Interagency Ecological Program for the San Francisco Estuary

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Of Interest to Managers

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This issue of the Interagency Ecological Program (IEP) Newsletter contains two Status and Trends articles, one describing pelagic fish trends and a second relating to salvage operations, as well as an article describing a phytoplankton bloom that occurred in May of 2016.

First, **James White** (CDFW) presents the Status and Trends report for pelagic fishes in the upper San Francisco Estuary, in which he presents relative abundance indices from several long-term IEP surveys. He also provides catch updates for Delta Smelt, Longfin Smelt, Threadfin Shad, American Shad, age-0 Striped Bass, and Splittail. The indices for 2016 show minor increases among some species, but they remain low compared with historical values.

Geir Aasen and **Jerry Morinaka** (CDFW) summarize fish salvage and water export data collected at the two major water export facilities in the Delta, the federal Central Valley Project (CVP) and the State Water Project (SWP). They examine water years 1981 to 2016 and describe trends in salvage of Chinook Salmon, Steelhead, Striped Bass, Delta Smelt, Longfin Smelt, Splittail, and Threadfin Shad in addition to total salvage.

Finally, **Tiffany Brown** and **Michelle Nelson** (DWR) describe the community composition and biomass of a phytoplankton bloom that occurred in May of 2016. They compare their results to those observed during blooms that occurred prior to the introduction of the non-native clam Potamocorbula amurensis. This article also provides insight into how the physical characteristics of the phytoplankton species present, as well as estuary conditions, can affect the characteristics of a bloom, which may have implications at higher trophic levels.

Status and Trends

2016 Status and Trends Report for Pelagic Fishes of the Upper San Francisco Estuary

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Introduction

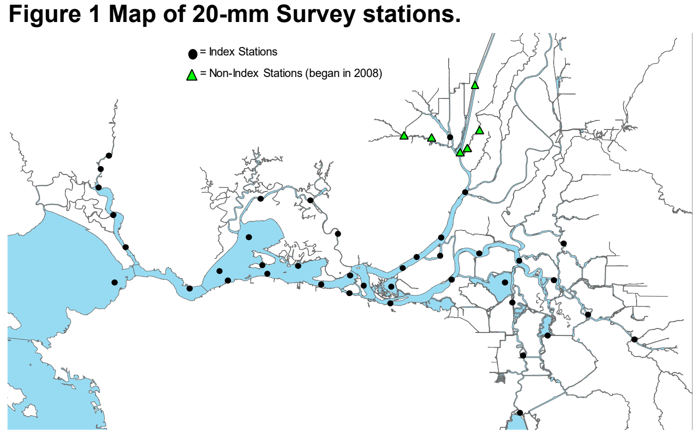
The 2016 Pelagic Fishes Status and Trends Report presents abundance trends for pelagic fishes using data from four of the Interagency Ecological Program's (IEP) long-term fish monitoring surveys: (1) 20-millimeter (mm) Survey, (2) Summer Townet Survey (STN), (3) Fall Midwater Trawl (FMWT), and (4) U.S. Fish and Wildlife Service (USFWS) Beach Seine Survey (Honey et al. 2004). The Status and Trends Report also normally includes data from the San Francisco Bay Study (SFBS), but SFBS data are not included in this year's report due to data gaps resulting from vessel breakdowns. 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 undergone significant population declines (Sommer et al. 2007).

Methods

Sampling Background

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 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 µm mesh net (Dege and Brown 2003). 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 mm fork length (FL) criterion is used to select length data for age-0 Delta Smelt, which are then averaged by survey for all stations sampled to determine when mean fork length reaches or surpasses 20 mm. The four surveys in which mean FL of Delta Smelt bound 20 mm (two surveys before and two after) 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 (Figure 1). CPUE for each tow is calculated by dividing catch by the volume (m^3) filtered during the sample and 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.,

Figure 1 Map of 20-mm Survey stations.

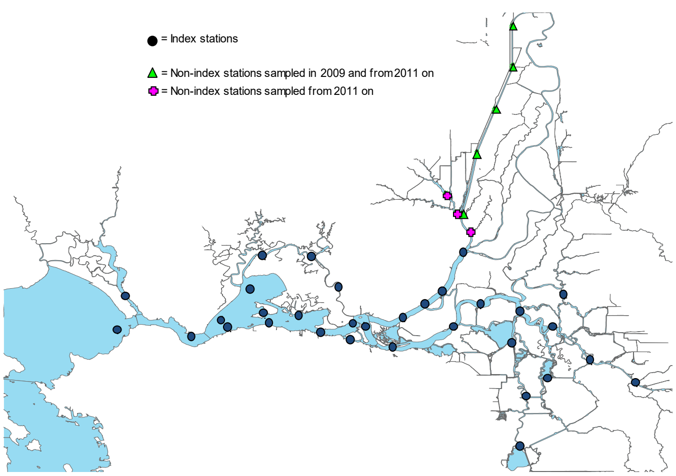


Note: Index stations have been sampled since survey inception in 1995. Data collected at index stations are used to calculate survey and annual abundance indices. Non-Index stations were added to the survey in 2008 to better assess the distribution of Delta Smelt and other pelagic fishes.

$log_{10}(x+1)$). These transformed values are averaged 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 Summer Townet Survey (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 and five surveys annually, depending on when the mean FL of age-0 Striped Bass exceeded 38.1mm, 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 August (Hieb et al. 2005). STN samples 32 historic stations, one of which is in the Napa River and excluded from index calculations because of historically infrequent sampling. 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.

Figure 2 Map of the Summer Townet Survey stations.

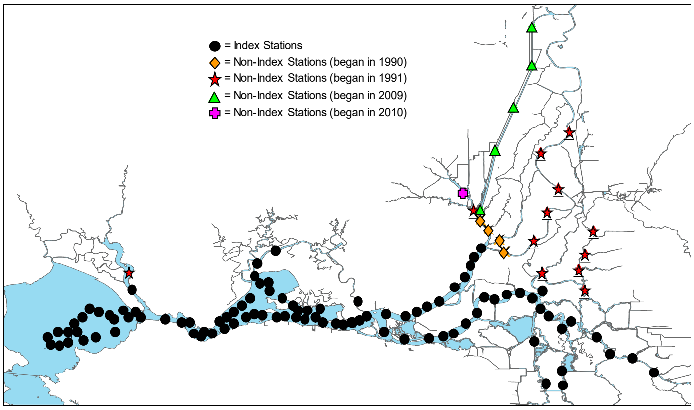


Note: Index stations have been sampled since survey inception in 1959 and their data are used for calculating survey and annual abundance indices. Non-index stations were added as indicated to better assess the distribution of Delta Smelt and other pelagic fishes.

Catch per tow data from the 31 STN index stations are used to calculate annual abundance indices for age-0 Striped Bass and Delta Smelt. First, catch of a species is summed across tows at each station. Then, the sum is multiplied by a volume-weighting factor (i.e., the estimated volume [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 because of equipment malfunction, so the index was calculated as the average of the indices for the second and third surveys.

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 annual abundance index calculation uses catch per tow data 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 survey abundance indices, the 100 index stations are grouped into 14 regions. Monthly indices are calculated by averaging index-station catch-per-tow in each region, multiplying these regional means by their respective weighting factors, and summing these products. Annual

Figure 3 Map of the 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.

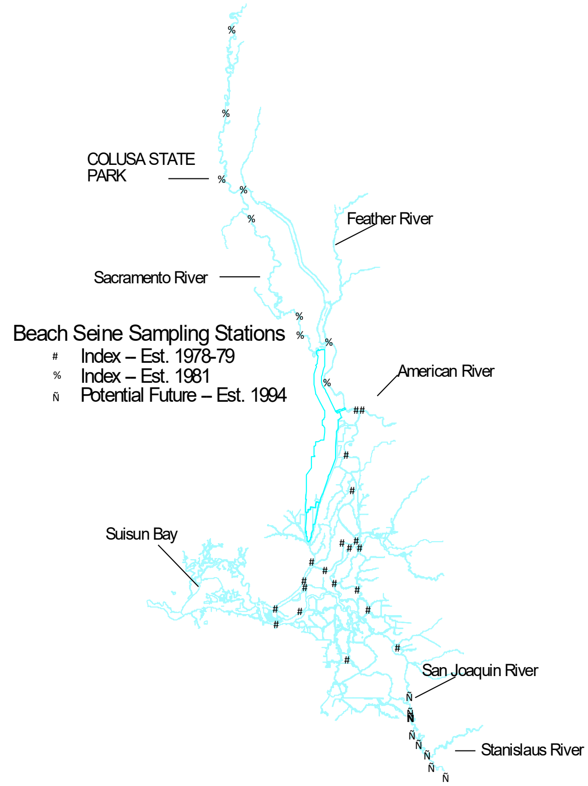
abundance indices are the sum of the four (September–December) monthly indices.

The San Francisco Bay Study (SFBS) data are not included in this year's report because of data gaps resulting from vessel breakdowns.

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 2000). Data from 33 stations are used to calculate the annual age-0 Splittail abundance index (Figure 4). These stations range from Sherman Lake to Ord Bend on the Sacramento River, 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) and ≥ 85 mm in May and ≥ 105 mm in June (cutoffs for age -1) are removed from calculations. The 33 index stations are grouped into 10 regions. The annual index is calculated as the mean catch per m^3 for seine hauls conducted first at each station and month for the months May and June, and then across months for each sub-region. Finally, the mean catch per cubic meter (m^3) for each year and sub-region was summed across regions to produce the annual index.

FMWT data were used to describe abundance trends and distribution patterns of all six fish species listed in the introduction. In normal years, SFBS 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; however, because of repeated boat breakdowns in 2016, no SFBS data are reported here. 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.

Figure 4 Map of USFWS beach seine survey stations.



Note: Data from the Sacramento River are used for Splittail annual abundance indices.

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, Yuba and American rivers from April through June. Juveniles 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 whereas females mature 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 post-spawning mortality is higher among females than males (Walburg and Nichols 1967).

The 2016 FMWT index for American Shad was 313, the highest index since 2012 and a 296 percent increase from the 2015 FMWT index value (Figure 5). 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.

Throughout the 2016 FMWT sampling season, 249 American Shad were collected at index stations throughout the upper estuary and Delta. In September, American Shad were collected at index stations in Suisun Bay (n = 43), the lower Sacramento River (n = 11), and the lower San Joaquin River (n = 4). American Shad were collected at non-index stations in Cache Slough (n = 1) and the SRDWSC (n = 36). In October, they were collected at index stations in San Pablo Bay (n = 5), Suisun Bay (n = 9), the lower Sacramento River (n = 9), and the lower San Joaquin River (n = 15). American Shad were collected at non-index stations in the Sacramento River north of Isleton (n = 3) and the SRDWSC (n = 86). November catches were from index stations in San Pablo Bay (n = 3), Suisun Bay (n = 5), and the lower Sacramento (n = 87) and San Joaquin rivers (n = 1). November non-index catches were from the SRDWSC (n = 13). In December, American Shad were collected at index stations in San Pablo Bay (n = 3), Carquinez Strait (n = 1), Suisun Bay (n = 40), the eastern Delta (n = 1), the lower Sacramento River (n = 3), and the lower San Joaquin River (n = 9). American Shad were collected at non-index stations in Cache Slough (n = 1), the Napa River (n = 1), the Sacramento River (n = 1), and the SRDWSC (n = 9).

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 2016 was 660, making it the 8th lowest index on record (Figure 6). Abundance was highest during the late 1990s and early 2000s, with the two highest indices occurring in 1997 (15,267) and 2001 (14,401).

During FMWT, 515 Threadfin Shad were collected at index stations across the entire sampling region from San Pablo Bay to the Sacramento and San Joaquin rivers and the south Delta. In September, Threadfin Shad were collected at index stations in Suisun Bay (n = 12), the lower Sacramento River (n = 52), and the lower San Joaquin River (n = 33). Threadfin Shad were collected at non-index stations in Cache Slough (n = 1) and

Figure 5 Annual abundance indices of American Shad from the Fall Midwater Trawl Survey, 1967–2016 (all sizes).

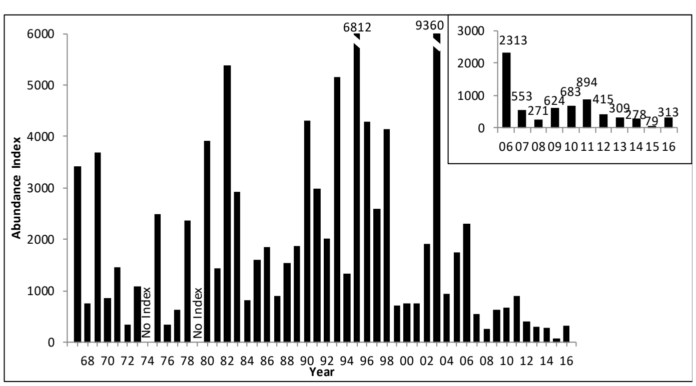
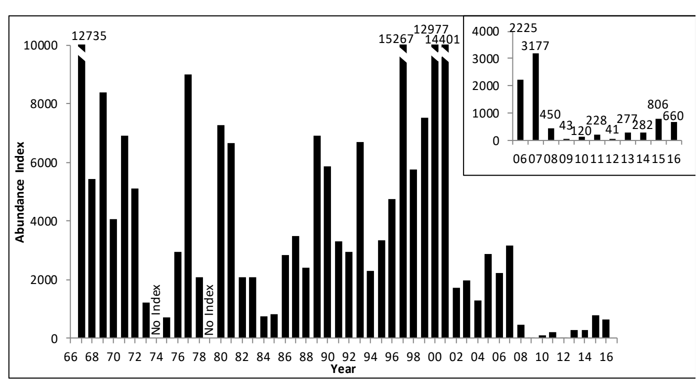


Figure 6 Annual abundance indices of Threadfin Shad from the Fall Midwater Trawl Survey, 1967–2016 (all sizes).



the SRDWSC (n = 217). Threadfin Shad catch shifted downstream and decreased in the Delta in October, with fish collected at index stations in San Pablo Bay (n = 2), Suisun Bay (n = 39), the lower Sacramento River (n = 1), and the lower San Joaquin River (n = 8). They were collected at non-index stations in the SRDWSC (n = 178). Catches increased again in November, driven by large numbers once again at index stations in the Sacramento River (n = 119), San Pablo Bay (n = 9), the lower San Joaquin River (n = 62), and the eastern Delta (n = 1). Threadfin Shad were collected at non-index stations in the SRDWSC (n = 142). In December, Threadfin Shad were collected at index stations in San Pablo Bay (n = 10), Carquinez Strait (n = 16), Suisun Bay (n = 94), the lower Sacramento River (n = 28), the eastern Delta (n = 2), and the lower San Joaquin River (n = 27). Threadfin Shad were collected at non-index stations in the Sacramento River upstream of Isleton (n = 4) and the SRDWSC (n = 120).

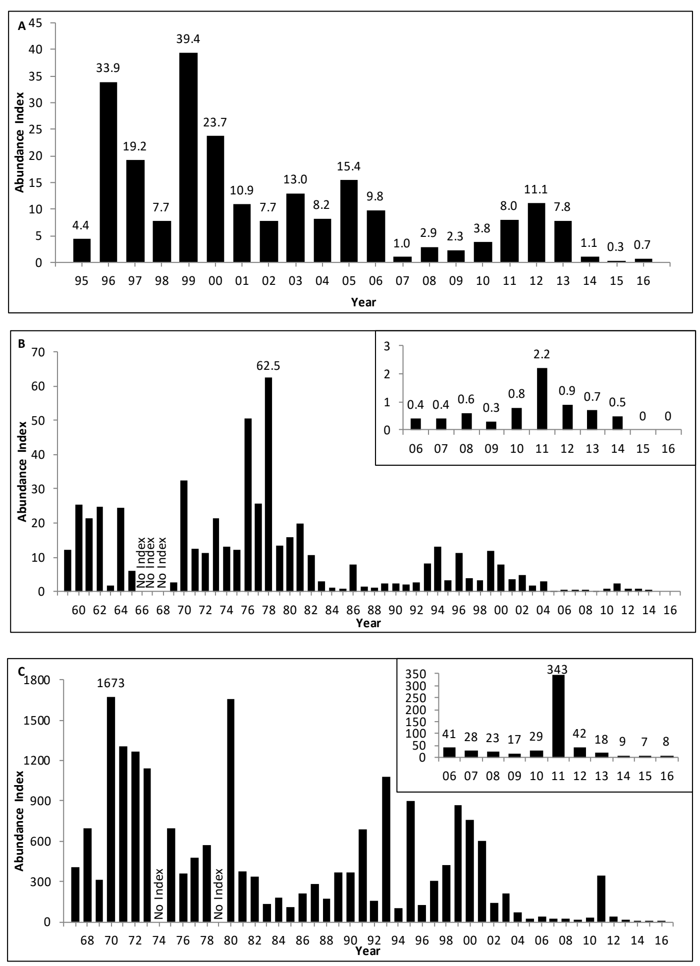
Delta Smelt

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 (Figures 7 B–C) and in 1993 was listed as a threatened species by State and federal agencies. It is considered environmentally sensitive because it has an annual life cycle, dependence on a spatially-limited oligohaline to freshwater habitat, and low fecundity (1,200 to 2,600 eggs per female on average [Moyle et al. 1992]). Low fecundity appears to be offset by the ability of females to produce multiple clutches in a single spawning season (Bennett 2005, Damon et al. 2017).

The 20-mm Delta Smelt index for 2016 was 0.7, the second-lowest on record (Figure 7A). The 2016 index was calculated from surveys 2–5, during which 25 Delta Smelt were collected from index stations. Another 73 Delta Smelt were caught at non-index stations in the Cache Slough and SRDWSC regions. Over the course of the 2016 20-mm surveys, a total of 128 Delta Smelt were collected, with the majority collected at a single station in the lower SRDWSC (n = 84) during surveys 3 and 5. Catches during late March (survey 2) were low (n = 5), Delta Smelt were collected from the Lower Sacramento River (n = 1), SRDWSC (n = 2), and Cache Slough (n = 2). Surveys in April (surveys 3–4) had higher catches (n = 62), from Montezuma Slough (n = 4), and the Napa (n = 9) and Sacramento rivers (n = 1). Catches from non-index stations were substantial in the SRDWSC region (n = 46). May catches (surveys 5–6) were slightly lower (n = 41), driven by catches in the SRDWSC region (n = 28). Fish were also collected from the Confluence (n = 1), Montezuma Slough (n = 2), and the Napa (n = 1), lower Sacramento (n = 6), and San Joaquin rivers (n = 1). Delta Smelt were also collected from non-index stations in Miner Slough (n = 1). Catches dropped in June (surveys 7–8) (n = 18), with fish caught in Suisun Bay (n = 3), the Sacramento (n = 4) and San Joaquin (n = 1) rivers, Carquinez Straight (n = 1), and the Confluence (n = 1). Non-index catch came from the SRDWSC region (n = 8). Two fish were caught during July (survey 9) in the Suisun Bay.

The STN Delta Smelt index for 2016 was 0 for the second consecutive year (Figure 7B). Catch during the

Figure 7 Annual abundance indices of Delta Smelt.



Note: (A) 20mm Survey (larvae and juveniles; 1995–2016); (B) Summer Townet Survey (juveniles; 1959–2016); (C) Fall Midwater Trawl Survey (sub-adults; 1967–2016).

two June surveys used to calculate the index consisted of five fish, only two of which were from index stations in Montezuma Slough (n = 1) and the confluence (n = 1). The other three were collected at non-index stations in the SRDWSC region (n = 3). No Delta Smelt were collected during the second survey. One additional Delta Smelt was collected in Grizzly Bay during Survey 5, which is not included in index calculations.

The FMWT Delta Smelt index for 2016 was 8, resulting in three consecutive years of record low index values (Figure 7C). In 2016, seven Delta Smelt were collected at index stations, with all catches occurring on the lower Sacramento River in November. This year's catch is consistent with the low catches and limited geographic distribution seen in recent years.

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 may wait longer while others appear capable of spawning in their first year. A few individuals may survive to spawn a second time (Wang 1986).

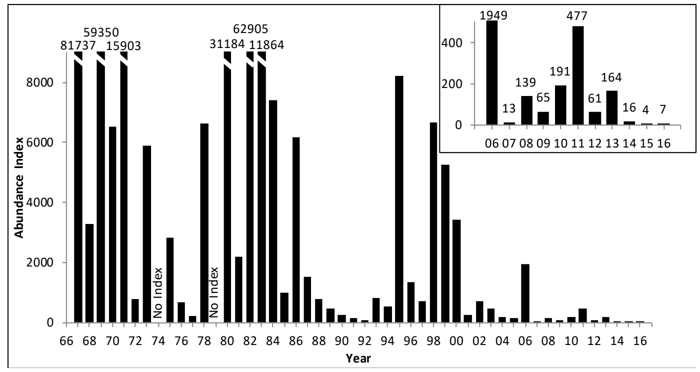
The 2016 FMWT Longfin Smelt index was 7, the second lowest on record and only 44 percent of the 2014 index (Figure 8). Longfin Smelt abundance was highest in the late 1960s and peaked again in the early 1980s. After a brief increase in the late 1990s, abundance dropped again and has remained relatively low for most recent years.

Five Longfin Smelt were caught in total during the 2016 FMWT survey. These fish were collected from San Pablo (n = 1) and Suisun (n = 1) bays in September, San Pablo Bay (n = 1) in November, and Suisun Bay (n = 1) and the Sacramento River (n = 1) in December. One Longfin Smelt was caught at a non-index station in the SRDWSC in December as well.

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

Figure 8 Annual abundance indices of Longfin Smelt from Fall Midwater Trawl Survey (all sizes; 1967–2016).



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 inundation lasting 30 days or longer (Moyle et al. 2004).

The 2016 USFWS Beach Seine index for age-0 Splittail was 4, a four-fold increase over the previous year (Figure 9A). Regional abundance was highest in Delta region, lower in the Sacramento River and zero in the San Joaquin River.

The 2016 FMWT Splittail index for all ages was 0, tied with 1977, 2008, 2010, and 2015 for the lowest index on record (Figure 9B). The FMWT Splittail index tends to be low or zero except in relatively wet years, such as 2011, when age-0 fish tend to be abundant. FMWT operates in water > 2 m deep, whereas Splittail, particularly age-0 fish, appear to primarily inhabit water < 2 m deep. So, during most years, FMWT data probably does not accurately reflect trends in age-0 Splittail abundance. Nevertheless, FMWT does effectively detect strong year classes, such as the one in 1998 and the most recent one in 2011.

Age-0 Striped Bass

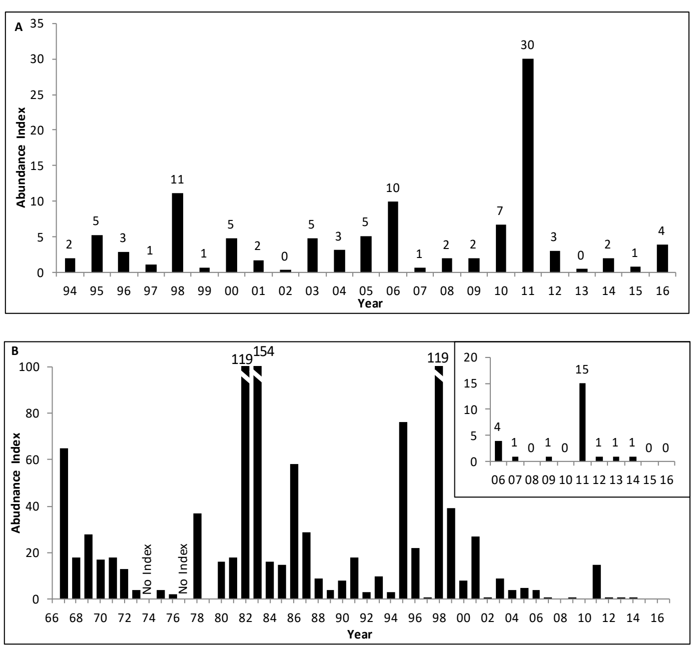
The Striped Bass is a long-lived anadromous fish first introduced to the San Francisco Estuary in 1897 (Dill and Cordone 1997). Mature individuals forage in near-shore marine habitats, including coastal bays and estuaries. Many adults migrate to the Delta in fall and early winter, where they remain until swimming upstream to spawn in the spring. 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. Larvae are then transported to rearing areas in fresh and brackish waters (Dill and Cordone 1997).

Both STN and FMWT indices showed declines in age-0 Striped Bass abundance in the mid-1970s (Figures 10A & 10B). 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) loss to 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) cautioned against attributing low values solely to a change in habitat use.

The 2016 STN index for age-0 Striped Bass was 2.2, a sevenfold increase over the previous year and its highest value since 2011 (Figure 10A). In 2016, age-0 Striped Bass reached an average fork length of 38.1 mm on July 6, between survey 2 (June 27–July 1) and survey 3 (July 11–July 15). In survey 2, 84 age-0 Striped Bass were collected from index stations, which include Suisun Bay (n = 24), the Confluence (n = 44), the lower Sacramento River (n = 18), and the lower San Joaquin River (n = 8). This survey also collected three fish at non-index stations in the SRDWSC (n = 1) and Cache Slough (n = 2). In survey 3, 52 age-0 Striped Bass were collected from index stations: from Suisun Bay (n = 19), the Confluence (n = 17), in the lower Sacramento River (n = 14), and in the south Delta (n = 2). This survey also collected two fish at non-index stations in the Napa River (n = 1) and Cache Slough (n = 1).

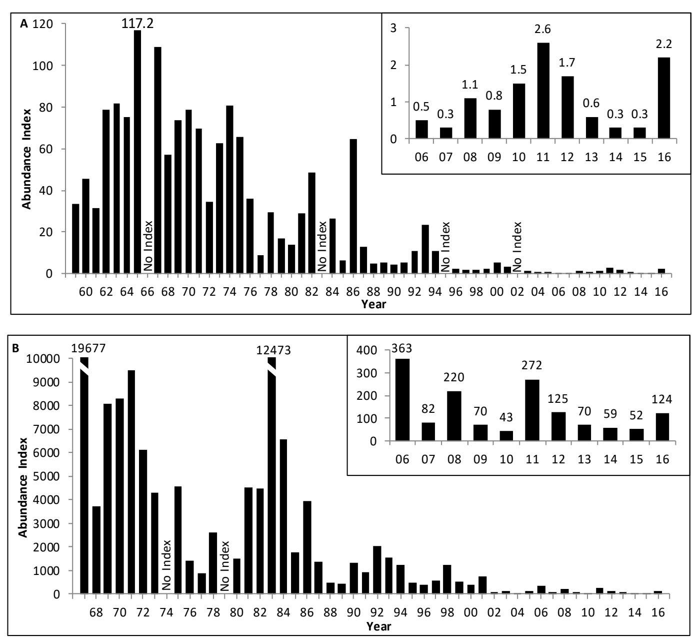
During the entire 2016 STN season, a total of 620 age-0 Striped Bass were collected from locations ranging from the Suisun Bay to the lower Sacramento and San

Figure 9 Annual abundance indices of Splittail.



Note: (A) USFWS Beach Seine Survey (juveniles ≥ 25mm), 1994–2016; (B) Fall Midwater Trawl Survey (all sizes), 1967–2016.

Figure 10 Annual abundance indices of age-0 Striped Bass from: (A) Summer Townet, 1959–2016 (all sizes); (B) Fall Midwater Trawl Survey (all sizes), 1967–2016.



Joaquin rivers, as well as in the SRDWSC and the south Delta. Catches were consistently concentrated in the Confluence (n = 256), and to a lesser extent Montezuma Slough (n = 132). Age-0 Striped Bass were also collected from Cache Slough (n = 28), Carquinez Straight (n = 5), Napa (n = 1), Sacramento (n = 81), and San Joaquin (n = 26) rivers, the south Delta (n = 23), the SRDWSC (n = 30), and Suisun Bay (n = 38). Catch declined steeply over time from 440 in survey 1 down to 7 in survey 6.

The 2016 FMWT index for age-0 Striped Bass was 124, the highest value since 2012 (Figure 10B). The index 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 and in the early 2000s it dropped and has remained low since then.

Ninety-five age-0 Striped Bass were collected at FMWT index stations spanning 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 = 38) and the eastern Delta (n = 1). In October, they were collected in Suisun Bay (n = 4). In November, age-0 Striped Bass were collected from San Pablo Bay (n = 1), Suisun Bay (n = 1), and the lower Sacramento River (n = 2). At a non-index station in the SRDWSC, an additional age-0 Striped Bass was collected (n = 1). In December, fish were caught in San Pablo Bay (n = 1), Carquinez Strait (n = 10), Suisun Bay (n = 13), and the lower Sacramento (n = 9) and San Joaquin (n = 15) rivers. At non-index stations, age-0 Striped Bass were collected in Steamboat Slough (n = 5). Age-0 Striped Bass were conspicuously absent from Cache Slough, given the high catch there in 2014 (n = 44).

Conclusion

Annual abundance indices in 2016 continued the recent trend of record low or near-record low values observed for these six fish species over the past several years. While species such as the Threadfin Shad, American Shad, and age-0 Striped Bass exhibited an increase in recent years, their current levels are only 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 sizes are near the threshold of detection for most life stages. Given that abundance indices from these studies have specific management implications, index values of “0” have been and will continue to be problematic. Catches in the south Delta also continue to decline. For example, during the entire 2016 FMWT season, only four tows yielded fish of any species in the south Delta (one age-0 Striped Bass, one American Shad, and three Threadfin Shad). Future reviews should look at changes in regional abundance in more detail.

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Fish Salvage at the State Water Project's and Central Valley Project's Fish Facilities during the 2016 Water Year

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Introduction

Two facilities mitigate fish losses associated with water export by the federal Central Valley Project (CVP) and California's State Water Project (SWP). The CVP's Tracy Fish Collection Facility (TFCF) and the SWP's Skinner Delta Fish Protective Facility (SDFPF) divert (salvage) fish from water exported from the southern end of the Sacramento-San Joaquin Delta (Delta) located in Byron, California (Aasen 2013). Both facilities use louver-bypass systems to divert fish from the exported water. The salvaged fish are periodically loaded into tanker trucks and transported to fixed release sites in the western Delta. Operations began in 1957 at the TFCF and in 1968 at the SDFPF.

Methods

This report summarizes the 2016 water year (WY) salvage information from the TFCF and the SDFPF, and examines data from water years (WYs) 1981 to 2016 for possible relevance to salvage trends in recent years. The following species were given individual consideration: Chinook Salmon (*Oncorhynchus tshawytscha*), Steelhead (*O. mykiss*), Striped Bass[1] (*Morone saxatilis*), Delta Smelt[1] (*Hypomesus transpacificus*), Longfin Smelt[1] (*Spirinchus thaleichthys*), Splittail (*Pogonichthys macrolepidotus*), and Threadfin Shad[11] (*Dorosoma petenense*).

Systematic sampling was used to estimate the numbers and species of fish salvaged at both facilities. Bypass flows into the fish-collection buildings were sub-sampled generally once every 1 or 2 hours for 1 to 30 minutes (= 24.75 minutes, standard deviation [sd] = 9.85) at the SDFPF and generally once every 2 hours for 10 to

1 Pelagic Organism Decline (POD) species

60 minutes (= 29.99, sd = 0.72) at the TFCF. Fish 20-mm fork length (FL) or larger were identified, counted, and measured. These fish counts were expanded to estimate the total number of fish salvaged in each 1- to 2-hour period of water export. For example, subsample duration of 30 minutes over a 120-minute export period equals an expansion factor of 4, which was multiplied by the number of fish per species collected from the fish count. These incremental salvage estimates were then summed across time to develop monthly and annual species-salvage totals for each facility.

Chinook Salmon loss is the estimated number of juvenile Chinook Salmon entrained by the facility minus the number of Chinook Salmon that survive salvage operations (California Department of Fish and Game 2006). Salmon salvage and loss were summarized by origin (i.e., hatchery fish defined as adipose fin clipped or wild fish defined as non-adipose fin clipped) and race (fall, late-fall, winter, or spring). Race classification of wild and hatchery Chinook Salmon was determined solely by the Delta Model Length-at-Date table, which is based on length at date of salvage (California Department of Fish and Wildlife 2014). This table was created by the U.S. Fish and Wildlife Service, who further modified the California Department of Water Resources modified version of the Fisher Model by changing the upper and lower boundaries for winter-run Chinook Salmon (Matt Dekar, personal communication[2]). Nevertheless, apparent growth rates and size ranges among races are variable, leading to potential misclassification with the Delta Model (Harvey and Stroble 2013).

Larval fish were also collected and examined to determine the presence of Delta Smelt and Longfin Smelt less than 20 mm FL. Larval sampling at the SDFPF ran from March 1 through June 8 and from March 1 through June 7 at the TFCF. Larval samples were collected once for every six hours of water export. Duration of larval samples was the same as the duration for counts. To retain these smaller fish, the fish screen used in the routine counts was lined with a 0.5 mm Nitex net. Larval fish from the TFCF were identified to species by TFCF personnel, and larval fish from the SDFPF were identified to the lowest taxa possible by California Department of Fish and Wildlife personnel.

2 Dekar, M. 2015. U.S. Fish and Wildlife Service.

Water Exports

The SWP exported 2.43 billion cubic meters (m^3) of water, an increase from WY 2015 (1.38 billion m^3) and the record low exports in WY 2014 (1.12 billion m^3), but a decrease from the record high in WY 2011 (4.91 billion m^3) (Figure 1). The CVP exported 1.68 billion m^3 of water, an increase from the record low in WY 2015 (0.86 billion m^3) and WY 2014 (1.17 billion m^3), but lower than WY 2011 (3.13 billion m^3). The increased exports at both facilities coincided with increased rainfall compared to WYs 2014 and 2015. Both of which were critical water years occurring at the end of a 4-year drought. Exports in WY 2016 at both facilities were below the WYs 1981–2015 average (3.07 billion m^3 at SWP and 2.82 billion m^3 at CVP).

Exports at the SWP peaked July through September 2016 (Figure 2). During this period, the SWP exported

Figure 1 Annual water exports in billions of cubic meters for the SWP and the CVP, WYs 1981 to 2016.

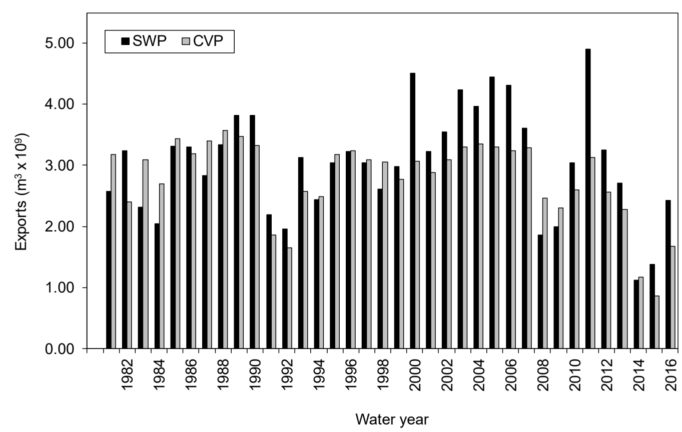
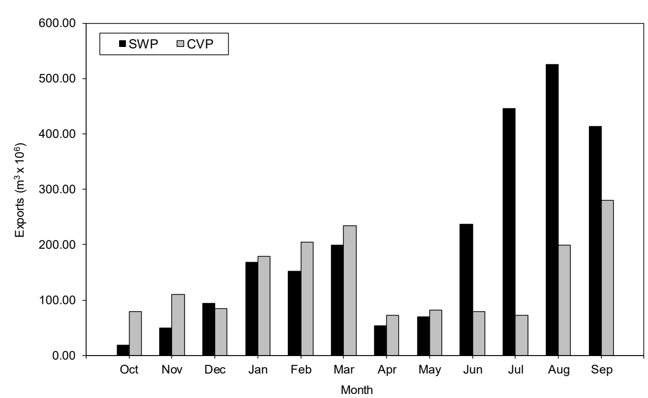


Figure 2 Monthly water exports in millions of cubic meters for the SWP and the CVP, WY 2016.



1.39 billion m^3, which represented 57.1 percent of annual export. Exports at the CVP were higher in the months of January through March and August through September 2016. The cumulative water export for those months was 1.10 billion m^3, which represented 65.4 percent of the annual export. SWP monthly exports ranged from 18.67 to 526.12 million m^3. CVP monthly exports ranged from 72.99 to 280.40 million m^3.

Total Salvage and Prevalent Species

Total fish salvage (all fish species combined) at the SDFPF was 2,832,631 (Figure 3). This was a large increase from WY 2015 (347,882) and the record low in WY 2014 (236,846), but below WY 2013 (3,042,176). Total fish salvage at the TFCF was 1,437,551. This was a large increase from WY 2015 (295,854) and the record low in WY 2014 (160,681), but below WY 2013 (2,828,514). The marked increase in total fish salvage at both facilities in WY 2016 was most likely affected by an increase in exports since salvage in recent years has been influenced by exports (i.e., higher salvage at higher exports).

Threadfin Shad was the most-salvaged species at both the SDFPF and TFCF (Figure 4 and Table 1). Striped Bass and Bluegill (*Lepomis macrochirus*) were the 2nd and 3rd most-salvaged fish at SDFPF, respectively. Bluegill and Striped Bass were the 2nd and 3rd most-salvaged fish at TFCF, respectively. Native species comprised 0.2 percent of total fish salvage at SDFPF and 0.7 percent of total fish salvage at TFCF. Relatively few Chinook Salmon, Steelhead, Delta Smelt, and Longfin Smelt were salvaged at the SDFPF (0.04 percent combined of total fish salvage) and at the TFCF (0.11 percent). These percentages represent a decrease for both facilities from WY 2015 (0.22 percent) and WY 2014 (0.10 percent) at the SDFPF and WY 2015 (0.14 percent) and WY 2014 (0.95 percent) at the TFCF.

Figure 3 Annual salvage of all fish taxa combined at the SDFPF and the TFCF, WYs 1981 to 2016.

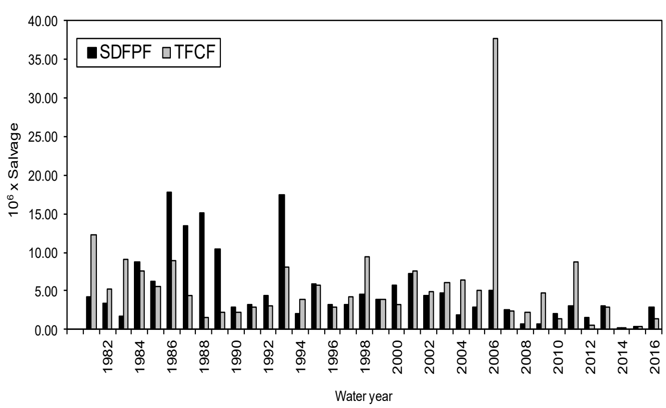
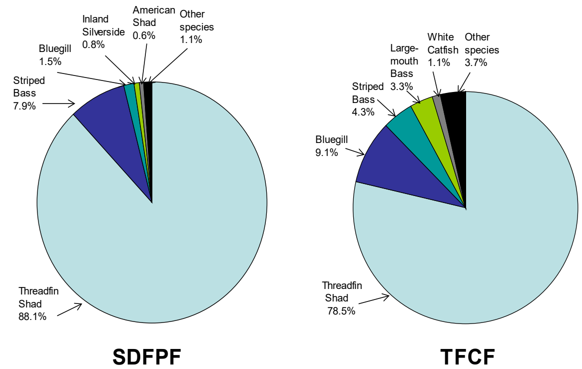


Figure 4 Percentages of annual salvage for the five most prevalent fish species and other fish species combined at the SDFPF and TFCF, WY 2016.



Chinook Salmon

Annual salvage estimates of Chinook Salmon (all races and origins combined) at both facilities continued the low salvage trend since WY 2001 (Figure 5). SDFPF salvage of juvenile and large (> 300 mm FL) Chinook Salmon (362) increased from WY 2015 (221) and increased from the record low in WY 2014 (64). Mean salvage for Chinook Salmon in WYs 2001–2016 at SDFPF was only 8.2 percent of the mean salvage in WYs 1981–2000. Salvage of juvenile and large Chinook Salmon at the TFCF (970) was a large increase from the record low in WY 2015 (187), but decreased slightly from WY 2014 (1,177). Mean WYs 2001–2016 TFCF salvage was only 10.3 percent of the mean salvage in WYs 1981–2000.

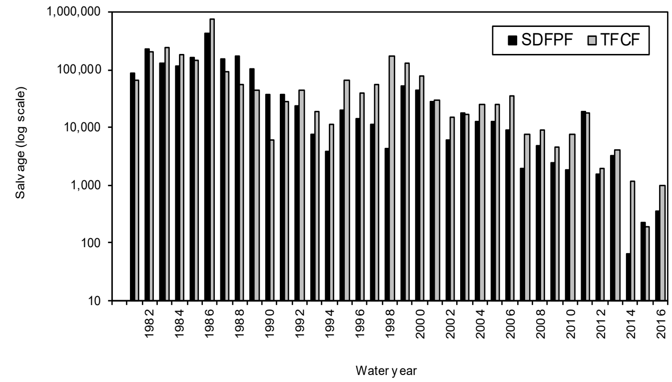
Salvaged Chinook Salmon at the SDFPF were primarily hatchery winter-run sized fish, which comprised 56.2 percent of hatchery fish, but only 33.3 percent of all salmon salvaged (Table 2). Salvaged Chinook Salmon at the TFCF were primarily hatchery spring-run sized fish, which comprised 83.0 percent of hatchery fish. The majority of hatchery winter-run fish at the SDFPF were salvaged in January while the majority of hatchery spring-run fish at the TFCF were salvaged in March.

Wild Chinook Salmon at both facilities were primarily spring-run sized fish, which comprised 34.9 percent of wild

Table 1 Annual fish salvage and percentage of annual fish salvage (%) collected from the SDFPF and TFCF in WY 2016.

SDFPF			*TFCF*		
Species	***Salvage***	***%***	***Species***	***Salvage***	***%***
Threadfin Shad	2,494,795	88.1	Threadfin Shad	1,127,956	78.5
Striped Bass	224,967	7.9	Bluegill	131,079	9.1
Bluegill	41,665	1.5	Striped Bass	61,787	4.3
Inland Silverside	22,297	0.8	Largemouth Bass	47,736	3.3
American Shad	16,878	0.6	White Catfish	15,165	1.1
Shimofuri Goby	12,052	0.4	Inland Silverside	11,223	0.8
Largemouth Bass	6,889	0.2	Shimofuri Goby	8,443	0.6
White Catfish	3,710	0.1	Rainwater Killifish	6,869	0.5
Prickly Sculpin	2,665	<0.1	Golden Shiner	4,985	0.3
Splittail	1,951	<0.1	American Shad	4,553	0.3
Bigscale Logperch	1,555	<0.1	Pacific Lamprey	2,418	0.2
Black Crappie	1,268	<0.1	Lamprey Unknown	2,356	0.2
Steelhead	789	<0.1	Prickly Sculpin	2,069	0.1
Chinook Salmon	362	<0.1	Channel Catfish	1,859	0.1
Lamprey Unknown	196	<0.1	Western Mosquitofish	1,776	0.1
Channel Catfish	191	<0.1	Redear Sunfish	1,381	0.1
Yellowfin Goby	123	<0.1	Black Crappie	1,208	<0.1
Golden Shiner	115	<0.1	Chinook Salmon	970	<0.1
Western Mosquitofish	36	<0.1	Red Shiner	886	<0.1
Rainwater Killifish	34	<0.1	Sacramento Sucker	661	<0.1
Redear Sunfish	16	<0.1	Steelhead	652	<0.1
Common Carp	12	<0.1	Yellowfin Goby	532	<0.1
Black Bullhead	11	<0.1	Bigscale Logperch	277	<0.1
Delta Smelt	8	<0.1	Threespine Stickleback	217	<0.1
Green Sunfish	6	<0.1	Splittail	109	<0.1
Starry Flounder	6	<0.1	Warmouth	96	<0.1
Goldfish	4	<0.1	Black Bullhead	58	<0.1
Green Sturgeon	4	<0.1	Brown Bullhead	36	<0.1
Spotted Bass	4	<0.1	Green Sunfish	36	<0.1
Striped Mullet	4	<0.1	Striped Mullet	28	<0.1
White Crappie	4	<0.1	Spotted Bass	20	<0.1
Shokihaze Goby	3	<0.1	River Lamprey	16	<0.1
Brown Bullhead	2	<0.1	Shokihaze Goby	16	<0.1
Hitch	2	<0.1	Smallmouth Bass	16	<0.1
Longfin Smelt	2	<0.1	Delta Smelt	12	<0.1
Threespine Stickleback	2	<0.1	Common Carp	8	<0.1
Wakasagi	2	<0.1	Fathead Minnow	8	<0.1
Tule Perch	1	<0.1	Longfin Smelt	8	<0.1
			Sacramento Blackfish	8	<0.1
			Starry Flounder	8	<0.1
			Pacific Staghorn Sculpin	4	<0.1
			Tule Perch	4	<0.1
			White Crappie	2	<0.1

Figure 5 Annual salvage of Chinook Salmon (all races and wild and hatchery origins combined) at the SDFPF and the TFCF, WYs 1981 to 2016.



Note: The logarithmic scale is $\log_{10}$.

fish at SDFPF and 47.3 percent at the TFCF (Table 2). The majority of wild spring run fish at both the SDFPF and the TFCF were salvaged in March.

Annual loss of Chinook Salmon (all origins and races) was higher at the SDFPF (1,557) than at the TFCF (680) (Table 2). Greater entrainment loss at the SDFPF than at the TFCF was attributable to greater pre-screen loss.

Steelhead

Salvage of Steelhead (wild and hatchery origins combined) continued the pattern of low salvage observed since WY 2005 (Figure 6). SDFPF salvage of juvenile and large (> 350 mm FL) Steelhead (789) increased from both WY 2015 (442) and the record low in WY 2014 (84). Juvenile salvage at the TFCF (652) increased from the record low in WY 2015 (124) and WY 2014 (330).

The SDFPF salvaged 731 hatchery Steelhead and 58 wild Steelhead. The TFCF salvaged 591 hatchery Steelhead and 61 wild Steelhead. Salvage of wild Steelhead at both facilities peaked around the middle of the water year (Figure 7). Wild Steelhead were salvaged most frequently in March at both the SDFPF and the TFCF.

Striped Bass

Salvage of juvenile and sub-adult Striped Bass at the SDFPF (224,967) was a large increase from the record low in WY 2015 (35,070). Salvage at the TFCF (61,787) was also an increase from the near record low in WY 2015 (21,398). Salvage at the SDFPF and the TFCF continued a

Table 2 Chinook Salmon annual salvage, percentage of annual salvage, race and origin (wild or hatchery), and loss at the SDFPF and the TFCF, WY 2016.

Facility	Origin	Race	Salvage	%	Loss
SDFPF					
	Wild	Fall	39	27.3	168
		Late-fall	36	25.2	159
		Spring	50	34.9	214
		Winter	8	5.6	35
		Unknown race	10	7.0	*
	Total Wild		143		576
	Hatchery				
		Fall	1	0.5	4
		Late-fall	61	27.8	272
		Spring	34	15.5	147
		Winter	123	56.2	558
	Total Hatchery		219		981
	Grand Total		362		1,557
TFCF					
	Wild	Fall	80	35.1	57
		Late-fall	8	3.6	7
		Spring	108	47.3	83
		Winter	28	12.3	21
		Unknown race	4	1.7	**
	Total Wild		228		168
	Hatchery				
		Fall	4	0.6	3
		Late-fall	32	4.3	26
		Spring	616	83.0	413
		Winter	90	12.1	70
	Total Hatchery		742		512
	Grand Total		970		680

* No loss was calculated for SDFPF large unknown run Chinook Salmon (n = 2) since they were too large to fit the loss calculation

** No loss was calculated for TFCF large unknown run Chinook Salmon (n = 1) since they were too large to fit the loss calculation

declining trend observed since the mid-1990s (Figure 8). Prior to WY 1995, annual Striped Bass salvage estimates were generally above 1,000,000 fish.

Most Striped Bass salvage at the SDFPF and TFCF occurred in May, June, and July (Figure 9). Salvage at the SDFPF in May (35,773), June (122,761), and July

Figure 6 Annual salvage of Steelhead (wild and hatchery origins combined) at the SDFPF and the TFCF, WYs 1981 to 2016.

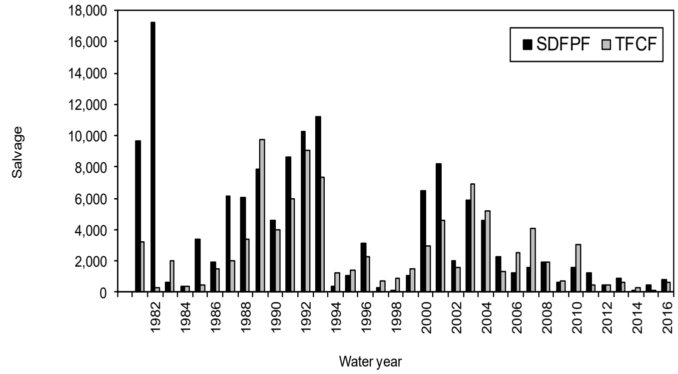


Figure 7 Monthly salvage of wild Steelhead at the SDFPF and the TFCF, WY 2016.

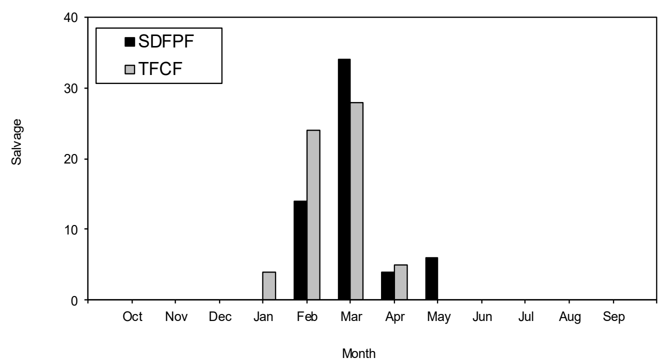
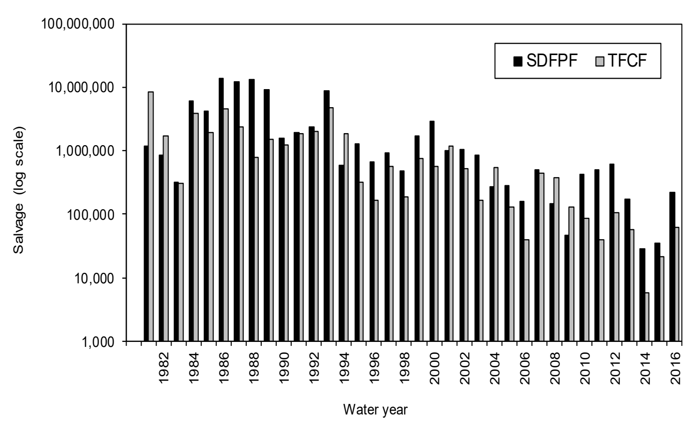


Figure 8 Annual salvage of Striped Bass at the SDFPF and the TFCF, WYs 1981 to 2016.



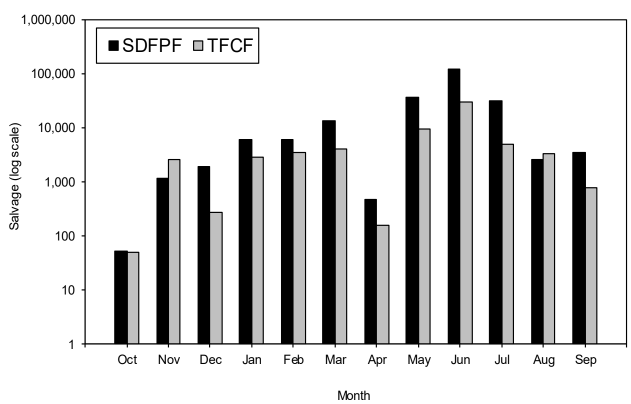
Note: The logarithmic scale is $\log_{10}$.

(31,635) accounted for 84.5 percent of total WY salvage. At the TFCF, salvage in May (9,463), June (29,894), and July (4,940) accounted for 71.7 percent of total WY salvage. Striped Bass were salvaged every month at both the SDFPF and the TFCF, with the lowest monthly salvages occurring both in October at the SDFPF (51) and at the TFCF (48).

Delta Smelt

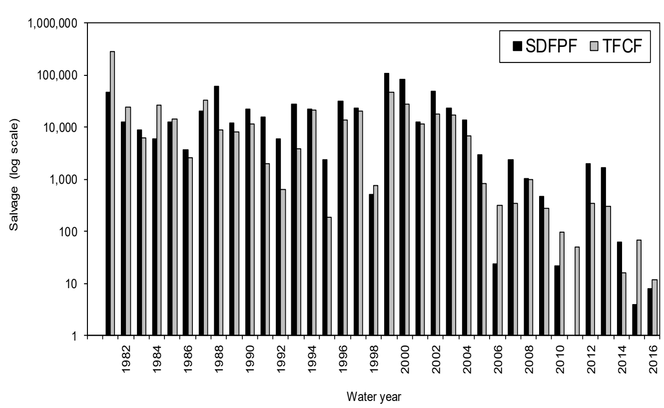
Salvage of Delta Smelt continued the pattern of mostly low salvage observed since WY 2005 (Figure 10). Salvage was a record low at the TFCF (12), which was a decrease from WY 2015 (68), similar to WY 2014 (16), and a large decrease from WY 2013 (300). Salvage at

Figure 9 Monthly salvage of Striped Bass at the SDFPF and the TFCF, WY 2016.



Note: The logarithmic scale is $\log_{10}$.

Figure 10 Annual salvage of Delta Smelt at the SDFPF and the TFCF, WYs 1981 to 2016.



Note: The logarithmic scale is $\log_{10}$.

the SDFPF (8) increased slightly from WY 2015 (4), but decreased from WY 2014 (62) and WY 2013 (1,701).

Salvage of Delta Smelt at both facilities occurred predominantly in winter and spring. Adult Delta Smelt at SDFPF were only salvaged in February (4). Juvenile Delta Smelt at SDFPF were only salvaged in April (4). Adult Delta Smelt at TFCF were salvaged equally in January (4) and February (4). Juvenile Delta Smelt at TFCF were only salvaged in April (4).

No Delta Smelt less than 20 mm FL were detected at the SDFPF in WY 2016, which was a decrease from WY 2015 (1) and WY 2014 (14). No Delta Smelt less than 20 mm FL were detected at the TFCF in WY 2016, as in WY 2015, which was a decrease from WY 2014 (6).

Longfin Smelt

Salvage of Longfin Smelt at the SDFPF in WY 2016 (2) decreased from WY 2015 (102), WY 2014 (32) and WY 2013 (659) while salvage at the TFCF (8) was equal to WY 2014 (8), but decreased from WY 2015 (28) and WY 2013 (241) (Figure 11). No adult Longfin Smelt were salvaged at either facility, and juvenile Longfin Smelt were only salvaged in March at the SDFPF (2) and at the TFCF (8).

No Longfin Smelt less than 20 mm FL were detected at the SDFPF in WY 2016 which was a decrease from WY 2015 (13) and WY 2014 (37). Only one Longfin Smelt less than 20 mm FL was detected at the TFCF on March 16th which was a decrease from WY 2015 (5) and WY 2014 (2).

Splittail

Annual salvage estimates of juvenile and adult Splittail at both facilities were markedly different from each other (Figure 12). Salvage at the TFCF was low (109), but an increase from the record lows in WY 2015 (12) and WY 2014 (12). Salvage at the SDFPF (1,951) was an increase from WY 2015 (656). Annual Splittail salvage estimates have followed a boom-or-bust pattern, often varying year to year by several orders of magnitude.

Threadfin Shad

Annual salvage of juvenile and adult Threadfin Shad was higher at the SDFPF (2,494,795) than at the TFCF

(1,127,956) (Figure 13). Salvage at the SDFPF was substantially higher than WY 2015 (186,368) and the record low in WY 2014 (63,237). Similarly, TFCF salvage was substantially higher than in WY 2015 (114,804) and the record low in WY 2014 (47,603). Similar to Splittail, annual salvage estimates of Threadfin Shad have varied greatly through time.

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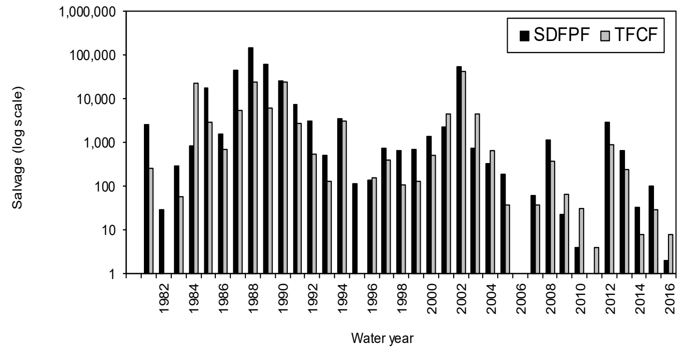
http://www.water.ca.gov/iep/activities/calendar.cfm

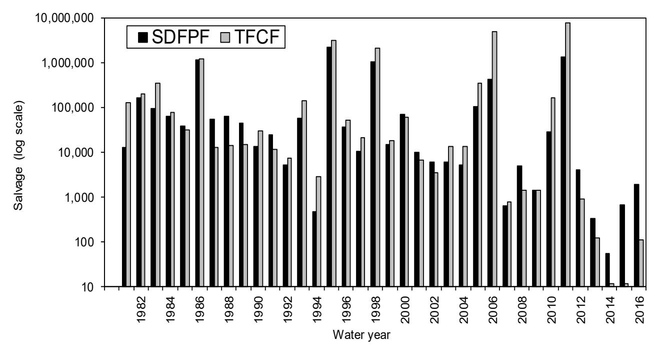
http://www.water.ca.gov/iep/highlights/index.cfm

Figure 11 Annual salvage of Longfin Smelt at the SDFPF and the TFCF, WYs 1981 to 2016.



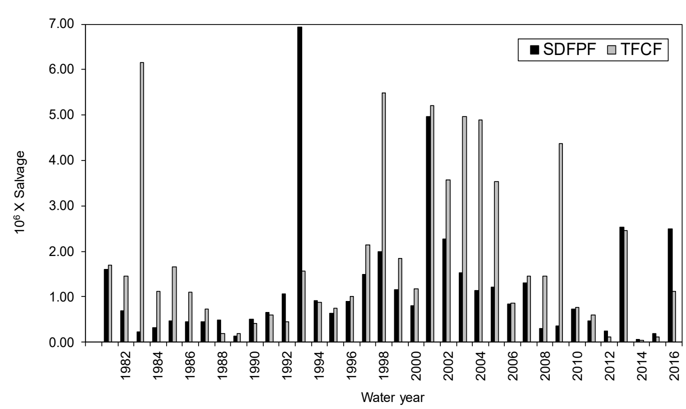
Note: The logarithmic scale is $\log_{10}$.

Figure 12 Annual salvage of Splittail at the SDFPF and the TFCF, WYs 1981 to 2016.



Note: The logarithmic scale is $\log_{10}$.

Figure 13 Annual salvage of Threadfin Shad at the SDFPF and the TFCF, WYs 1981 to 2016.



Contributed Papers

Characteristics of the May 2016 Phytoplankton Bloom: Community Composition and Biomass

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Introduction and Background

Phytoplankton are small, floating, photosynthetic organisms that occur in aquatic habitats throughout the world (van den Hoek et. al. 1995, Wehr and Sheath 2003). They include both eukaryotic protists (cells with membrane-bound organelles) and prokaryotic cyanobacteria (cells without membrane-bound organelles). Cyanobacteria are sometimes called "blue-green algae" because of their color (van den Hoek et. al. 1995). Phytoplankton can occur as single cells, colonies, or filaments (Wehr and Sheath 2003). In addition to cyanobacteria, phytoplankton include diverse organisms such as diatoms, green algae (including green algal flagellates), and various other flagellate groups (Wehr and Sheath 2003). They play an important role in aquatic food webs and the global carbon cycle (van den Hoek et. al. 1995, Wehr and Sheath 2003; Cloern and Dufford 2005). Diatom production in particular plays an important role as a net sink for carbon dioxide (Cloern and Dufford 2005).

Common to all photosynthetic organisms, including phytoplankton, is the light-absorbing pigment chlorophyll-*a* that makes photosynthesis possible (Raven et. al. 1992). Chlorophyll-*a* can also be used as an indicator of phytoplankton productivity and biomass (Wehr and Sheath 2003, Cloern and Dufford 2005). But chlorophyll-*a* alone cannot be used to distinguish between phytoplankton taxa, so it is often used alongside phytoplankton identification and counts in water quality monitoring (American Public Health Association 2012). Chlorophyll-*a* values below 10 micrograms per liter (µg/L) have been shown to be food-limiting for zooplankton in the Sacramento-San Joaquin Delta (Delta) (Müller-Solger et. al. 2002). Historically, there were regular spring and summer phytoplankton blooms in the Delta and other regions of the San Francisco Estuary (Estuary) dominated by large, single-celled diatoms, and with chlorophyll-*a* values regularly above 10 µg/L (Ball and Arthur 1979, Arthur and Ball 1980). The introduction and establishment of the Asian overbite clam (*Potamocorbula amurensis*) in 1986 greatly altered the food web of the Estuary (Carlton et.al. 1990, Alpine and Cloern 1992), and now phytoplankton blooms in the spring and summer months are rare (Cloern and Jassby 2012).

The California Department of Water Resources (DWR) and the U.S. Bureau of Reclamation (Reclamation) are required by Water Right Decision 1641 (D-1641) to collect phytoplankton and chlorophyll-*a* samples in order to monitor algal community composition and biomass at selected sites in the upper Estuary. The sampling sites range from San Pablo Bay east to the mouths of the Sacramento, Mokelumne, and San Joaquin rivers (Figure 1). These sites represent a variety of aquatic habitats, from narrow freshwater channels in the Delta to broad estuarine bays. DWR's Environmental Monitoring Program (EMP) has conducted this monitoring since the 1970s. This extensive period of record was able to document both the introduction and subsequent establishment of *Potamocorbula amurensis* and its effect on the food web. It has also documented when and where phytoplankton blooms, though rare compared to historical events, still occur.

In May 2016, the EMP's monthly discrete sampling detected elevated levels of chlorophyll-*a* (above 10 µg/L)

Figure 1 Map of stations that had elevated chlorophyll-*a* levels in May 2016.

at several sites in the Delta, suggesting the occurrence of a phytoplankton bloom. The purpose of this article is to describe the phytoplankton species present at those sites, their relative abundance and biomass, and potential effects of the bloom on the Delta and Estuary.

Methods

Study Area

The Delta is formed by the confluence of the Sacramento and San Joaquin rivers, and makes up most of the upper San Francisco Estuary (Ball and Arthur 1979). The Estuary itself is considered one of the most altered estuaries in the world by human activity (Nichols et. al. 1986), and one of most highly invaded in the world (Cohen and Carlton 1998). The Delta consists of 1,100 km of waterways, with approximately 80 percent of the flow coming from the Sacramento River, 15 percent from the San Joaquin River, and the remaining 5 percent from smaller streams entering the eastern Delta (Ball and Arthur 1979).

Sample Collection and Analysis

Samples for phytoplankton and chlorophyll-*a* are collected on a monthly basis at 15 sites throughout the Estuary: 13 fixed-location sites and two "floating" sites where bottom electrical conductance (EC) is 2,000 µS/cm and 6,000 µS/cm, +/-10 percent. Samples are collected with a submersible pump from a depth of 1 meter below the surface. Phytoplankton samples are stored in 60-milliliter (mL) glass bottles with 2 milliliters of Lugol's solution to stain and preserve the samples. Bottles are kept out of direct sunlight until analyzed. Phytoplankton samples are analyzed according to the Utermöhl microscopic method (Utermöhl 1958) and American Public Health Association (APHA) Standard Methods (American Public Health Association 2012). An aliquot is placed into a counting chamber and allowed to settle for a minimum of 15 hours. The aliquot volume, normally 10 mL, is adjusted according to the algal population density and turbidity of the sample. A minimum of 300 to 400 total natural algal units (cell, colony, or filament) are counted using a Leica DMIL inverted microscope at 800X, with at least 100 of those units being from the dominant taxon (genus or species). For taxa that were in filaments or colonies, the number of cells per filament or colony is recorded. Up to 10 cells of the major taxon and up to five cells of each minor taxon are measured for biovolume using a shape formula appropriate for the shape of the cell (e.g., cylinder, prism). A list of shape codes and their formulas can be found on the EMP's website at http://www.water.ca.gov/bdma/meta/phytoplankton.cfm. Samples are processed by BSA Environmental, Inc.

Water for chlorophll-*a* is immediately filtered in the field onto a Gelman glass fiber Type A/E filter; a small amount of magnesium carbonate is added after filtering. The volume of water filtered depends on the turbidity of the sample, with more turbid samples using a smaller volume of water due to the extra time needed for filtering. Filters are placed into a manila envelope and immediately frozen. They are processed for chlorophyll-*a* within 28 days of collection using the methods described in section 10200 H of APHA Standard Methods (American Public Health Association 2012).

Calculations

Phytoplankton count data is converted to organisms per mL using the following formula:

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

where:

Organisms = Number of organisms (number per milliliter [#/mL] of natural algal units)
C = Count obtained (natural algal units)
Ac = Area of cell bottom (in square millimeters [mm^2])
Af = Area of each grid field (mm^2)
F = Number of fields examined (#)
V = Volume settled (mL)

Because biomass can be dominated by a few large organisms not necessarily reflected in the count data, biovolumes were converted to picograms of carbon to compare with the number of organisms per mL. Individual cell biovolumes were converted to picograms of carbon per cell (pg C/cell) using the equations in Menden-Deuer and Lessard (2000). Diatom carbon per cell was calculated using the following equation:

pg C/cell = 0.288 x $V^{0.811}$

where V is the biovolume of an individual diatom cell. Total diatom carbon per mL was calculated by the following equation:

Total C/mL = pg C/cell x number of cells/unit x organisms/mL

For non-diatom phytoplankton, individual cell biovolumes were converted to pg C/cell using the following equation:

$$\text{pg C/cell} = 0.216 \times V^{0.939}$$

where V is the biovolume of an individual non-diatom cell. Total non-diatom carbon per mL was calculated using the same multiplication formula as for diatoms.

Stations For Analysis

Stations were selected for analysis if they recorded chlorophyll-*a* values above 10 µg/L during May 2016, and had a corresponding phytoplankton sample that could be analyzed for phytoplankton community composition and biovolume.

Results

In May 2016, there were seven stations with chlorophyll-*a* levels above 10 µg/L, and six of them had chlorophyll-*a* levels above 30 µg/L (Table 1, Figure 1; the floating site EZ2 was in the same location as D4 during sampling so they are shown as a single location, though they were sampled separately). Phytoplankton count data (organisms per mL) were dominated by the small, colonial cyanobacterium *Chroococcus microscopicus* at all stations, but total phytoplankton carbon (total carbon per mL) varied from station to station (Figures 2 through 8). At C10A, *C. microscopicus* dominated both the count data and the total carbon, while the charophyte *Klebsormidium subtile* and the centric diatom *Cyclotella* sp. also contributed to the total carbon (Figure 2).

Table 1 Stations with elevated chlorophyll-*a* levels in May 2016.

Station Name	*Station Number*	*Sample Date*	*Chlorophyll-a (µg/L)*
San Joaquin River near Vernalis @ SJR Club	C10A	5/10/2016	30.78
Franks Tract near Russo's Landing	D19	5/11/2016	62.39
Old River @ Rancho Del Rio	D28A	5/11/2016	49.7
San Joaquin River @ Potato Point	D26	5/12/2016	66.87
SF Estuarine Entrapment Zone- 6000 µS/cm bottom EC	EZ6	5/13/2016	27.38
SF Estuarine Entrapment Zone- 2000 µS/cm bottom EC	EZ2	5/13/2016	54.17
Sacramento River above Point Sacramento	D4	5/13/2016	57.34

At stations D19, D26, and D28A, the total carbon was dominated by the chain-forming centric diatom *Aulacoseria* sp. (Figures 3, 4, and 5); the colonial cyanobacterium cf. *Synechococcus salinarum* also contributed carbon at D19. At D4 and EZ2, both *C. microscopicus* and *Aulacoseira* sp. contributed to the total carbon, with D4 having more carbon from *Aulacoseira* sp. and EZ2 having more carbon from *C. microscopicus* (Figures 6 and 7). Counts and total carbon at EZ6 were completely dominated by *C. microscopicus*, with a small contribution from cf. *Synechococcus salinarum* (Figure 8).

Discussion

The May 2016 phytoplankton was characterized by high chlorophyll-*a* values and phytoplankton biomass,

Figure 2 Organisms per mL and Total Carbon per mL of the dominant taxa at C10A.

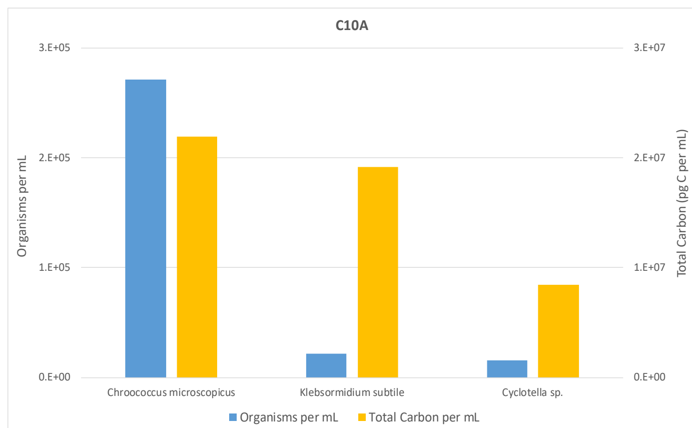
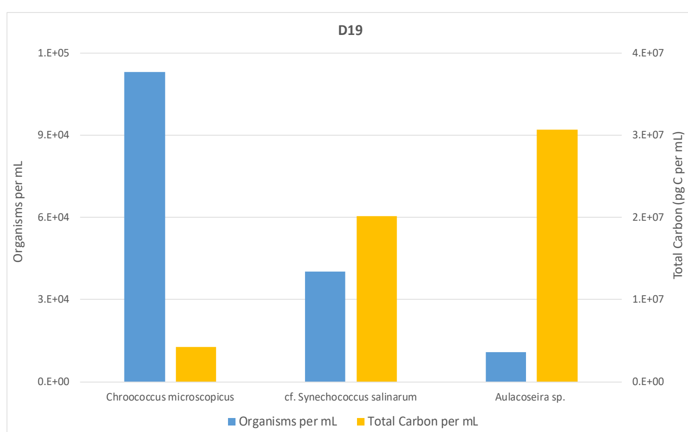
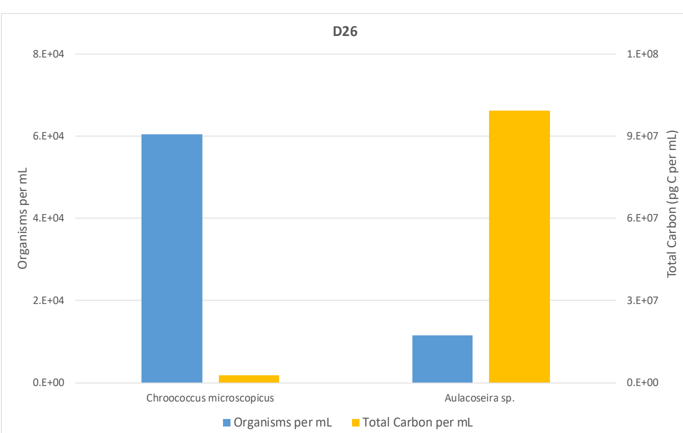


Figure 3 Organisms per mL and Total Carbon per mL of the dominant taxa at D19.



similar to historical blooms that occurred regularly before the introduction of *Potamocorbula amurensis* (Ball and Arthur 1979, Arthur and Ball 1980; Carlton et. al. 1990; Alpine and Cloern 1992). Unlike historical blooms that were dominated by large, single-celled diatoms (Ball and Arthur 1979; Arthur and Ball 1980), the May 2016 bloom was dominated by the cyanobacterium *Chroococcus microscopicus* and the chain-forming centric diatom *Aulacoseira* sp. Salinity and temperature may play a role in which species dominate a bloom; the bloom occurred in the more freshwater portion of the Estuary, at temperatures below 20 degrees Celsius (ºC). Both *C. microscopicus* and *Aulacoseira* sp. are common freshwater taxa that can thrive in cooler waters (Komárek 2003; Stoermer 2003). Diatoms, in particular, are able to grow in cooler conditions that are limiting for other phytoplankton (Cloern and Dufford 2005). *Aulacoseira* sp., especially, can be considered "one of the most successful, in terms of distribution in time and space, of freshwater centric diatoms" (Stoermer 2003). *C. microscopicus* is also well-documented from temperate freshwater areas throughout the United States (Komárek 2003). Also, the location of the stations where the bloom occurred is upstream from the densest populations of *P. amurensis* (Alpine and Cloern 1992), so benthic grazing pressure was likely reduced. The one exception is EZ6, whose location in May 2016 was close to Suisun Bay where *P. amurensis* dominates the benthic community. Because of its small size, *C. microscopicus* is less likely to settle out of the water column and be subject to benthic grazing, unlike the much larger and heavier *Aulacoseira* sp. This may explain why *C. microscopicus* overwhelmingly dominated both the organisms per mL and total carbon per mL at this station.

Figure 4 Organisms per mL and Total Carbon per mL of the dominant taxa at D26.



Nutrients can also play a role in the development of a bloom (Ball and Arthur 1979; Cloern and Dufford 2005). Though nutrients (including silica, which is essential for diatoms) are not limiting in the Estuary, different types of phytoplankton respond differently to nutrient pulses (Lehman 2007), and diatoms, in particular, respond rapidly to nutrient pulses (Cloern and Dufford 2005). Cell size is also determined by nutrient supply, among other things, and phytoplankton biomass throughout the Estuary is usually dominated by large taxa (Cloern and Dufford 2005). Though individual cells of *C. microscopicus* are orders of magnitude smaller than those of diatoms, their colonial growth habit increases the amount of carbon they can potentially contribute to total biomass, as seen at some stations during the May 2016 bloom. The chain-forming growth of *Aulacoseria* sp. plays a similar role, as the chains can consist of hundreds of cells linked together, increasing their overall contribution to total carbon.

Figure 5 Organisms per mL and Total Carbon per mL of the dominant taxa at D28A.

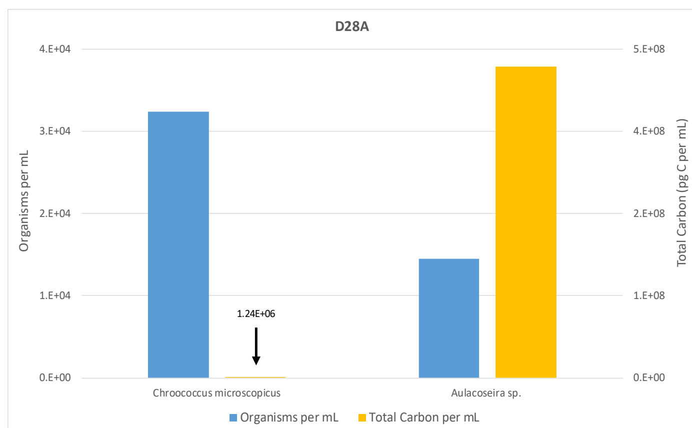
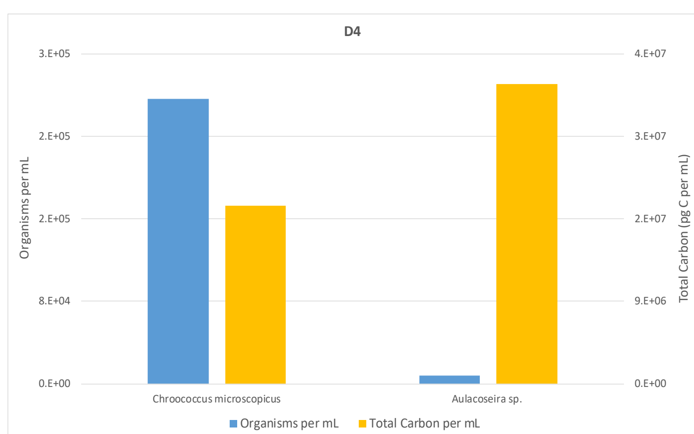


Figure 6 Organisms per mL and Total Carbon per mL of the dominant taxa at D4.



What is not fully clear are the sources of phytoplankton that were responsible for the bloom and higher level trophic effects. While phytoplankton of all types can be transported throughout an ecosystem by various methods (Wehr and Sheath 2003), larger phytoplankton cells such as diatoms require a certain amount of mixing to keep them suspended in the water column (Stoermer 2003). Downstream transport could play a role in which phytoplankton taxa are observed during a bloom by moving phytoplankton into an area where conditions are more favorable for growth (Wehr and Sheath 2003). Some diatoms, including several freshwater species of *Aulacoseira*, can produce resting stages when conditions deteriorate or nutrients are depleted by fast growth, allowing them to survive until conditions improve (McQuoid and Hobson 1996). *Aulacoseira* sp. can also survive prolonged periods of entrainment and burial in sediment (Stoermer 2003), and resumes growth after mixing re-suspends them in the water column.

Figure 7 Organisms per mL and Total Carbon per mL of the dominant taxa at EZ2.

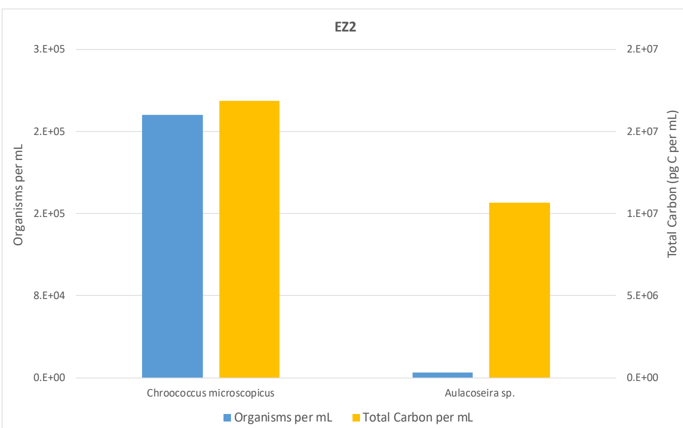
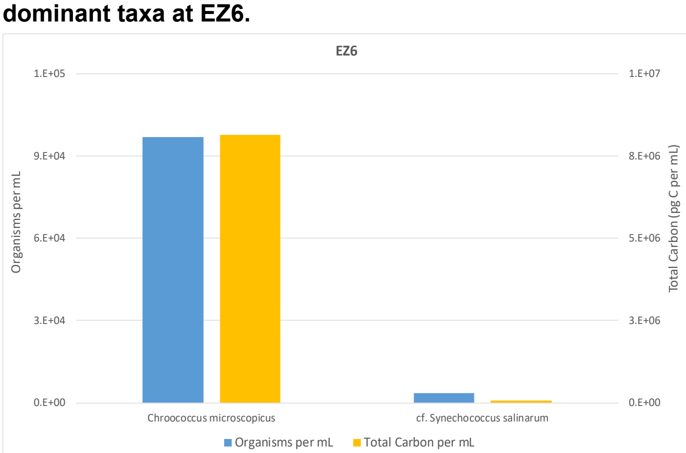


Figure 8 Organisms per mL and Total Carbon per mL of the dominant taxa at EZ6.



Zooplankton growth is affected by the quality of their food (Müller-Solger et. al. 2002; Müller-Navarra et. al. 2004), and phytoplankton with high contents of highly unsaturated fatty acids (HUFAs) are considered higher quality food for zooplankton (Müller-Navarra et. al. 2004). Cyanobacteria generally have low HUFA content, while diatoms have high HUFA content (Müller-Navarra et. al. 2004). The large biomass of *Aulacoseira* sp. at some stations in May 2016 suggests that the potential food quality for zooplankton at these stations would be higher than those dominated only by cyanobacteria. Nonetheless, the size selectivity of zooplankton also affects what they are able to prey on, as well as predator:prey ratios (Lehman 2007).

The May 2016 bloom was an unusual event in an ecosystem where phytoplankton blooms were once regular occurrences (Ball and Arthur 1979; Arthur and Ball 1980; Cloern and Jassby 2012). The causes of the bloom and the sources of the primary phytoplankton observed are not fully understood, but are likely related to factors such as salinity, nutrients, temperature, downstream transport, and benthic grazing pressure. Unlike historical blooms, this bloom was dominated by the colonial cyanobacterium *Chroococcus microscopicus* and the chain-forming centric diatom *Aulacoseira* sp. Historical blooms were dominated by large, single-celled diatoms (Ball and Arthur 1979; Arthur and Ball 1980). Those stations with high total diatom carbon may have provided a better food source for zooplankton, but the density and size selectivity of different zooplankton must also be considered. The EMP's monitoring efforts over the past four decades have documented historical phytoplankton blooms, introduced species, and other important ecological events in the San Francisco Estuary. While the needs of monitoring and management will change over the life of any monitoring program, the need for such long-term programs has never been greater (Cloern and Jassby 2012). The ability to detect events such as the May 2016 phytoplankton bloom is only possible through regular, ongoing monitoring, and such monitoring continues to be essential in studying and managing the San Francisco Estuary.

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