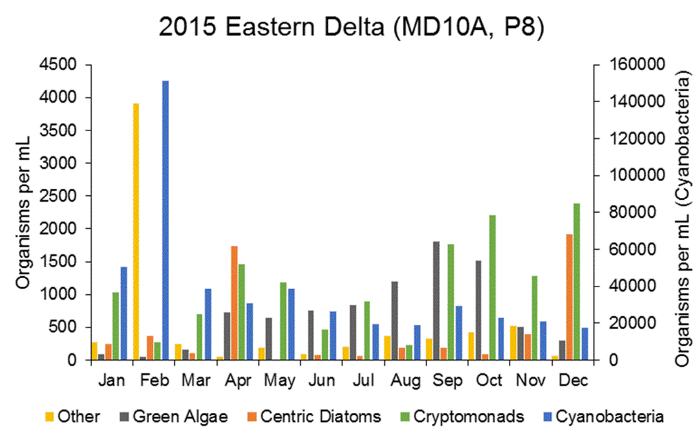

Figure 17. Monthly average of Eastern Delta phytoplankton groups, 2015.

Note: Other = pennate diatom, chrysophytes, euglenoids, and xanthophytes.

and cryptomonads in fall 2015 (Figure 17). Green algae, cryptomonads, and other types of phytoplankton contributed and represented less than 7 percent of the yearly averages (Figures 14 and 17), and had generally low densities (Figures 16 and 17).

Confluence (D4) and Suisun Bay (D6, D7, D8)

The confluence of the Sacramento and San Joaquin rivers and the Suisun Bay region were heavily dominated by cyanobacteria in both years (Figures 18 and 19). Other phytoplankton were minor in comparison, representing less than 2 percent of the yearly average for 2014 and 2015 (Figures 18 and 19). Although the region had a diverse group of phytoplankton (Figures 18 and 19), aside from cyanobacteria, the rest of the phytoplankton were low in number and made minor contributions to the total organisms per mL (Figures 20 and 21).

San Pablo Bay (D41, D41A)

San Pablo Bay was heavily dominated by cyanobacteria in both years (Figures 22 and 23), with larger peaks in the summer and fall months of 2014 and in the spring and fall of 2015 (Figures 24 and 25). Other types of phytoplankton made only minor contributions (Figures 24 and 25).

Summary

Phytoplankton monitoring by the EMP showed that all of the regions of the San Francisco Estuary were heavily dominated by cyanobacteria in 2014 and 2015. The San Joaquin River region (C10A) was the only region that

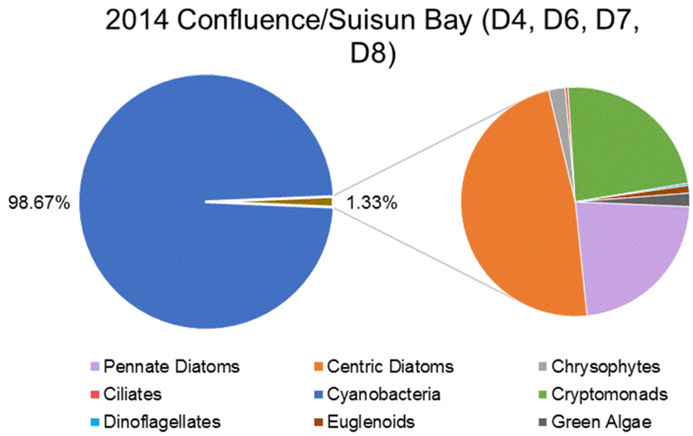

Figure 18. Yearly average of Confluence and Suisun Bay (D4, D6, D7, D8) phytoplankton groups, 2014.

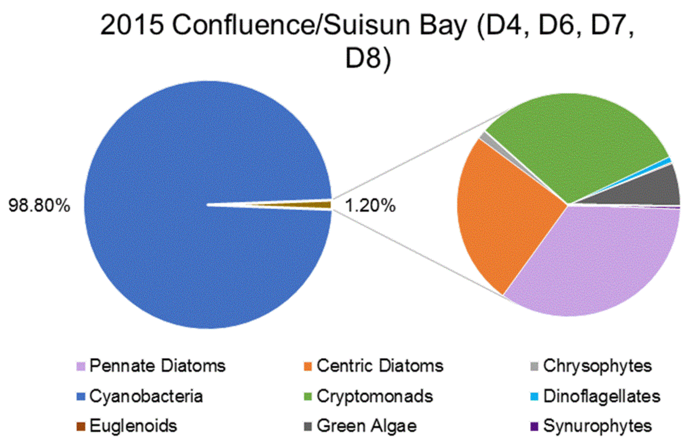

Figure 19. Yearly average of Confluence and Suisun Bay phytoplankton groups, 2015.

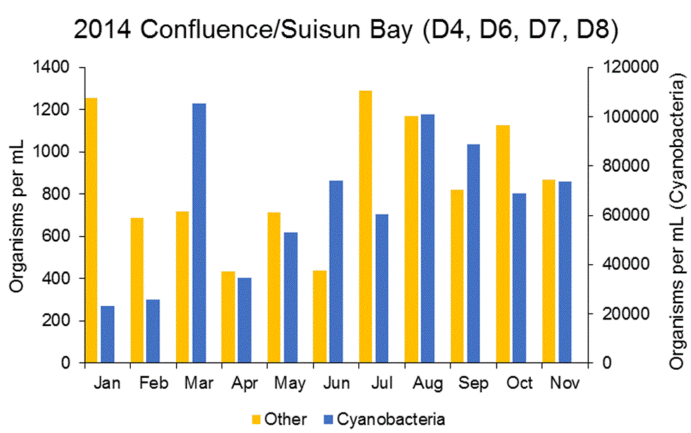

Figure 20. Monthly average of Confluence and Suisun Bay phytoplankton groups, 2014.

Note: Other = pennate diatom, centric diatom, chrysophytes, ciliates, cryptomonads, dinoflagellates, euglenoids, and green algae.

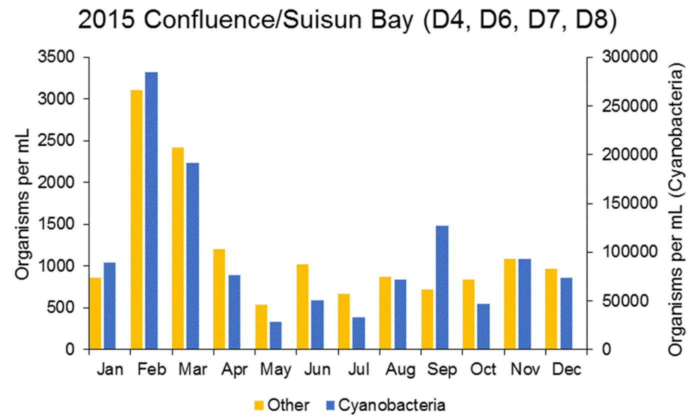

Figure 21. Monthly average of Confluence and Suisun Bay phytoplankton groups, 2015.

Note: Other = pennate diatom, centric diatom, chrysophytes, cryptomonads, dinoflagellates, euglenoids, green algae, and synurophytes.

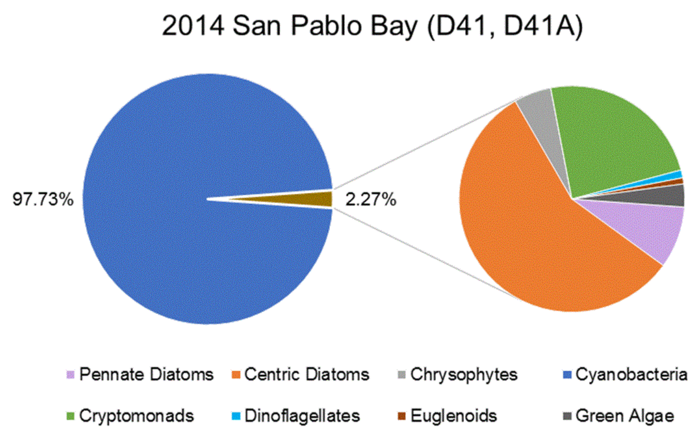

Figure 22. Yearly average of San Pablo Bay (D41, D41A) phytoplankton groups, 2014.

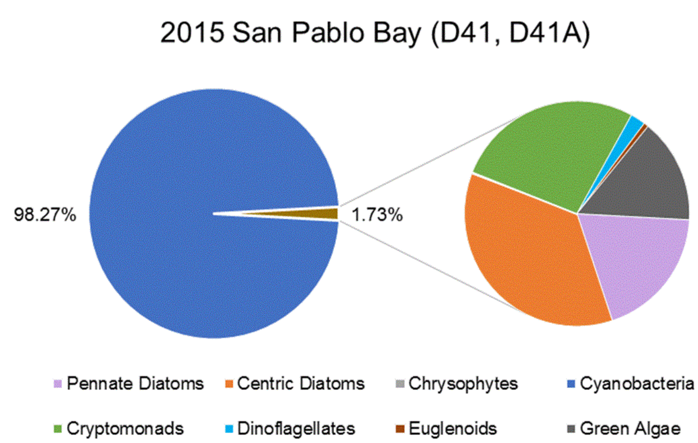

Figure 23. Yearly average of San Pablo Bay phytoplankton groups, 2015.

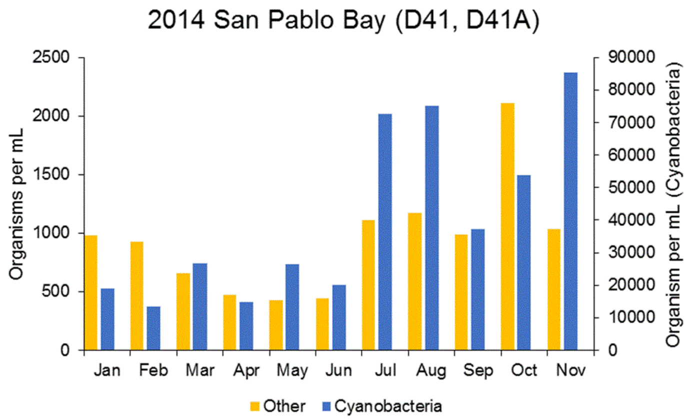

Figure 24. Monthly average of San Pablo Bay phytoplankton groups, 2014.

Note: Other = pennate diatom, centric diatom, chrysophytes, cryptomonads, dinoflagellates, euglenoids, and green algae.

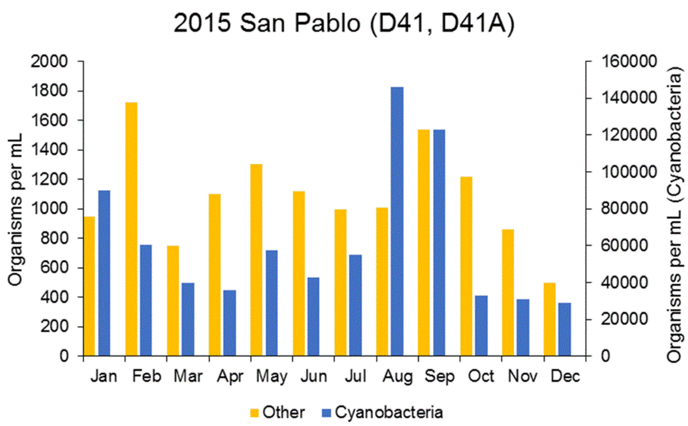

Figure 25. Monthly average of San Pablo Bay phytoplankton groups, 2015.

Note: Other = pennate diatom, centric diatom, chrysophytes, cryptomonads, dinoflagellates, euglenoids, and green algae.

had two other phytoplankton groups with yearly averages greater than 5 percent in 2014 and 2015. In comparison, the phytoplankton community was more complex in pre-drought years, with organisms falling under twelve categories, and most of the organisms collected being cyanobacteria, centric and pennate diatoms, cryptomonads, and haptophytes (Brown 2012). Monitoring during the pre-drought years also recorded the community showing more seasonal differences (Brown 2012).

Although the quantity of cyanobacteria is high in 2014 and 2015, their sizes are considerably smaller than other phytoplankton, such as centric and pennate diatoms, often by an order of magnitude or more. The biovolume of a large single-celled diatom, such as *Coscinodiscus* sp., can be equal to or greater than a few hundred small cyanobacterial cells. Count data is necessary to determining the structure of the phytoplankton community, while biovolume is important for assessing the potential food quality of phytoplankton available to higher trophic levels. Though cyanobacteria quantity may be high, they are also inferior food as they are low in fatty acids (Brett and Müller-Navarra 1997). Measuring both of these aspects of phytoplankton spatially and temporally are key in understanding the cyclical changes in the lower food web and its influence on the higher trophic level.

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Issue	*Article Submission Deadline*
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Issue 2 (Spring)	April 15, 2016
Issue 3 (Summer)	July 15, 2016
Issue 4 (Fall)	October 15, 2016

Submit articles to Shaun Philippart.

■ Interagency Ecological Program for the San Francisco Estuary ■

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U.S. Army Corps of Engineers

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