Interagency Ecological Program for the San Francisco Estuary

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Of Interest to Managers

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The Spring issue of the IEP Newsletter has traditionally been devoted to status and trends reporting, and that's the case for this issue as well, though for many reasons some reporting will be spread to subsequent issues. In particular, look for upper Estuary Zooplankton and Bay Fishes articles in upcoming issues. In addition, this issue begins a change in style for fish common name reporting. The American Fisheries Society recently adopted capitalizing the first letter(s) of common names of fishes, and we will use this convention for the IEP Newsletter as well.

In the lone Highlights article, **Dan Yamanaka** (DWR) and **Reza Shahcheraghi** (DWR) present a first quarter 2013 outflow and export summary. After a spectacular start to the water year (mostly not shown), flows declined from 1 January to relatively low winter levels by late in the month, and decline still farther through March. Declining and low flows as well as fish concerns combined to limit exports throughout this period.

In the first Status and Trends article, **Heather Fuller** (DWR) reports that in 2012 the Suisun Bay population of the overbite clam, *Potamocorbula amurensis*, bounced back from lower densities in 2011. The author hypothesizes that lower outflows in 2012 resulted in higher clam numbers. Conversely, amphipod communities in San Pablo Bay and in the confluence area and upstream did better during 2011 with its higher outflow. Thus, the lower clam densities and higher fish food (i.e., amphipod) densities detected in 2011 were short-lived.

The upper Estuary fish populations currently indexed by IEP surveys responded poorly in 2012. **Dave Contreras** (CDFW), **Katherine Osborn** (CDFW), **Randy Baxter** (CDFW), and **Steve Slater** (CDFW) report index declines between 2011 and 2012 for all the upper Estuary pelagic fishes. Most disheartening were the Delta Smelt indices, which showed good abundance in the spring 2012 20 mm Survey, only to decline to low levels in the Summer Townet and Fall Midwater Trawl surveys. Longfin Smelt abundance is not tracked by the 20 mm or Summer Townet surveys, but the Fall Midwater Trawl survey showed its abundance near a record low. These authors included Splittail as a pelagic fish, but in spring, small juveniles are well captured along the shoreline by the USFWS beach seine survey. Splittail abundance in the beach seine declined substantially in 2012, but remained modest and reflected some recruitment from the San Joaquin River in a low outflow year. In a decade of record low indices, the near record low Threadfin Shad index provides the most dramatic recent decline, dropping almost two orders of magnitude since 2007.

One use of salvage – that is expanded counts of fishes diverted from exported water taken regularly throughout the day at the fish facilities – is as an index of south and central Delta fish abundance. **Geir Aasen**'s (CDFW) article describes trends in salvage of seven selected fish species. Although annual water exports declined modestly, salvage of juvenile Chinook Salmon (all races total) reached a record low in 2012, likely resulting from below average returns of spawning adults in 2011 (see Azat this issue) and export restrictions in winter and spring 2012. Both Striped Bass and Threadfin Shad salvage mimicked low to very low abundance in trawl surveys (compare with Contreras and others this issue) and Splittail salvage followed beach seine and trawl indices; however, salvage of Delta Smelt and Longfin Smelt both increased sharply in 2012, in contrast to low indices in trawl surveys.

Prior poor returns of Central Valley fall-run Chinook Salmon to spawning tributaries resulted in commercial fishing closures in 2008 and 2009 and substantial restrictions to both commercial and sport fisheries in 2010. Since then, some races have shown improvement. **Jason Azat** (CDFW) reports some good news and some bad news in his summary by race of 2012 spawner returns to Central Valley streams. He shows that better than average spring-run and fall-run returns led to good numbers overall for the Central Valley. Late-fall-run and winter-run Chinook Salmon continue to show weak returns.

In 2007 or 2008, two fish monitoring surveys began recording visual observations of *Microcystis aeruginosa,* a toxic blue-green alga now prevalent in the upper San Francisco Estuary. **Trishelle Morris** (CDFW) summarizes visual observations of *Microcystis aeruginosa* collected at 32 (2008-2010) or 40 (2011-2012) Summer Townet stations ranging from the eastern San Pablo Bay to Rio Vista on the Sacramento River and to Stockton on the San Joaquin River. *M. aeruginosa* density was ranked on a 1-5 scale, with 1 being an absence of visible colonies and 5 being a contiguous mat or scum, and compared against other environmental measurements taken at the same time. Results showed high temperatures, relatively clear water and low salinities during summer favor the growth of *M. aeruginosa*. In addition, the high summer temperatures could promote high toxicity by these organisms, which could be detrimental to wildlife. High water clarity, as seen in much of this region, may enable this species to outcompete other, more palatable phytoplankton species, which could further alter the food web base.

Based on the same visual density ranking of *M. aeruginosa* used by Morris (above), **Trishelle Morris** (CDFW) and **Michael Civiello** (CDFW) reported further observations of *M. aeruginosa* collected later in the year. Since 2007, visual density of *M. aeruginosa* has been recorded at up to 122 Fall Midwater Trawl stations sampled once per month from September through December. Fall Midwater Trawl stations range from western San Pablo Bay to Hood on the Sacramento River, and to Stockton on the San Joaquin River. They compared these fall data with the Summer Townet data to gain a more comprehensive view of *M. aeruginosa* trends. Unlike *M. aeruginosa* in the Summer Townet surveys, there were few fall observations in ranks 3 or 4, and none in rank 5 in Fall Midwater Trawl surveys. *M. aeruginosa* was observed throughout most of the Delta, with predominance in the warm, clear waters of the San Joaquin River and south Delta. The high temperatures, relatively low salinities, and clear waters often seen in the estuary provide a suitable habitat for *M. aeruginosa*.

IEP QUARTERLY HIGHLIGHTS

Delta Water Project Operations - January to March 2013

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The precipitation pattern in the Delta region from January through March was reflective of the recorded rainfall at Stockton Fire Station (California Data Exchange Center Code of "SFS") (Figure 1). By the end of March, the water year type was established as "Dry" for Sacramento River Basin and "Critical" for San Joaquin River Basin (see CA Department of Water Resources Bulletin 120).

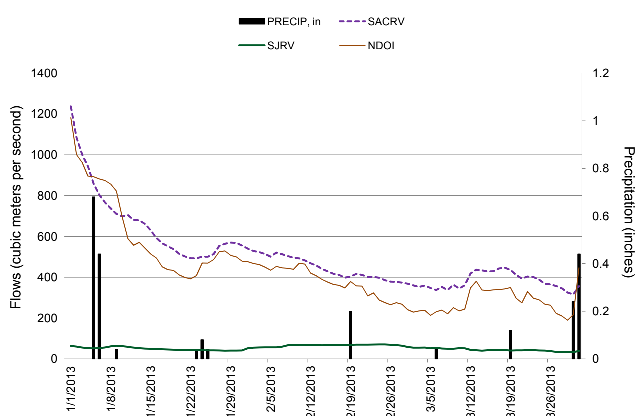

Figure 1 Sacramento River, San Joaquin River, Net Delta Outflow, and Precipitation, January 1 through March 31, 2013

The majority of the Delta inflows during these months came from a combination of contributions from the upstream reservoir releases and other in-basin accretions originating within the Sacramento and San Joaquin river basins.

The Sacramento River flow at Freeport (SACRV) ranged between 315 cms and 1240 cms, and the San Joaquin River at Vernalis (SJRV) ranged between 35 cms and 70 cms. Net Delta Outflow Index (NDOI) peaked at a high of 1180 cms and receded to 190 cms during the 3-month period (Figure 1).

The CVP and SWP Projects' combined export was as low as 45 cms and peaked as high as 180 cms (Figure 2).

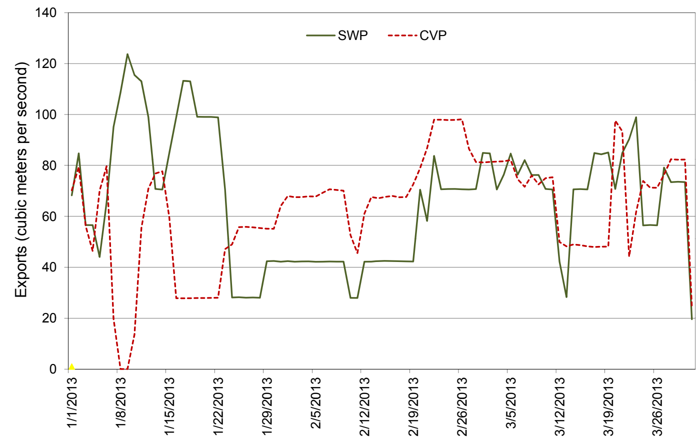

Figure 2 State Water Project and Central Valley Project Exports, January 1 through March 31, 2013

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

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

Status and Trends

Benthic Monitoring, 2012

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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 within the upper San Francisco Estuary. Benthic species are relatively long-lived and respond to changes in physical factors within the system, such as freshwater inflows, salinity, and substrate composition. As a result, benthic data can provide an indication of physical changes occurring within the estuary. Because operation of the State Water Project can impact 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 newly introduced into the upper estuary. The results below report on the benthic communities found at the EMP's benthic monitoring sites in 2012, and highlight some of the differences seen in the communities between 2011 and 2012.

Methods

Benthic monitoring was conducted monthly at 10 sampling sites distributed throughout several estuarine regions from San Pablo Bay through the Sacramento-San Joaquin Delta (Figure 1). EMP staff collected five bottom grab samples at each station using a Ponar dredge with a sampling area of 0.052 m^2. Four replicate grab samples were used for benthic macrofauna analysis; the fifth sample was used for sediment analysis. Benthic macrofauna samples were analyzed by Hydrozoology, a private laboratory under contract with the Department of Water Resources. All organisms were identified to the lowest taxon possible and enumerated. Sediment composition analysis was conducted at the Department of Water Resources' Soils and Concrete Laboratory. Field collection methodology and laboratory analysis of benthic macroinvertebrates and sediment composition are described in detail in the benthic metadata found at http://www.water.ca.gov/bdma/meta/benthic.cfm.

Prior to data analyses, individual species counts per grab were expanded to number per unit area of the species at the given site and sample date by first averaging the individual counts of each species in the four replicate grabs, unless otherwise noted. The average count was divided by 0.052, the area of the Ponar dredge in m^2 to get an abundance of organisms per m^2. The densities for all phyla were then plotted month by month to depict seasonal patterns in benthic communities.

The 2012 water year was considerably drier than the 2011 water year. Consequently, the benthic communities at many of the monitoring sites in 2012 were expected to differ from the communities of the sites in 2011, both in species composition and in organism abundances, particularly at sites in the low salinity zone.

Results

One new species was added to the benthic species list in 2012, an unknown species of chironomid in the genus *Stempellina*. This species is not necessarily new to the upper San Francisco estuary, but was collected for the first time in 2012 by the benthic monitoring component of the EMP.

Nine phyla were represented in the benthic fauna collected in 2012: 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), Phorinda (phoronids), and Chordata (tunicates). Of these phyla, Annelida, Arthropoda, and Mollusca accounted for 98% of all organisms collected in 2012.

Of the 118 benthic species collected in 2012, 10 represented 85% of all organisms collected. These include several amphipods, the Asian clams, and several 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.

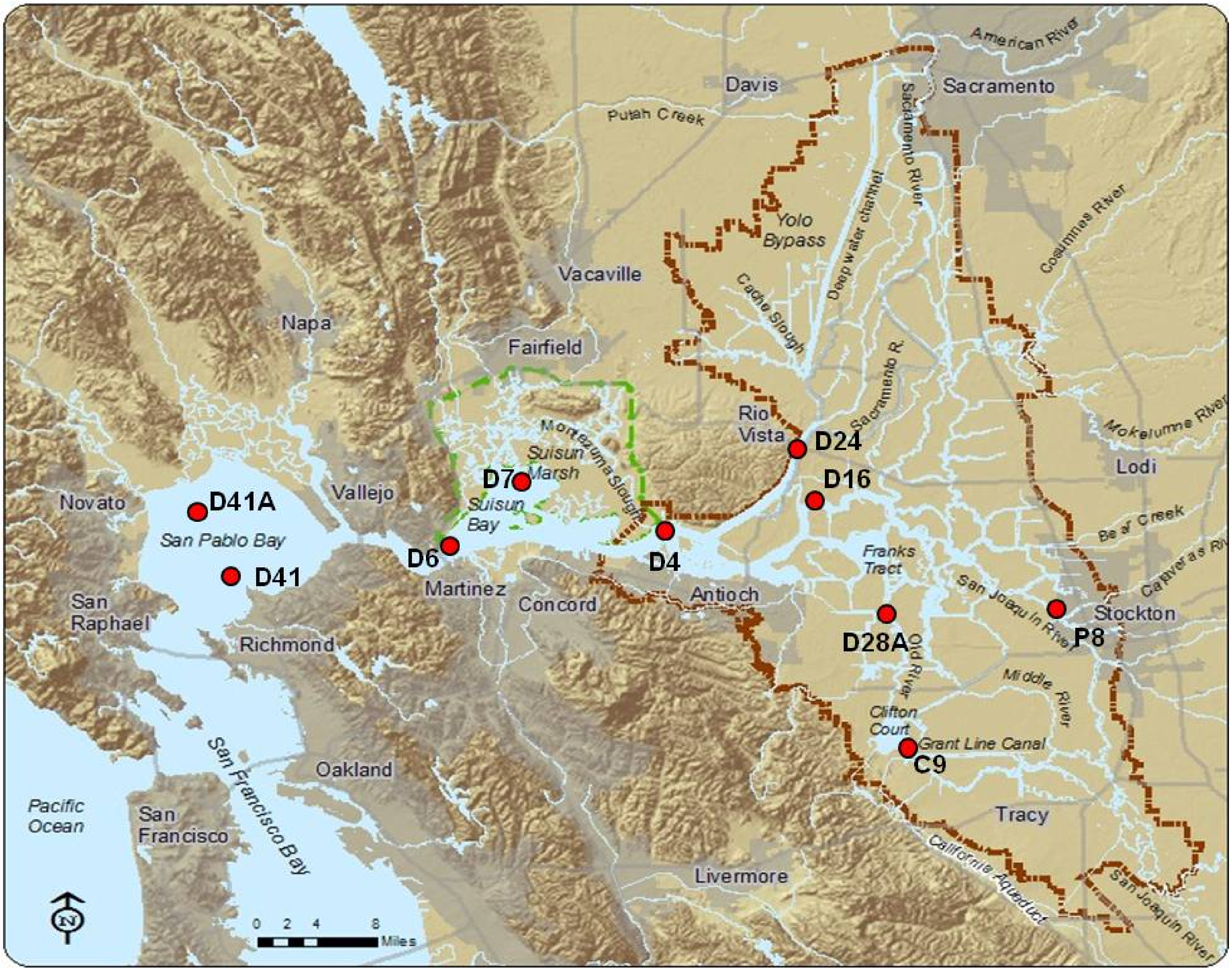

Figure 1 Locations of the Environmental Monitoring Program's (EMP) benthic monitoring stations

North Delta (D24)

D24 is located on the Sacramento River, just south of the Rio Vista Bridge (Figure 1). The substrate at this station in 2012 was consistently made up of sand each month. Mollusca was the most abundant phylum at D24 in all months (Figure 2), accounting for 77% of all organisms collected in 2012. Nearly all (97%) of the mollusks found at D24 in 2012 were *Corbicula fluminea*. Annelids (dominated by *Varichaetadrilus angustipenis* and *Limnodrilus hoffmeisteri*) and Arthropods (dominated by *Gammarus daiberi*) were also commonly found at D24 in 2012 (Figure 2). The benthic community found at D24 in 2012 was very similar to the community found there in 2011, though *C. fluminea* abundances were slightly higher in 2012.

Central Delta (D16, D28A)

The benthic monitoring program sampled at two stations in the central Delta. D16 is located in the lower San Joaquin River near Twitchell Island (Figure 1). In 2012, the substrate composition of D16 varied from month to month; in some months it was primarily sand, in others it was primarily fines (clay or silt or both), and in some months it was a mixture of both. Arthropoda was the most abundant phylum (58% of all organisms collected) for 6 months of the year, while Mollusca was most abundant in the remaining months (31% of all organisms collected; Figure 3). The most abundant arthropods at D16 in 2012 were *G.daiberi* and *Americorophium spinicorne* and the most abundant mollusk was *C. fluminea*. October abundances at D16 were nearly 3 times as high as the next most abundant month, due to a large number of *G. daiberi* (nearly 3000 per m^2) collected there that month. The benthic community at D16 in 2012 was similar to the community found there in 2011.

Table 1 Most abundant species collected by the benthic monitoring component of the EMP in 2012

Species	*Organism Type*	*Station(s) at which the species was abundant*	*Month(s) in which the species was abundant*	*Total Count for 2012*[a]
Potamocorbula amurensis	Asian clam	D41A, D6, D7	Abundant all months	36920
Varichaetadrilus angustipenis	Tubificidae worm	D28A, P8, D4, C9	Abundant all months	19721
Americorophium spinicorne	Amphipod	D4	Jan-Aug	18772
Corophium alienense	Amphipod	D7	Abundant all months	16262
Limnodrilus hoffmeisteri	Tubificidae worm	P8, C9, D4, D28A	Jan-Aug	14301
Ampelisca abdita	Amphipod	D41, D41A	Jan-Jun	10795
Gammarus daiberi	Amphipod	D4, D24, D16, D28A	Mar-May	10142
Americorophium stimpsoni	Amphipod	D4, P8	Jan-Jun	9876
Corbicula fluminea	Asian clam	D24, D16, D28A, P8, D4	Abundant all months	9533
Manayunkia speciosa	Sabellidae polychaete worm	P8, D28A	Jan-Jun	7707

[a] Total number of individuals collected by the benthic monitoring program at all stations in all months, 2012 (the four replicate grabs collected at each station each month were summed).

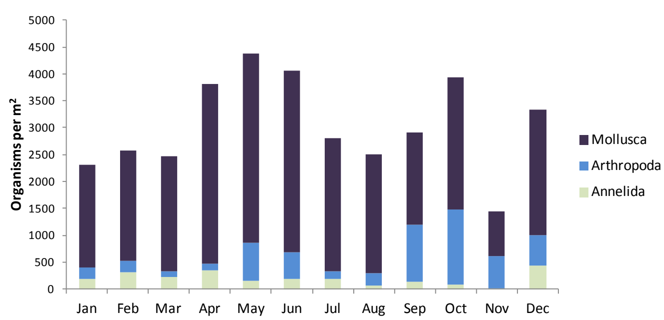

Figure 2 Abundance of benthic organisms, grouped by phyla, collected at station D24 (Sacramento River at Rio Vista) by month, 2012. Very rare phyla (defined as fewer than 100 individuals per square meter total for the year) were omitted from this figure.

D28A is located in Old River near Rancho Del Rio (Figure 1). The substrate at this station generally consisted of a high percentage of sand with some fines and organic matter, though the amount of each varied greatly throughout the year, with some months containing very large quantities of peat. Likewise, the number of benthic organisms found at D28A varied greatly between months (Figure 4). Annelida was the most abundant phylum at D28A in all months except October (70% of all organisms collected), when Arthropoda was most abundant. The most abundant annelid was *V. angustipenis* (30% of all annelids collected) and the dominant arthropod was the amphipod *Americorophium stimpsoni* (64% of all arthropods collected). The number of arthropods collected at D28A in 2012 was half the number collected there in 2011, due in large part to the very low numbers of the ostracod *Cyprideis* sp. *A* collected in 2012 compared to 2011.

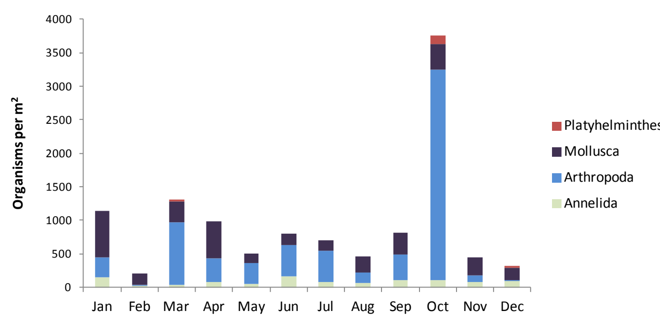

Figure 3 Abundance of benthic organisms, grouped by phyla, collected at station D16 (San Joaquin River at Twitchell Island) by month, 2012. Very rare phyla (defined as fewer than 100 individuals per square meter total for the year) were omitted from this figure.

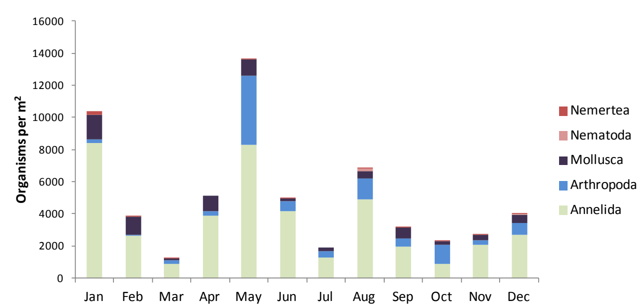

Figure 4 Abundance of benthic organisms, grouped by phyla, collected at station D28A (Old River) by month, 2012. Very rare phyla (defined as fewer than 100 individuals per square meter total for the year) were omitted from this figure.

South Delta (P8, C9)

The benthic monitoring program sampled at two stations in the southern Delta. P8 is located on the San Joaquin River at Buckley Cove (Figure 1). The substrate was generally made up of a mix of fines (silt or clay or both) and organics, though the amount of each varied slightly throughout the year. Annelida was the most abundant phyla at this station for all months in 2012, accounting for 73% of all organisms collected (Figure 5). The dominant annelid was *Manayunkia speciosa*, which accounted for 51% of all Annelids collected at P8 in 2012. Arthropod abundances at P8 were substantially lower in 2012 than in 2011. However, arthropod abundances at P8 in 2012 were comparable to abundances seen there in 2010.

C9 is located at the Clifton Court Forebay intake (Figure 1). The substrate at this station was consistently a fairly even mix of sand and fines (clay or silt), occasionally with some peat. Annelida was by far the dominant phylum in all months (Figure 6), accounting for 76% of all organisms collected. *L. hoffmeisteri* and *V. angustipenis* were the dominant annelids at C9 in 2012, accounting for 39% and 34% of the total annelids collected, respectively. The benthic community at C9 in 2012 was similar to the benthic community in 2011, with the exception of the rare phyla Platyhelminthes, Nemertea, and Cnidaria that were found at C9 in low abundances in 2012 but were absent in 2011. Organism abundances (particularly annelid abundances) were much lower in the fall of 2012 than the fall of 2011.

Confluence (D4)

D4 is located near the confluence of the Sacramento and San Joaquin rivers, just above Point Sacramento (Figure 1). The substrate at this station generally consisted of a mix of organic matter, sand, and fines, though the amount of each varied greatly throughout the year. In most months fines (clay or silt or both) dominated the sediment sample, though organic matter (peat) dominated the sample in several months. Arthropoda was the most abundant phylum from January to August, accounting for 74% of all organisms collected (Figure 7). Annelida was the most abundant phylum in September through December, and accounted for 21% of all organisms collected. *A. spinicorne* was the most abundant arthropod at this station in 2012 (56% of all arthropods collected), whereas *V. angustipenis* was the most abundant annelid (65% of all annelids collected). For the most part the benthic community at D4 in 2012 was fairly similar to the community found there in 2011, however there were a few differences in seasonal trends between the years. Annelids were substantially less abundant in January-July in 2012 than in 2011, while arthropods were substantially less in abundant in January-May of 2012 than 2011.

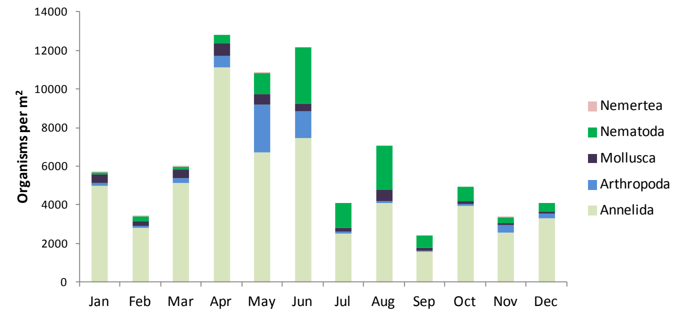

Figure 5 Abundance of benthic organisms, grouped by phyla, collected at station P8 (San Joaquin River at Buckley Cove) by month, 2012. Very rare phyla (defined as fewer than 100 individuals per square meter total for the year) were omitted from this figure.

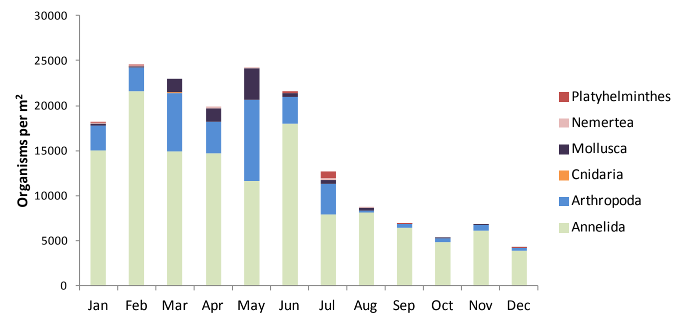

Figure 6 Abundance of benthic organisms, grouped by phyla, collected at station C9 (Clifton Court) by month, 2012. Very rare phyla (defined as fewer than 100 individuals per square meter total for the year) were omitted from this figure.

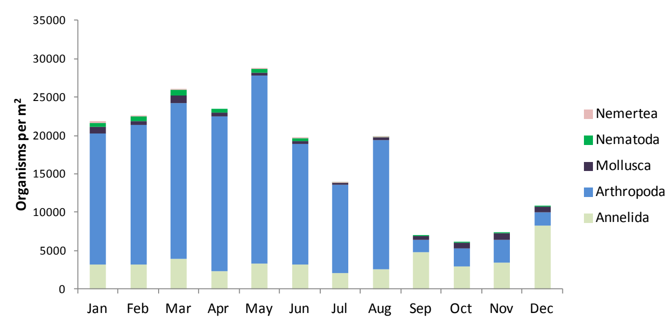

Figure 7 Abundance of benthic organisms, grouped by phyla, collected at station D4 (Confluence) by month, 2012. Very rare phyla (defined as fewer than 100 individuals per square meter total for the year) were omitted from this figure.

Suisun Bay (D6 and D7)

The benthic monitoring program sampled at two stations in the Suisun Bay area. D6 is located in Suisun Bay near Martinez (Figure 1). The substrate at D6 was consistently made up of fines (a mix of clay and silt, though generally mostly clay). Mollusca was by far the dominant phylum in all months at this station (Figure 8), accounting for 93% of all organisms collected. With the exception of one individual, all mollusks collected at D6 in 2012 were *Potamocorbula amurensis*. The total number of mollusks collected in 2012 at D6 was about 35% higher than the amount collected there in 2011. A difference in seasonal trends between 2011 and 2012 was noted; many more mollusks were collected in the summer of 2012 than in the summer of 2011. This trend was likely tied to the much lower spring flows in 2012 versus 2011.

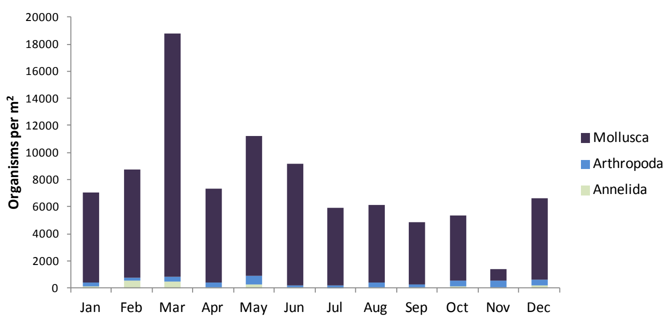

Figure 8 Abundance of benthic organisms, grouped by phyla, collected at station D6 (Suisun Bay) by month, 2012

D7 is located in Grizzly Bay, near Suisun Slough (Figure 1). The substrate at D7 was consistently made up of fines (a mix of clay and silt, though generally mostly clay). Arthropoda was the most abundant phylum in all months except June (Figure 9) and accounted for 64% of organisms collected in 2012. The amphipod *Corophium alienense* was by far the dominant arthropod at D7 in 2012, accounting for 96% of arthropods collected. Mollusks (made up almost exclusively of *P. amurensis*) were substantially more abundant in winter and spring of 2012 than in the winter and spring of 2011. Overall, more than twice as many mollusks were collected at D7 in 2012 than in 2011.

San Pablo Bay (D41, D41A)

The benthic monitoring program sampled at two stations in San Pablo Bay. D41 is located near Pinole Point (Figure 1) and has a benthic community primarily comprised of marine organisms. The substrate at this station was consistently a mix of fines and sand, with some organics (primarily clamshells). Arthropoda was the most abundant phylum at D41 accounting for 56% of organisms collected (Figure 10). Arthropod abundances were particularly high in March, July, and October. The most common arthropod by far was the amphipod *Ampelisca abdita* which accounted for 80% of all arthropods collected in 2012. The benthic community of D41 in 2012 was mostly similar to that found there in 2011, though arthropod abundances were lower in 2012 than 2011.

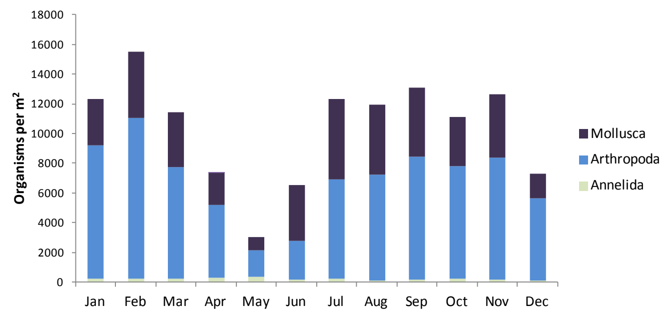

Figure 9 Abundance of benthic organisms, grouped by phyla, collected at station D7 (Grizzly Bay) by month, 2012. Very rare phyla (defined as fewer than 100 individuals per square meter total for the year) were omitted from this figure.

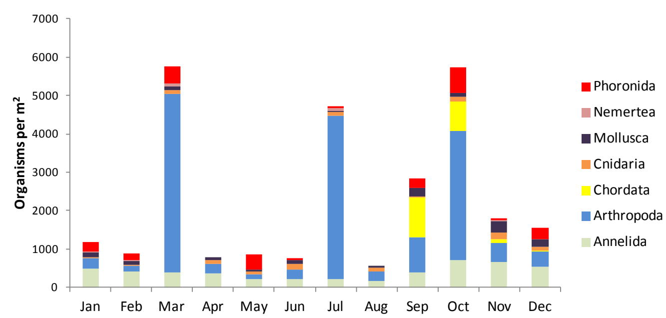

Figure 10 Abundance of benthic organisms, grouped by phyla, collected at station D41 (San Pablo Bay) by month, 2012. Very rare phyla (defined as fewer than 100 individuals per square meter total for the year) were omitted from this figure.

D41A is located near the mouth of the Petaluma River (Figure 1). The substrate of this station was made up of fines (primarily clay) in all months. The most abundant phylum at this station in January through April as well as October through December was Arthropoda (accounting for 49% of organisms collected in 2012; Figure 11). The dominant arthropod was *A. abdita* (87% of arthropods collected). Monthly trends in arthropod abundances differed between 2011 and 2012; in 2012 abundances were highest in January through June, while in 2011 abundances were highest in October-December. Mollusca (almost exclusively *P. amurensis*) was by far the most abundant phylum in May through September (Figure 11) at D41A, accounting for 49% of the organisms collected in 2012. *P. amurensis* was less abundant at D41A in 2012 than in 2011, particularly in the fall months.

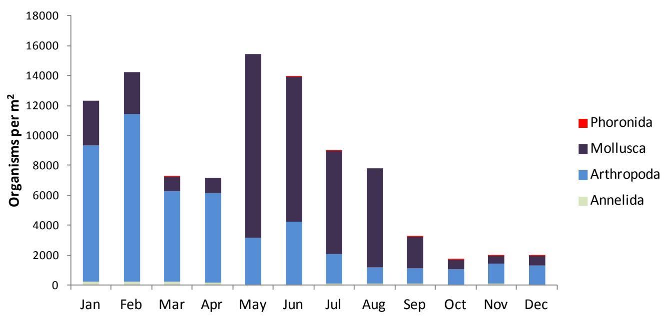

Figure 11 Abundance of benthic organisms, grouped by phyla, collected at station D41A (San Pablo Bay) by month, 2012. Very rare phyla (defined as less than 100 individuals per square meter total for the year) were omitted from this figure.

References

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

2012 Status and Trends Report for Pelagic Fishes of the Upper San Francisco Estuary

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Introduction

The 2012 Status and Trends report includes pelagic fish data from 4 of the Interagency Ecological Program's (IEP) long-term monitoring surveys, conducted in the upper San Francisco Estuary: 1) the Summer Townet Survey (STN), 2) the Fall Midwater Trawl Survey (FMWT), 3) the 20 mm Survey, and 4) the U.S. Fish and Wildlife Service (USFWS) Beach Seine Survey (See Honey et al. 2004 for additional information). We present the most recent abundance indices, long-term abundance trends, and distributional information phylogenetically for 7 species: American Shad (*Alosa sapidissima*), Threadfin Shad (*Dorosoma petenense*), Delta Smelt (*Hypomesus transpacificus*), Longfin Smelt (*Spirinchus thaleichthys*), Wakasagi (*Hypomesus nipponensis*), Splittail (*Pogonichthys macrolepidotus*) and age-0 Striped Bass (*Morone saxatilis*). Threadfin Shad, Delta Smelt, Longfin Smelt, and age-0 Striped Bass spawn and rear in the upper estuary, have undergone severe declines in recent years (Sommer et al. 2007).

1 Authorship: Introduction and methods, S. Slater and R. Baxter; American and Threadfin Shad, Longfin Smelt, Delta Smelt, Wakasagi and Striped Bass, D. Contreras, K. Osborn and R. Baxter; and Splittail, D. Contreras, R. Baxter.

Methods

We now briefly discuss the methods for the 4 studies that contribute to our report on the pelagic fishes listed in the introduction. The 20 mm Survey monitors distribution and relative abundance of larval and juvenile Delta Smelt throughout their historical spring range. This includes the entire Delta downstream to eastern San Pablo Bay and the Napa River. Since 1995, surveys have been conducted on alternate weeks from early March through early July, with 9 surveys completed in 2012. Three tows are completed at each of the 47 stations (Figure 1) using a 1,600-µm mesh net (Dege and Brown 2004). Five Napa River stations were added in 1996. In 2008, 2 stations each were added in Lindsey Slough, Miner Slough, and the Sacramento Deep Water Shipping Channel (SDWSC). The survey name comes from the size (20 mm) 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 facilities.

The Summer Townet Survey (STN) began in 1959. The data have been used to calculate age-0 Striped Bass indices for all years except 1966, 1983, 1995, and 2002. Age-0 Delta Smelt indices have also been calculated for the period of record, except for 1966-1968. The STN field season currently kicks off in June and samples 32 historic sites (31 of which are used in index calculation) distributed from eastern San Pablo Bay to Rio Vista on the Sacramento River and to Stockton on the San Joaquin River (Figure 2). Historically, 2 to 5 surveys were conducted annually, depending on how quickly Striped Bass exceeded 38.1 mm in length, the length criterion used to establish the surveys used to calculate the Striped Bass abundance index. Beginning in 2003, California Department of Fish and Wildlife (CDFW) standardized sampling to 6 surveys per year (Hieb and others, 2005), which start in early June and run on alternate weeks through August. In 2011, STN added 8 supplemental stations in the Cache Sl-SDWSC region to increase spatial coverage and better describe Delta Smelt range and habitat (Figure 2). At least 2 tows are completed at most stations, and a third is conducted if any fish are caught during the first 2 tows. At least 1 tow is completed at the new Cache Sl-SDWSC stations. To reduce Delta Smelt take, a second tow is only performed at these stations if Delta Smelt catch from the first tow is less than ten. During the field season, the estimated date that age-0 Striped Bass reach or surpass a mean fork length (FL) of 38.1 mm is determined; the index is calculated based on the two survey indices that bracket that date (Chadwick 1964, Turner and Chadwick 1972). In contrast, the Delta Smelt annual index is the average of the first two survey abundance indices of each survey year.

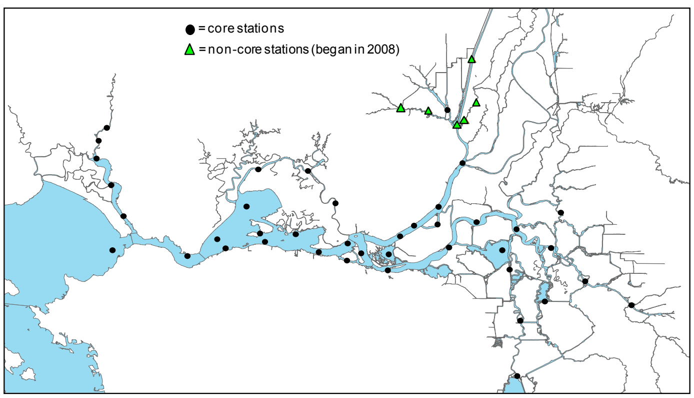

Figure 1 20 mm Survey station map. Core stations represent those used for indices. Non-core stations were added to the survey at a later date.

The Fall Midwater Trawl (FMWT) Survey began in 1967. Surveys have been conducted annually in all years, except for 1974 and 1979. The CDFW established the FMWT survey to examine age-0 Striped Bass relative abundance and distribution in the estuary (Stevens, 1977). Later, FMWT developed abundance and distribution information for other upper-estuary pelagic species, including American Shad, Threadfin Shad, Delta Smelt, Longfin Smelt, and Splittail. The FMWT survey currently samples 122 stations monthly, from September to December, in an area ranging from San Pablo Bay to Hood on the Sacramento River and Stockton on the San Joaquin River (Figure 3). The index calculation uses catch data from 100 of the 122 stations (see Stevens 1977); the remaining 22 stations were added over time in 1990, 1991, 2009, and 2010 to improve our understanding of Delta Smelt habitat use (Figure 3). The 100 index stations are grouped into 17 regional "areas" based on their location. Monthly indices are calculated by averaging catch per tow for index stations in each regional area, multiplying these regional means by their respective weighting factors (i.e., a scalar based on water volume), and summing these products for all 17 areas. Annual abundance indices are the sum of the 4 (September-December) monthly indices.

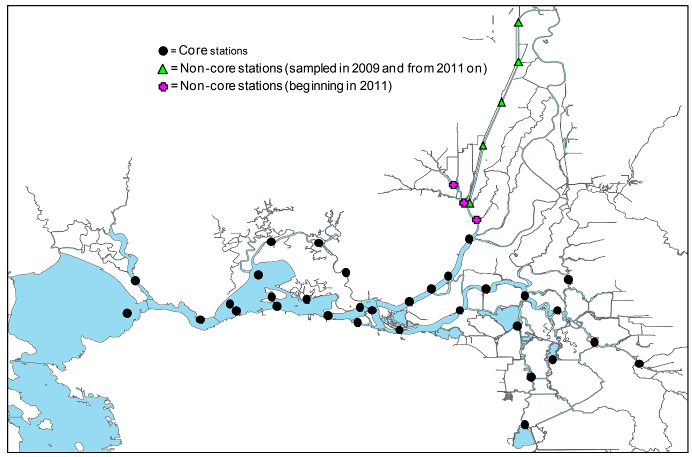

Figure 2 Summer Townet Survey station map. Core stations represent those sampled since survey inception and used for indices. Non-core stations were added to the survey at a later date.

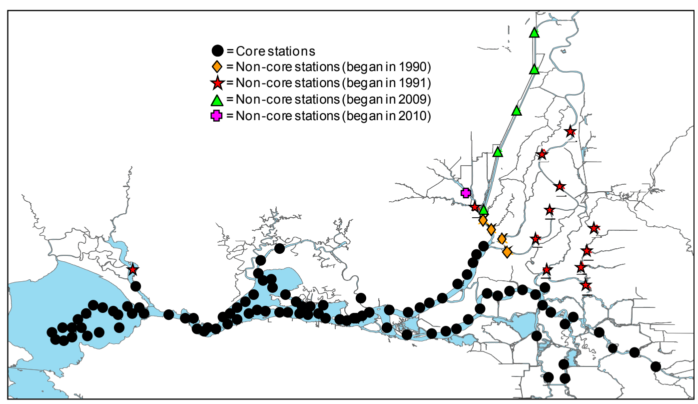

Figure 3 Fall Midwater Trawl Survey station map. Core stations represent those sampled since survey inception and used for indices. Non-core stations were added to the survey at a later date

Since 1994, USFWS has conducted beach seine sampling weekly at approximately 40 stations in the Delta and the Sacramento and San Joaquin rivers (Brandes and McLain 2001) (Figure 4). Data from 33 stations, ranging from Sherman Lake at the confluence of the Sacramento and San Joaquin rivers (hereafter referred to as the Confluence), upstream to Ord Bend on the Sacramento River (not pictured), and to just downstream of the Tuolumne River confluence (hereafter referred to as the Tuolumne confluence; pictured) on the San Joaquin River, are used to calculate the annual age-0 Splittail abundance index. All Splittail with a fork length < 25 mm (measured individuals and proportions resulting via plus counts) were removed from calculations. Stations were grouped into 10 regions, and the annual index is calculated as the average of regional mean catch per m³ for May and June sampling.

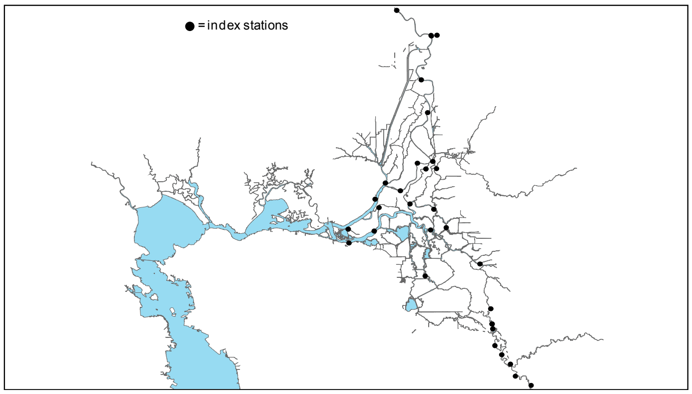

Figure 4 USFWS beach seine survey map. Core stations represent those used for indices. Non-core stations were added to the survey at a later date. (8 stations on the Sacramento River not pictured.)

We used data sets from the STN and FMWT surveys to describe abundance trends and distribution patterns of the 7 upper estuary pelagic fishes listed in the introduction. Two data sets provided only single species indices: the 20 mm Survey data for a combined larval and small juvenile Delta Smelt index and the USFWS beach seine data for age-0 Splittail index. Catch-per-unit-effort (CPUE), reported as catch per tow, was consistently used to analyze and report distribution.

Results

American Shad

The American Shad was introduced into the Sacramento River in 1871 (Dill and Cordone 1997) and are now found throughout the estuary. This anadromous species spawns in rivers in late spring, rears in fresh water through summer (including the Delta starting in late May), and migrates to the ocean in late summer and fall. It spends approximately 3 to 5 years maturing in the ocean before returning to freshwater to spawn. Most males reach maturity by 3 or 4 years of age, while females typically reach maturity at 4 to 5 years. Spawning occurs in the Sacramento, Feather, and American rivers from April through June, after which a large percentage of adults die (Stevens 1966). American Shad are planktivorous at all life stages.

The 2012 FMWT American Shad (all ages) index was 46% the 2011 index (Figure 5). With the exception of the 2006 index and the record high index in 2003, indices have been below the study-period mean since 1998. American Shad were collected in all areas of the upper estuary in 2012, but from September through November were most common from the Cache Sl-SDWSC downstream through the lower Sacramento River. By December 60% of the catch occurred downstream of the Confluence.

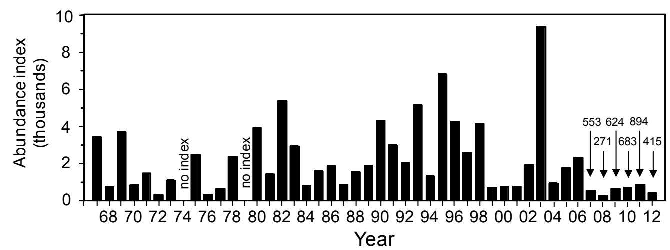

Figure 5 Annual abundance indices of American Shad (all sizes) from the Fall Midwater Trawl Survey, 1967-2012

Threadfin Shad

The Threadfin Shad was introduced to reservoirs in the watersheds of the Sacramento and San Joaquin rivers in the late 1950's and quickly became established in the Delta. Although they are found throughout the estuary, Threadfin Shad prefer oligohaline to freshwater, dead-end sloughs and other low-velocity waterways (Wang 1986). They are planktivorous their entire life, and feed on zooplankton and algae (Holanov and Tash 1978). Threadfin Shad may reach maturity at the end of their first year and can live up to 4 years. Spawning occurs in late spring and summer and peaks from May to July (Wang 1986).

The 2012 FMWT Threadfin Shad (all ages) index was 18% the 2011 index (Figure 6) and the lowest index on record. Since 2002, Threadfin Shad abundance has been below the study period mean, but showed a slight increasing trend through 2007 before dropping off precipitously. During all survey months few Threadfin Shad were found in the lower Sacramento River and Cache Slough. In October, they were also caught in Suisun Bay. In November, they were caught in the lower San Joaquin River. By December, Threadfin Shad were distributed from the South Delta and lower Sacramento River through the confluence and San Pablo Bay. As seen in previous years, Threadfin Shad were most common (n=1541) in the SDWSC during all survey months.

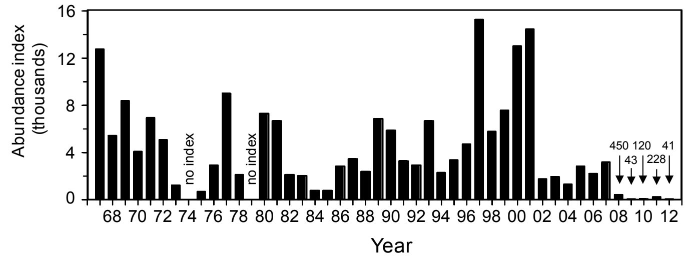

Figure 6 Annual abundance indices of Threadfin Shad (all sizes) from the Fall Midwater Trawl Survey, 1967-2012

Delta Smelt

The Delta Smelt is a small (55-90 mm FL) osmerid endemic to the upper San Francisco Estuary. The Delta Smelt population declined dramatically in the 1980s, and in 1993 it was listed as a State and federal threatened species. Delta Smelt are considered environmentally sensitive because they typically live for 1 year, reside primarily in the interface between salt and fresh water (limited range) and possess low fecundity (1,200 to 2,600 eggs on average; Moyle et al. 1992). This low fecundity may be offset by the ability of some females to produce more than 1 batch of eggs per spawning season (Bennett 2005, CDFW unpublished data).

The 2012 20 mm Survey Delta Smelt index was 1.4 times the 2011 index (Figure 7A). Like the 2011 index, the 2012 index was more consistent with indices from the early 2000s than it was with indices from 2007-2010. March and April saw low Delta Smelt larval catches, concentrated in Suisun Bay. There was also low presence in the lower Sacramento River and the SDWSC. Delta Smelt larval catch peaked in May and June, ranging from Suisun Bay through the SDWSC. Catch dropped off in July, although the distribution remained consistent with May and June. Delta Smelt had a small presence in the South Delta and the lower San Joaquin River, which peaked in May.

The 2012 STN age-0 Delta Smelt index was less than half of the 2011 index (Figure 7B). The 2012 index was consistent with low indices recorded since 2005, and ranked as the eighth lowest index during the study period. Delta Smelt survey catch dropped through the sampling season, from 69 fish in early June to 11 fish in early August. In early June, more than half of the Delta Smelt were caught in the SDWSC and Cache Slough (n=34 and 16). Delta Smelt catch was concentrated in the SDWSC through late August, while CS catch dropped off in late July. At index stations, Delta Smelt had the strongest presence in Suisun Bay, where they were caught throughout the field season. There was a relatively high catch in the Confluence in late June (n=20), followed by a catch of 26 Delta Smelt in the lower Sacramento River in early July. Delta Smelt were absent from the south Delta STN sampling in 2012.

The 2012 FMWT Delta Smelt index was 12% the 2011 index and the seventh lowest on record (Figure 7C). No Delta Smelt were caught in September. In October, the Delta Smelt distribution was limited to the Confluence, lower Sacramento River, and SDWSC. By November, they were only distributed in the lower Sacramento River and SDWSC. In December, Delta Smelt were caught in Suisun Bay, Cache Sl., and SDWSC.

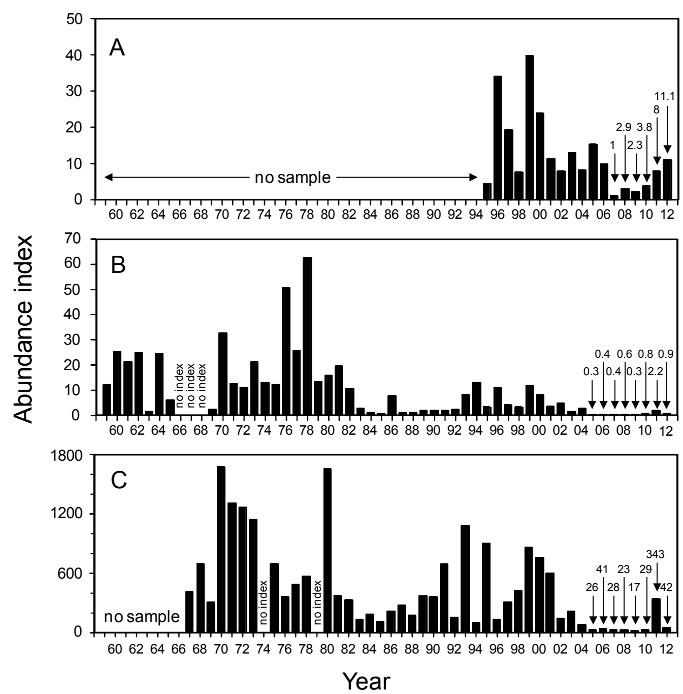

Figure 7 Annual abundance indices of Delta Smelt from: A) 20 mm Survey (larvae and juveniles, 1995-2012); B) Summer Townet Survey (juveniles; 1959-2012); C) Fall Midwater Trawl Survey (subadults; 1967-2012)

Longfin Smelt

The Longfin Smelt is a short-lived, anadromous fish that spawns in freshwater in winter and spring and rears primarily in brackish water. Some age-0 and age-1 fish migrate to the ocean in summer and fall, often returning to the estuary in late fall or winter of the same year. A few Longfin Smelt mature at the end of their first year and most at the end of their second year, with some living to spawn or spawn again at age-3 (Wang 1986).

The 2012 FMWT Longfin Smelt (all ages) index was 13% the 2011 index and the second lowest index on record (Figure 8). A few Longfin Smelt were caught each month from September through November in Suisun Bay, with fish also collected in San Pablo Bay in September and November and the Confluence in November. Approximately 61% of the catch occurred in December and occurred from Cache Slough downstream to San Pablo Bay.

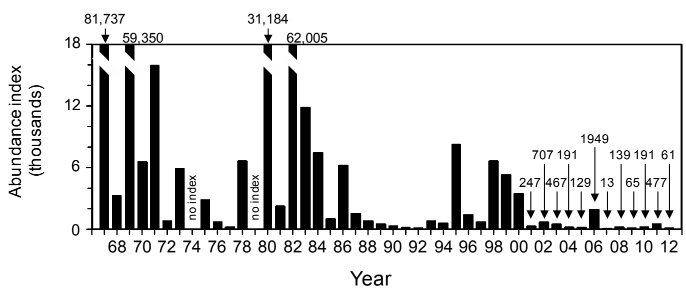

Figure 8 Annual abundance indices of Longfin Smelt (all sizes) from the Fall Midwater Trawl Survey, 1967-2012

Wakasagi

The Wakasagi was purposely introduced as baitfish into California lakes and reservoirs from Japan in 1959 (Wales 1962, Dill and Cordone 1997). Wakasagi were first detected in the San Francisco Estuary in 1990, but may have escaped and traveled from California lakes as early as 1974 (Moyle et al. 1992). Although generally found in freshwater, they have a higher salinity tolerance than Delta Smelt (Swanson et al. 2000). Wakasagi and Delta Smelt are typically planktivorous and reach maturity within a year (Moyle et al. 1992). We report on Wakasagi to track their abundance and investigate their distribution overlap with that of Delta Smelt.

Since 1995, STN has caught 40 Wakasagi, more than half of them in 2011 in the Cache Sl-SDWSC region, coincident with expansion of trawling in that region. In 2012, 5 Wakasagi were collected, 4 in the SDWSC and 1 in the lower San Joaquin River (Table 1).

Few Wakasagi have been caught (n=44) by the FMWT survey. Prior to 2009, Wakasagi were sporadically collected (n=10) in Grizzly Bay, Montezuma Slough, the lower Sacramento River, and Cache Slough. In 2012, only one Wakasagi was collected in the SDWSC (Table 2).

Table 1 Summer Townet Survey Wakasagi total annual catch by region, 1995 to 2012 (regions where no Wakasagi have ever been caught were removed)

Year	*Suisun Bay*	*Con-fluence*	*Lower Sac River*	*SDWSC*	*Lower San Joaquin*	*South Delta*	*Cache Slough*
1995	0	0	1	no sample	0	0	no sample
1996	0	0	1	no sample	0	1	no sample
1997	0	0	0	no sample	0	0	no sample
1998	2	0	0	no sample	0	0	no sample
1999	0	0	0	no sample	0	0	no sample
2000	0	0	1	no sample	0	1	no sample
2001	0	0	0	no sample	0	0	no sample
2002	0	0	0	no sample	0	0	no sample
2003	0	0	0	no sample	0	0	no sample
2004	0	0	0	no sample	0	0	no sample
2005	0	0	0	no sample	0	0	no sample
2006	0	0	0	no sample	0	0	no sample
2007	0	0	0	no sample	0	0	no sample
2008	0	0	0	no sample	0	0	no sample
2009	2	0	1	4	0	0	no sample
2010	0	0	0	no sample	0	0	no sample
2011	2	0	0	15	0	0	6
2012	0	0	0	4	1	0	0

Table 2 Fall Midwater Trawl Survey Wakasagi total annual catch by region, 1995 to 2012 (regions where no Wakasagi have ever been caught were removed)

Year	*Suisun Bay*	*Con-fluence*	*Lower Sac River*	*SDWSC*	*South Delta*	*Cache Slough*
1995	0	0	3	no sample	0	0
1996	1	0	0	no sample	0	0
1997	1	0	0	no sample	0	0
1998	0	0	0	no sample	0	0
1999	0	0	0	no sample	0	0
2000	0	0	0	no sample	0	3
2001	0	0	1	no sample	0	0
2002	0	0	0	no sample	0	0
2003	0	0	0	no sample	0	0
2004	0	0	0	no sample	0	0
2005	0	0	0	no sample	0	0
2006	0	0	0	no sample	0	0
2007	0	0	0	no sample	0	0
2008	0	0	0	no sample	0	0
2009	1	0	0	8	0	0
2010	0	0	0	8	0	1
2011	4	0	0	9	0	3
2012	0	0	0	1	0	0

Splittail

The Splittail is endemic to the San Francisco Estuary and its watershed. Adults migrate upstream during periods of increased river flows in late fall through spring; they move from tidal brackish and freshwater habitats to inundated floodplains and river margins, in order to forage and spawn (Sommer et al. 1997, Moyle et al. 2004). Such migrations are known to occur in the Sacramento, San Joaquin, Cosumnes, Napa, and Petaluma rivers, as well as Butte Creek, Sonoma Creek, and other small tributaries. Most spawning takes place from March through May. Young disperse downstream either as larvae when river levels drop, or as juveniles when backwater and edge-water habitats diminish due to reduced flows in late spring and early summer. Year-class strength is related to the timing and duration of floodplain inundation; moderate to large Splittail year classes resulted from springtime inundation periods of 30 days or more (Sommer et al. 1997, Moyle et al. 2004).

Young Splittail possess a strong affinity for shallow water and may not be effectively sampled by surveys employing trawling, since the gear fishes in open, moderately deep (≥ 2 m) water. The USFWS Delta Juvenile Fish Monitoring Program conducts an annual beach seine survey and calculates an abundance index for age-0 Splittail. In addition to sampling along the shoreline, this survey samples throughout the Delta, upstream to Colusa on the Sacramento River, and up the San Joaquin River almost to the Tuolumne River confluence (see methods), so it can detect recruitment in the rivers upstream of current trawl sampling areas.

The 2012 Splittail age-0 beach seine index (USFWS data) was 10% of the 2011 index, but slightly above the overall average index (Figure 9A). Splittail in the Sacramento River comprised the largest contributor to the index (due to one large catch, n = 207), however Splittail were more consistently caught in the San Joaquin River. The variability of the age-0 Splittail abundances likely reflects the variability in outflows and floodplain/terrace inundation in recent history.

The 2012 FMWT Splittail (all ages) index was one (Figure 9B) and 9% the 2011 index. The FMWT gear does not effectively capture or portray Splittail abundance and distribution, but does tend to capture the strong year classes.

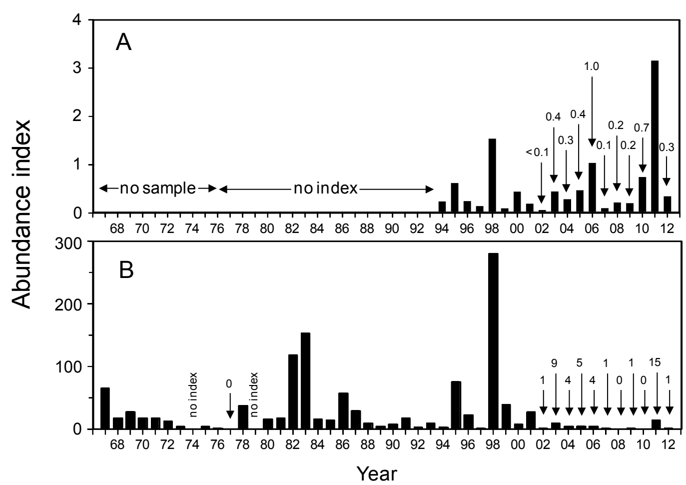

Figure 9 Annual abundance indices of Splittail from: A) USFWS beach seine (juveniles ≥ 25 mm), 1994-2012; B) Fall Midwater Trawl Survey (all sizes), 1967-2012

Age-0 Striped Bass

The Striped Bass is an anadromous fish first introduced to the San Francisco Estuary over 125 years ago. Adult Striped Bass forage in coastal bays and the nearshore ocean, and migrate up rivers to spawn in spring. Juveniles rear in the fresh and brackish waters of the estuary.

Age-0 Striped Bass abundance began to decline in the mid-1970s if not sooner (Figure 10). STN and FMWT indices declined in the late 1990s, and again early 2000s; indices have remained low since (Figure 10). Stevens et al. (1985) hypothesized that low Striped Bass recruitment was related to: 1) the declining adult population; 2) reduced plankton food supply; 3) loss of large numbers of young Striped Bass to water diversions; and 4) population-level effects of contaminants. A shift in distribution may also have contributed to more recent low age-0 abundance indices. Sommer et al. (2011) suggest that age-0 Striped Bass have shifted from channels to shoal areas, which continue to be under sampled by the FMWT survey.

The 2012 STN age-0 Striped Bass 38.1 mm index was 1.7, or 65% of the 2011 index (Figure 10A). Although this index was lower than the previous year's, it was consistent with low indices since 1996. Striped Bass juvenile catch peaked in early-June, and dropped throughout the field season. In June, Striped Bass were caught in all regions except San Pablo Bay. The majority of fish were captured in Suisun Bay and the Confluence; they also had a strong presence in the lower Sacramento River and the SDWSC. In July and August, catch was concentrated in Suisun Bay and the Sacramento River in the early part of each month, and in Suisun Bay and the Confluence in the later part of each month.

The 2012 FMWT age-0 Striped Bass index decreased to 46% of the 2011 index. This is the eighth lowest index on record and consistent with the low indices seen since 2002 (Figure 10B). During September, they were caught from San Pablo Bay through Suisun Bay, Cache Sl-SDWSC, and lower San Joaquin River. By October, they were collected from lower Sacramento and San Joaquin rivers to San Pablo Bay and SDWSC. In November, they were caught in San Pablo Bay and from lower Sacramento River to Suisun Bay. Distribution expanded in December as they were caught from the SDWSC and San Joaquin River through San Pablo Bay.

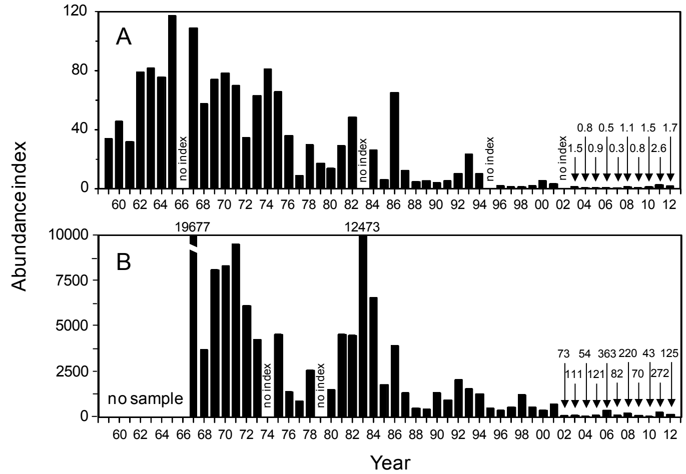

Figure 10 Annual abundance indices of age-0 Striped Bass from: A) Summer Townet, 1959-2012; B) Fall Midwater Trawl Survey, 1967-2012

Conclusion

All pelagic fish abundance indices reported decreased in 2012, except the 20 mm Delta Smelt index. The 2012 indices were consistent with low indices seen in recent years and low outflow water year. Threadfin Shad show an additional step decline has occurred since 2008.

Since extending our sampling into Cache Slough and SDWSC, this sampling has provided valuable habitat and catch information for several pelagic species, specifically Delta Smelt and Wakasagi. In 2012 approximately 20% of the total catch for Delta Smelt, all surveys combined, occurred in the Cache Sl-SDWSC region; in addition, these non-index stations continue to produce relatively high catches of American Shad (30 to 50+ per tow on the high end) and Threadfin Shad (100 to 900+ on the high end). Additionally, Wakasagi continue to show up in the SDWSC and Cache Slough area (1-6 per month). These two areas appear to provide year-round habitat for pelagic fish species.

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- Fall Midwater Trawl Survey, Dave Contreras (dave.contreras@wildlife.ca.gov)
- 20 mm Survey, Julio Adib-Samii (julio.adib-samii@wildlife.ca.gov)

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Fish Salvage at the State Water Project's and Central Valley Project's Fish Facilities during the 2012 Water Year

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Introduction

Two facilities are intended to reduce the fish loss 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. Both facilities use louver-bypass systems to remove fish from the exported water. The diverted fish are periodically loaded into tanker trucks and transported to fixed release sites in the western Delta. The TFCF began operations in 1957 and operations at the SDFPF began in 1967.

This report summarizes the 2012 water year (10/1/2011-9/30/2012) salvage information from the TFCF and the SDFPF, and discusses data from water years (WY) 1981 to 2012 for its relevance to salvage trends in recent years. The following species are 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[1] (*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 2.5 to 30 minutes ($\bar{x}$ = 24.9, sd = 8.8) at the SDFPF and once every 2 hours for 10 or 30 minutes ($\bar{x}$ = 29.5, sd = 17.1) at the TFCF. Fish 20 mm (fork length: FL) or larger were identified and numerated. 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, a sub-sample duration of 10 minutes over a 120-minute salvage period equals an expansion factor of 12. These incremental salvage estimates were then summed across time to develop monthly and annual species-salvage totals for each facility.

Chinook Salmon loss estimates are presented because the loss model has been widely accepted and has undergone extensive field validation. Loss is the estimated number of fish entrained by the facility minus the number of fish that survive salvage operations (California Dept. 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, spring). Race of Chinook Salmon is determined solely by criteria based on length and salvage date.

Larval fish (< 20 mm FL) were also collected and examined to determine the presence of sub-20 mm Delta Smelt. Larval sampling at both facilities ran from February 16 through June 30. Larval samples were collected once for every 6 hours of water export. 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 TFCF were identified to species by TFCF personnel and larval fish from SDFPF were identified to the lowest taxa by California Dept. of Fish and Wildlife personnel.

Water Exports

The SWP exported 3.25 billion m^3 of water which was a decrease from the record high export in WY 2011 (4.90 billion m^3) and comparable to WY 2010 (3.04 billion m^3) (Figure 1). The CVP exported 2.56 billion m^3 of water which was comparable to exports in WY 2008-2010, but a decrease in exports from 2011 (3.13 billion m^3) and WY 2002-2007 which ranged from 3.35 billion m^3 to 3.08 billion m^3.

The exports of the two water projects generally followed a similar seasonal pattern. Exports at the CVP reached a maximum in October-December 2011 and July -September 2012 (Figure 2). During these periods, 1.78 billion m^3 was exported by the CVP, which represented about 69.6% of annual export. Exports at the SWP reached a maximum in October and December 2011 and July-September 2012 (Figure 2). During these periods, 2.14 billion m^3 was exported by the SWP, which represented about 66.0% of annual export. CVP monthly exports ranged from 67.55 to 329.95 million m^3. SWP monthly exports ranged from 98.08 to 497.86 million m^3.

1 Pelagic Organism Decline (POD) species

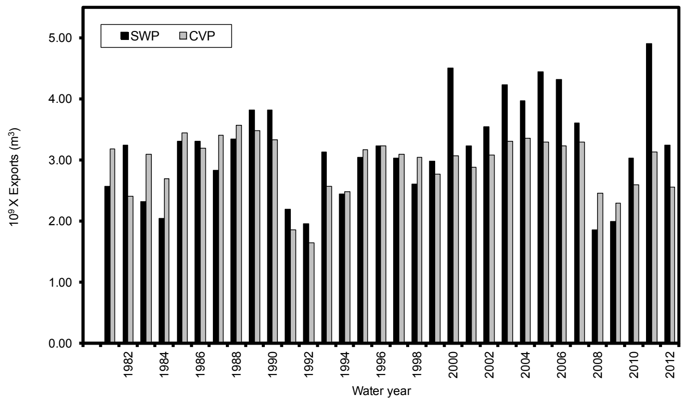

Figure 1 Annual (by water year: WY) water exports in billions of cubic meters for the SWP and the CVP, 1981 to 2012

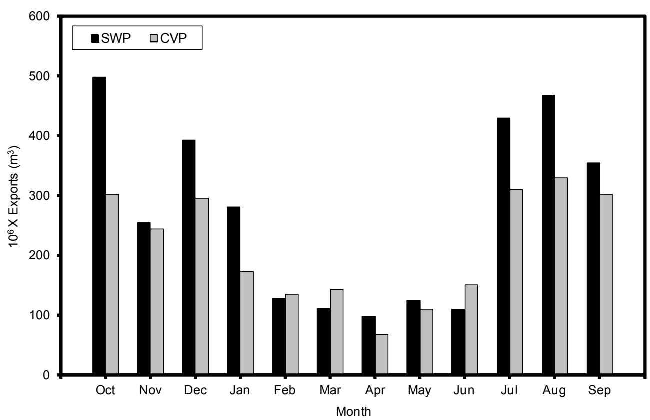

Figure 2 Monthly water exports in millions of cubic meters for the SWP and the CVP, WY 2012

Total Salvage and Prevalent Species

Annual fish salvage (all fish species combined) at the TFCF was a record low at 475,082 (Figure 3). TFCF salvage was a decrease from WY 2011 (8,724,498) and well below the record high salvage of 37,659,835 in WY 2006 (Figure 3). Annual salvage at the SDFPF was low at 1,607,286. SDFPF salvage was a decline from 2011 (3,092,553) and 2010 (2,080,353).

Striped Bass was the most-salvaged species at SDFPF while Threadfin Shad was the most-salvaged species at TFCF (Figure 4 and Table 1). American Shad (*Alosa sapidissima*) and Threadfin Shad were the 2nd and 3rd most-salvaged fish at SDFPF. Striped Bass and American Shad were the 2nd and 3rd most-salvaged fish at TFCF. Native species comprised 14.1% of annual fish salvage at SDFPF and 2.9% of annual fish salvage at TFCF. Relatively few Chinook Salmon, Steelhead, Delta Smelt, and Longfin Smelt were salvaged at the SDFPF (< 0.4% of total annual salvage combined) and the TFCF (< 0.8% of total annual salvage).

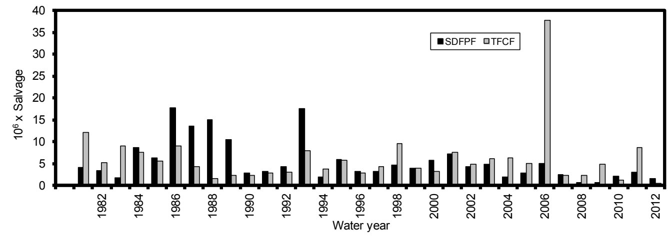

Figure 3 Annual salvage of all fish taxa combined at the SDFPF and the TFCF, WY 1981 to 2012

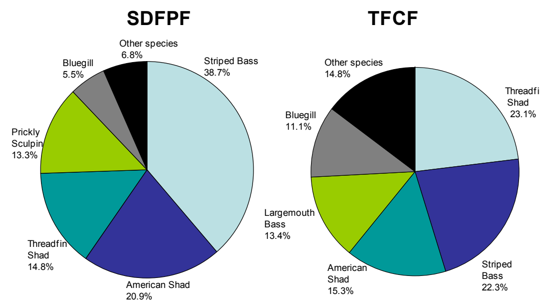

Figure 4 Percentages of annual salvage for the 5 most prevalent fish species and other fish species combined at the SDFPF and TFCF, WY 2012

Chinook Salmon

Record-low salvage (all races and origins combined) of Chinook Salmon occurred at both facilities and continued the low salvage trend since WY 2001 (Figure 5). SDFPF salvage (1,579) was a substantial decrease from WY 2011 (18,830) and a small decrease from WY 2010 levels (1,882). Mean WY 2001-2012 SDFPF salvage was about one-ninth of the mean salvages in the 1980s and the late 1990s. Salvage of Chinook Salmon at the TFCF (1,965) was substantially lower than in WY 2011 (18,135) and 2010 (7,463). Mean WY 2001-2012 TFCF salvage was about one-seventh of the mean salvages in the 1980s and the late 1990s.

Salvaged Chinook Salmon at TFCF were primarily wild spring-run and fall-run fish which comprised 70% of wild fish (Table 2). Salvaged Chinook Salmon at SDFPF were also primarily wild spring-run and fall-run fish which comprised 70% of wild fish. The majority of wild fall-run fish at the SDFPF and TFCF were salvaged in May (Figure 6).

Table 1 Annual (by water year) fish salvage and percentage of annual fish salvage (%) collected from the SDFPF and TFCF in WY 2012

SDFPF			TFCF		
Species	***Salvage***	***%***	***Species***	***Salvage***	***%***
Striped Bass	621,165	38.6	Threadfin Shad	109,610	23.1
American Shad	336,131	20.9	Striped Bass	105,760	22.3
Threadfin Shad	238,135	14.8	American Shad	72,603	15.3
Prickly Sculpin	213,859	13.3	Largemouth Bass	63,670	13.4
Bluegill	88,194	5.5	Bluegill	52,986	11.2
Largemouth Bass	35,171	2.2	White Catfish	29,069	6.1
Inland Silverside	28,238	1.8	Channel Catfish	10,121	2.1
White Catfish	12,430	0.8	Prickly Sculpin	8,606	1.8
Yellowfin Goby	6,543	0.4	Rainwater Killifish	6,025	1.3
Splittail	4,057	0.3	Inland Silverside	5,954	1.3
Common Carp	3,627	0.2	Chinook Salmon	1,965	0.4
Channel Catfish	3,046	0.2	Yellowfin Goby	1,755	0.4
Longfin Smelt	2,842	0.2	Golden Shiner	1,281	0.3
Bigscale Logperch	2,666	0.2	Splittail	929	0.2
Delta Smelt	1,999	0.1	Longfin Smelt	898	0.2
Black Crappie	1,940	0.1	Redear Sunfish	840	0.2
Shimofuri Goby	1,667	0.1	Black Crappie	629	0.1
Chinook Salmon	1,579	0.1	Rainbow / Steelhead Trout	493	0.1
Rainwater Killifish	1,257	0.1	Delta Smelt	355	0.1
Western Mosquitofish	888	0.1	Warmouth	318	0.1
Pacific Staghorn Sculpin	794	< 0.1	Bigscale Logperch	244	0.1
Rainbow / Steelhead Trout	443	< 0.1	Western Mosquitofish	212	< 0.1
Golden Shiner	196	< 0.1	Shimofuri Goby	162	< 0.1
Wakasagi	127	< 0.1	Common Carp	148	< 0.1
Redear Sunfish	61	< 0.1	Tule Perch	118	< 0.1
Starry Flounder	46	< 0.1	White Sturgeon	64	< 0.1
Lamprey, unknown	44	< 0.1	Brown Bullhead	54	< 0.1
Tule Perch	26	< 0.1	Threespine Stickleback	47	< 0.1
Brown Bullhead	24	< 0.1	Black Bullhead	35	< 0.1
Warmouth	18	< 0.1	Lamprey, unknown	31	< 0.1
Riffle Sculpin	17	< 0.1	Fathead Minnow	28	< 0.1
White Sturgeon	12	< 0.1	Wakasagi	24	< 0.1
Sacramento Pikeminnow	12	< 0.1	Pacific Staghorn Sculpin	17	< 0.1
Green Sunfish	8	< 0.1	Green Sunfish	13	< 0.1
Shokihaze Goby	4	< 0.1	Starry Flounder	8	< 0.1
Black Bullhead	4	< 0.1	Red Shiner	5	< 0.1
White Crappie	4	< 0.1	Sacramento Pikeminnow	4	< 0.1
Sacramento Blackfish	4	< 0.1	Hitch	1	< 0.1
Hitch	4	< 0.1			
Threespine Stickleback	4	< 0.1			

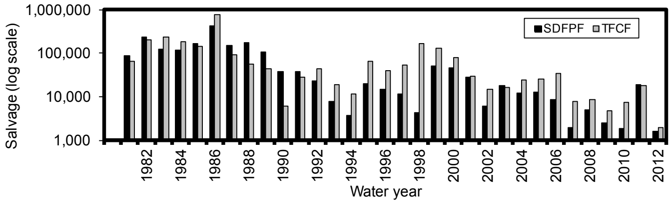

Figure 5 Annual salvage of Chinook Salmon (all races and wild and hatchery origins combined) at the SDFPF and the TFCF, WY 1981 to 2012. The Y axis is using Log_{10} logarithmic scale.

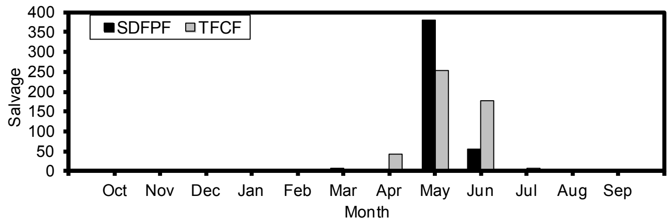

Figure 6 Monthly salvage of wild, fall-run Chinook Salmon at the SDFPF and the TFCF, WY 2012

Loss of Chinook Salmon (all origins and races) was higher at the SDFPF (6,956) than at the TFCF (1,511; 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 mostly low salvage observed since WY 2005 (Figure 7). Salvage at the SDFPF (443) was lower than in WY 2011 (1,213). Salvage at the TFCF (493) was slightly higher than in WY 2011 (445).

The TFCF salvaged 404 hatchery Steelhead and 89 wild Steelhead. The SDFPF salvaged 200 hatchery Steelhead and 243 wild Steelhead.

Salvage of wild Steelhead at both facilities occurred in the middle of the water year (Figure 8). Wild Steelhead were salvaged most frequently in March at both the TFCF and SDFPF.

Striped Bass

Salvage at the TFCF (105,760) was a near-record low. Salvage at the TFCF and SDFPF (621,165) continued the generally-low trend observed since the mid-1990s (Figure 9). Prior to WY 1995, annual Striped Bass salvage was generally above 1,000,000 fish.

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 2012

Facility	*Origin*	*Race*	*Salvage*	*Percentage*	*Loss*
SDFPF					
	Wild				
		Fall	447	35	2,002
		Late-fall	0	0	0
		Spring	445	35	1,900
		Winter	388	30	1,702
	Total Wild		***1,280***		***5,604***
	Hatchery				
		Fall	20	7	91
		Late-fall	0	0	0
		Spring	46	15	226
		Winter	233	78	1,035
	Total Hatchery		***299***		***1,352***
	Grand Total		***1,579***		***6,956***
TFCF					
	Wild	Fall	483	31	337
		Late-fall	20	1	14
		Spring	618	39	495
		Winter	453	29	376
	Total Wild		***1,574***		***1,222***
	Unknown Race		***4***		***4***
	Hatchery				
		Fall	40	10	26
		Late-fall	24	6	20
		Spring	96	25	63
		Winter	227	59	176
	Total Hatchery		***387***		***285***
	Grand Total		***1,965***		***1,511***

* loss range is listed since actual loss could not be calculated due to a missing length (not included in grand total of loss)

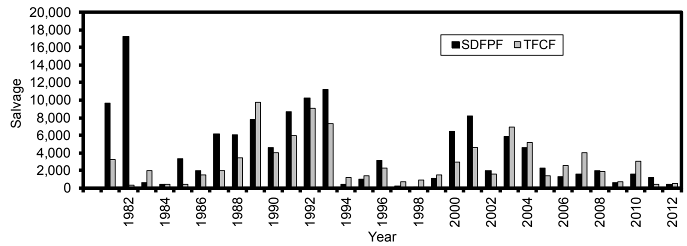

Figure 7 Annual salvage of Steelhead (wild and hatchery origins combined) at the SDFPF and the TFCF, WY 1981 to 2012

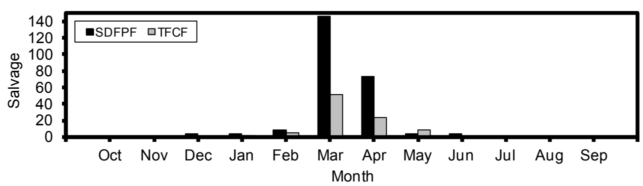

Figure 8 Monthly salvage of wild Steelhead at the SDFPF and the TFCF, WY 2012

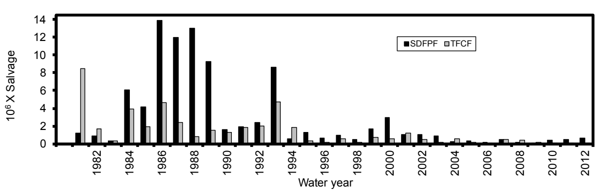

Figure 9 Annual salvage of Striped Bass at the SDFPF and the TFCF, WY 1981 to 2012

Most Striped Bass salvage at the SDFPF occurred in November 2011 and June-July, 2012. Most Striped Bass salvage at the TFCF occurred in June and July, 2012 (Figure 10). At the SDFPF, November salvage (164,579), June salvage (165,594), and July salvage (193,884) accounted for 84.4% of annual salvage. At the TFCF, salvage during June (53,999) and July (44,893) accounted for 93.5% of annual salvage. Striped Bass were salvaged every month at both facilities, with the lowest monthly salvage occurring in April at both the SDFPF (94) and the TFCF (12).

Delta Smelt

Salvage at the SDFPF (1,999) increased from WY 2011 (0) and 2010 (22), and was the highest salvage since WY 2007 (2,360) (Figure 11). Salvage at the TFCF (355) also increased from WY 2011 (51) and 2010 (99), and was the highest salvage since WY 2008 (1,009).

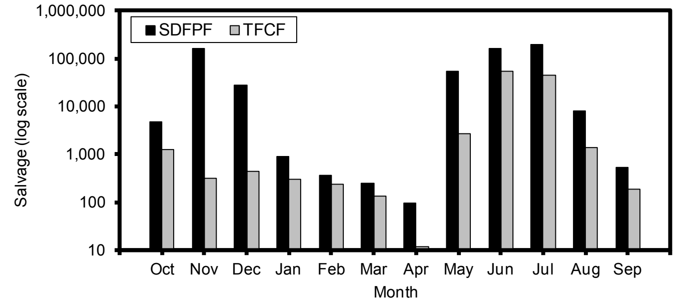

Figure 10 Monthly salvage of Striped Bass at the SDFPF and the TFCF, WY 2012. The logarithmic scale is $\log_{10}$.

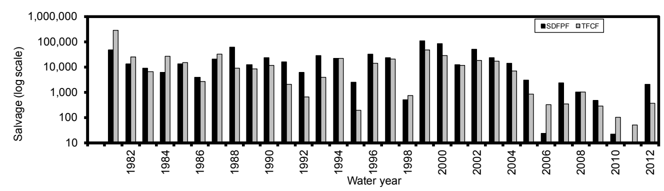

Figure 11 Annual salvage of Delta Smelt at the SDFPF and the TFCF, WY 1981 to 2012. The logarithmic scale is $\log_{10}$.

Salvage of Delta Smelt at both facilities occurred in the middle of the water year (Figure 12). Adult Delta Smelt were salvaged in February and March at the SDFPF. Juvenile Delta Smelt were salvaged in May (1,751) and June, where May salvage accounted for 87.6% of the total annual salvage. Adult Delta Smelt were salvaged January-April at the TFCF. Juvenile Delta Smelt were salvaged April-June, where May salvage (187) accounted for 52.7% of the total annual salvage.

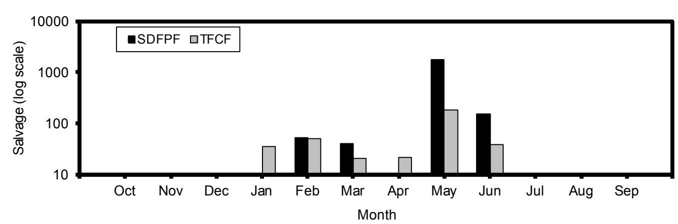

Figure 12 Monthly salvage of Delta Smelt at the SDFPF and the TFCF, WY 2012. The logarithmic scale is $\log_{10}$.

Delta Smelt less than 20 mm were first detected at the SDFPF on April 24 and were observed on 26 days of monitoring (Table 3). The longest period of consecutive daily detections was May 7-13. May was also the month with the most daily detections (14 days).

Table 3 Smelt less than 20 mm fork length (FL) observed in larval samples collected from SDFPF and TFCF in WY 2012. A "Y" indicates that Delta or Longfin Smelt < 20 mm FL were found while an "N" indicates no detection. Number of Smelt per day were recorded in parenthesis (a "Y" without a number indicates a catch of 1).

	SDFPF		TFCF	
DATE	***Delta Smelt larvae***	***Longfin Smelt larvae***	***Delta Smelt larvae***	***Longfin Smelt larvae***
2/19	N	Y	N	N
2/20	N	Y	N	Y
2/21	N	Y	N	N
2/22	N	Y	N	N
2/24	N	Y	N	Y
2/25	N	N	N	Y
2/26	N	Y (2)	N	Y
2/28	N	Y (8)	N	Y (2)
2/29	N	Y (2)	N	Y (2)
3/1	N	N	N	Y (4)
3/3	N	Y (2)	N	Y
3/5	N	Y (4)	N	Y (5)
3/6	N	N	N	Y (18)
3/7	N	Y (7)	N	N
3/8	N	N	N	Y (2)
3/9	N	N	N	Y
3/10	N	Y (3)	N	Y (2)
3/11	N	Y (19)	N	Y (5)
3/12	N	Y (2)	N	Y
3/13	N	Y (17)	N	Y
3/14	N	Y (11)	N	Y (4)
3/15	N	Y (11)	N	N
3/16	N	Y (6)	N	Y
3/17	N	Y	N	N
3/19	N	Y (2)	N	N
3/20	N	Y	N	N
3/21	N	Y (21)	N	Y
3/22	N	Y (2)	N	Y (5)
3/24	N	Y (3)	N	N
3/25	N	Y (6)	N	N
3/26	N	Y	N	N
3/27	N	N	N	Y (2)
3/28	N	Y	N	N
3/31	N	N	N	Y (2)
4/2	N	Y	N	N
4/5	N	Y	N	N
4/9	N	N	N	Y
4/10	N	N	N	Y
4/12	N	N	N	Y (6)
4/13	N	N	N	Y
4/15	N	N	N	Y
4/16	N	N	N	Y
4/24	Y (3)	N	N	N
4/25	Y (4)	N	N	N
4/26	N	N	Y (3)	N
4/28	N	N	Y	Y
4/29	N	N	Y (3)	Y
4/30	Y	N	N	N
5/1	N	N	Y (3)	N
5/3	Y	N	N	Y
5/4	Y (2)	N	Y	N
5/5	Y	N	Y (3)	N
5/6	N	N	Y	N
5/7	Y	N	Y (4)	N
5/8	Y (2)	N	Y	N
5/9	Y	N	Y (2)	N
5/10	Y (8)	N	Y	N
5/11	Y (8)	N	Y (4)	N
5/12	Y (5)	N	N	N
5/13	Y	N	N	N
5/14	N	N	Y	N
5/15	N	N	Y	N
5/18	N	N	Y	N
5/20	Y (7)	N	Y	N
5/21	Y	N	N	N
5/22	N	N	Y	N
5/23	Y	N	Y	N
5/24	N	N	Y (2)	N
5/25	Y	N	Y (4)	N
5/26	N	N	Y	N
5/27	N	N	Y (4)	N
5/29	N	N	Y	N
5/30	N	N	Y (5)	N
5/31	N	N	Y (8)	N
6/1	Y (5)	N	Y (6)	N
6/2	Y (1)	N	Y (4)	N
6/3	N	N	Y (12)	N
6/4	Y (3)	N	N	N
6/5	Y (5)	N	Y (8)	N
6/6	N	N	Y (7)	N
6/7	Y	N	Y (4)	N
6/8	N	N	Y	N
6/9	N	N	Y	N
6/10	N	N	Y (2)	N
6/11	N	N	Y (3)	N
6/12	Y (2)	N	Y	N
6/13	Y (5)	N	Y	N
6/14	Y	N	Y	N
6/16	N	N	Y	N
6/18	Y	N	Y (3)	N
6/22	N	N	Y	N
6/25	N	N	Y	N

Delta Smelt less than 20 mm were first detected at the TFCF on April 26 and were observed on 42 days of monitoring (Table 3). The longest period of consecutive daily detections was June 5-14. May was the month with the most daily detections (22 days).

Longfin Smelt

Salvage at the SDFPF (2,842) increased substantially from WY 2011 (0) and 2010 (4), and was the highest recorded salvage since WY 2002 (54,594) (Figure 13). Salvage at the TFCF (898) also increased from WY 2011 (4) and 2010 (31), and was the highest recorded salvage since WY 2003 (4,598).

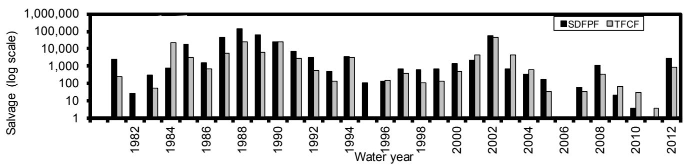

Figure 13 Annual salvage of Longfin Smelt at the SDFPF and the TFCF, WY 1981 to 2012. The logarithmic scale is $\log_{10}$.

Longfin Smelt were salvaged March-May at the SDFPF (Figure 14). March salvage (1,568) accounted for 55.2% of the total annual salvage. Longfin Smelt were salvaged February-May at the TFCF. April salvage (635) accounted for 70.7% of the total annual salvage.

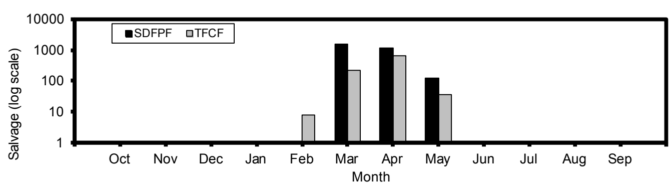

Figure 14 Monthly salvage of Longfin Smelt at the SDFPF and the TFCF, WY 2012. The logarithmic scale is $\log_{10}$.

Longfin Smelt less than 20 mm were first detected at the SDFPF on February 19 and were observed on 31 days of monitoring (Table 3). The longest period of consecutive daily detections was March 10-17. March was also the month with the most daily detections (19 days).

Longfin Smelt less than 20 mm were first detected at the TFCF on February 20 and were observed on 31 days of monitoring (Table 3). The longest period of consecutive daily detections was March 8-14. The month with the most daily detections was March (16 days).

Splittail

Salvage of Splittail at both facilities was lower than in WY 2011 (Figure 15). Salvage at the SDFPF (4,057) was much lower than in WY 2011 (1,326,065). Salvage was a near-record low at the TFCF (929) which was substantially lower than the record high in WY 2011 (7,660,024). Splittail salvage has followed a boom-or-bust pattern, often varying year to year by several orders of magnitude.

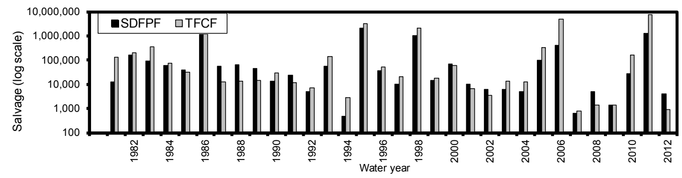

Figure 15 Annual salvage of Splittail at the SDFPF and the TFCF, WY 1981 to 2012. The logarithmic scale is $\log_{10}$.

Threadfin Shad

Annual salvage at the SDFPF (238,135) was higher than at the TFCF (109,610) (Figure 16). Salvage at the SDFPF was lower than in WY 2011 (463,610). Similarly, TFCF salvage in WY 2012 was much lower than in WY 2011 (591,111) and was a record low. Similar to Splittail, annual salvage of Threadfin Shad has varied greatly through time.

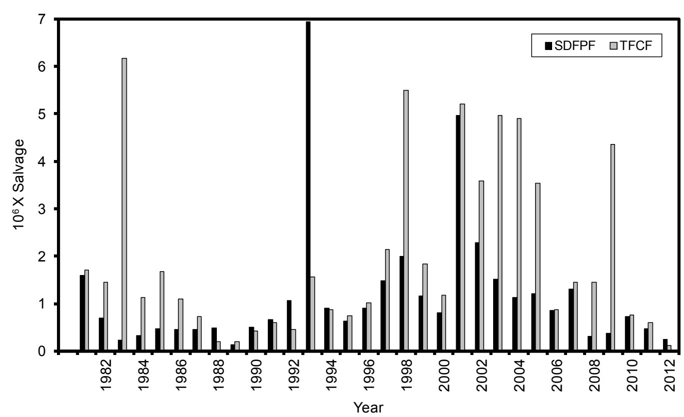

Figure 16 Annual salvage of Threadfin Shad at the SDFPF and the TFCF, WY 1981 to 2012

References

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Central Valley Chinook Salmon Harvest and Escapement

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This paper presents the available Chinook Salmon escapement and harvest estimates, with a focus on the California Central Valley escapement. The available estimates are compared to estimates from earlier years and the data are plotted. The data were collected from the PFMC Annual Fisheries Review, biologists throughout the Sacramento and San Joaquin River systems, and from the GrandTab database output.

California Ocean Harvest

The estimated harvest in California ocean waters was 337,663 Chinook Salmon in 2012 (PFMC 2013). This is the highest since 2005, but only 61% of the 40 year average ocean harvest of 555,780 (Figure 1).

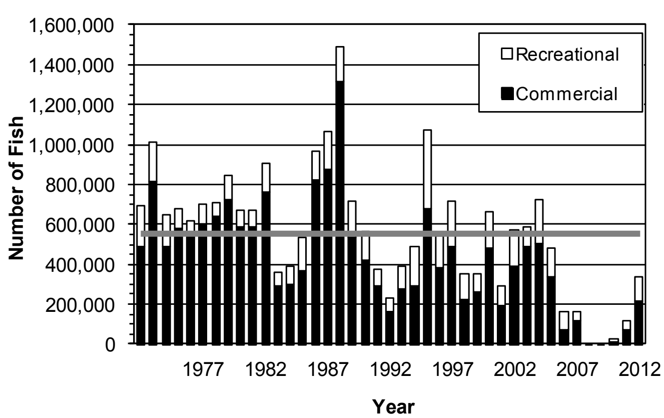

Figure 1 California commercial and recreational Chinook Salmon ocean catch from 1973 to 2012 and 40 year average (gray line)

California Central Valley Harvest

The estimated harvest in Central Valley waters was 83,145 Chinook Salmon in 2012, 1.3 times the harvest of 62,230 in 2011. The harvest of late-fall run was 930 in 2012, 54% less than the 1,730 in 2011. There was no winter run harvest in 2012, continuing the trend starting in 2010. The harvest of spring-run was 708 in 2012, about five times the 140 in 2011. The harvest of Sacramento fall-run was 76,628 in 2012, 32% more than the 57,833 in 2011. The harvest of San Joaquin fall-run was 4,869 in 2012, about 2 times the 2,183 Chinook Salmon in 2011.

California Central Valley Escapement

The California Central Valley contains the Sacramento and San Joaquin River systems. The Sacramento River System is made up of the mainstem Sacramento River and the many tributaries that flow into it. Likewise, the San Joaquin River also has many tributaries. Each year, escapement estimates are made for Chinook Salmon that return to spawn in natural areas and for those that return to hatcheries within these river systems. These estimates are in addition to the inland harvest estimates.

In 2012, the escapement estimate for Chinook Salmon returning to hatcheries and natural areas of California's Central Valley was 372,766 fish (Azat 2013). This is the highest since 2005, and 120% of the 40 year average of 311,497 (Figure 2). The late-fall-run escapement was 12,305, the winter-run escapement was 7,182, the spring-run escapement was 17,207, and the fall-run escapement was 341,759 Chinook Salmon. While escapement increased in 2012 compared to 2011 for most runs, late-fall estimates continued to decline.

Late-fall-run Escapement to the Sacramento River System

The estimated escapement of late-fall-run Chinook Salmon to the Sacramento River and its tributaries was 5,991 in 2012, the lowest on record since 1997 and 49% of the 40 year average of 12,305 (Figure 3). Escapement to the Sacramento River was 2,869. Escapement to Battle Creek was 3,045. Most of the late-fall run in Battle Creek were counted at Coleman National Fish Hatchery, where the fish are propagated.

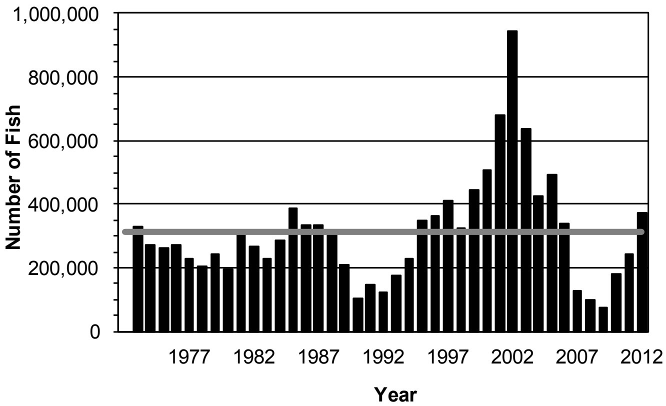

Figure 2 Annual Chinook Salmon escapement to the California Central Valley from 1973 to 2012 and 40 year average (gray line)

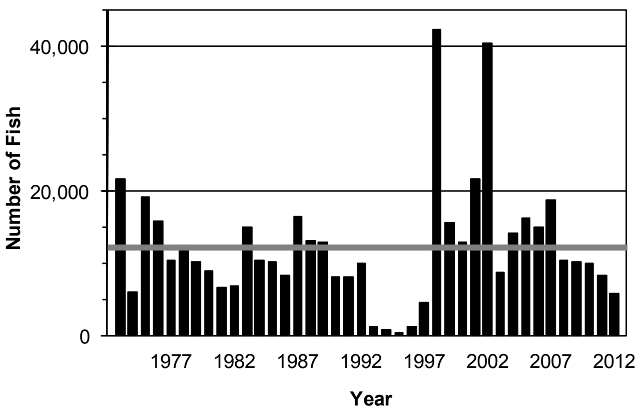

Figure 3 Annual late-fall-run Chinook Salmon escapement to the Sacramento River System from 1973 to 2012 and 40 year average (gray line)

Winter-run Escapement to the Sacramento River

The estimated escapement of winter-run Chinook Salmon to the Sacramento River in 2012 was 2,767. Though this is three times last year's escapement of 827, the 2012 estimate is the lowest since 2006, and 39% of the 40 year average of 7,150 (Figure 4).

Spring-run Escapement to the Sacramento River System

The estimated escapement of spring-run Chinook Salmon to the Sacramento River and its tributaries was 22,249 in 2012, three times the 2011 estimate, and 157% of the 40 year average of 14,207 (Figure 5). The majority of these fish were from Butte Creek with an estimate of 16,140 Chinook Salmon. It should be noted that carcass survey estimates have replaced the last 10 years of Butte Creek snorkel survey estimates in GrandTab as the official CDFW estimate. Clint Garman's work on Butte Creek shows that the snorkel survey estimate has been roughly 50% of the carcass survey estimate for each of the last 10 years. The snorkel survey data indicated an estimate of 8,615 fish.

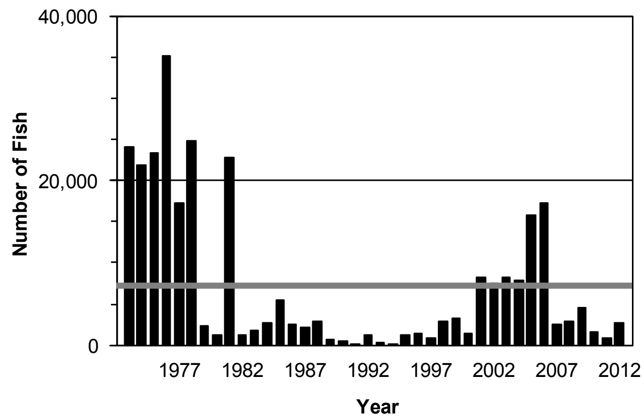

Figure 4 Annual winter-run Chinook Salmon escapement to the Sacramento River from 1973 to 2012 and 40 year average (gray line)

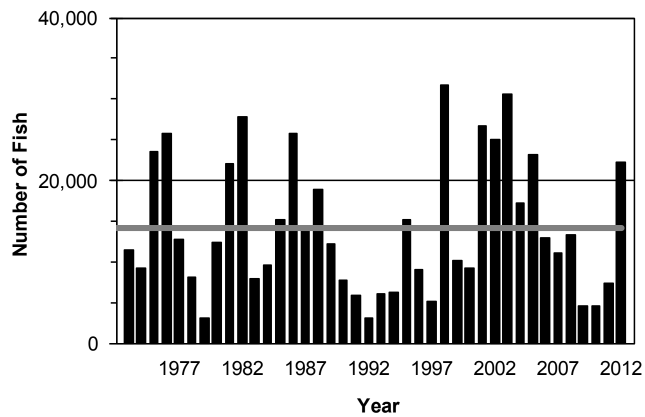

Figure 5 Annual spring-run Chinook Salmon escapement to Sacramento River Tributaries from 1973 to 2012 and 40 year average (gray line)

Fall-run Escapement to the Sacramento River System

The estimated escapement of fall-run Chinook Salmon to the Sacramento River and its tributaries was 320,861 in 2012, the highest since 2005, and 124% of the 40 year average of 259,230 (Figure 6).

Escapement to the Sacramento River and its tributaries upstream of Red Bluff Diversion Dam (RBDD) was 150,957, 142% of the 40 year average of 106,145 Chinook Salmon. Escapement to the Sacramento River and its tributaries between RBDD and Princeton Ferry was 8,029, 36% of the 40 year average of 22,379 Chinook Salmon. Escapement to Sacramento River tributaries between Princeton Ferry and Sacramento was 161,875, 124% of the 40 year average of 130,707 Chinook Salmon.

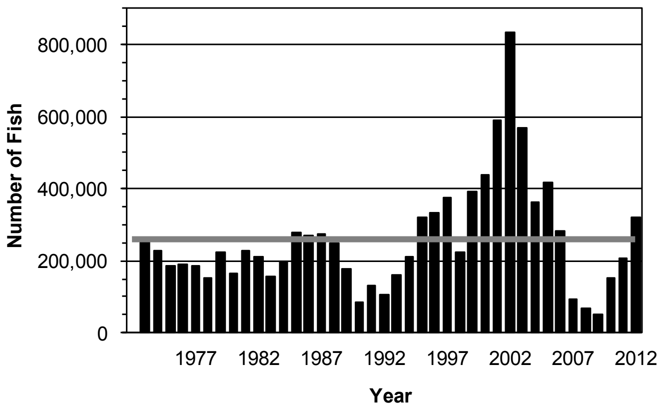

Figure 6 Annual fall-run Chinook Salmon escapement to the Sacramento River System from 1973 to 2012 and 40 year average (gray line)

Fall-run Escapement to the San Joaquin River System

The estimated escapement of fall-run Chinook Salmon to the San Joaquin River and its tributaries was 20,898 in 2012. This estimate is 116% of the 40 year average of 18,573 (Figure 7).

The Chinook escapement and harvest estimates presented in this paper do not attempt to give a total Chinook population estimate, but rather the data from those areas where estimates are made are presented for comparison with previous years. The GrandTab database is a collection of these estimates in the Central Valley. The estimates are reviewed, recalculated, and finalized by the Department of Fish and Wildlife Fisheries Branch, and though they cannot give a complete accounting of the Chinook population, they present the best available data.

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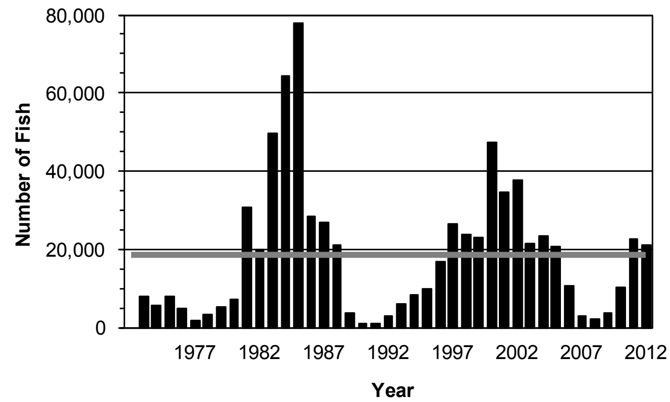

Figure 7 Annual fall-run Chinook Salmon escapement to the San Joaquin River system from 1973 to 2012 and 40 year average (gray line)

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Microcystis aeruginosa status and trends during the Summer Townet Survey

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Introduction

The California Department of Fish and Wildlife (CDFW) initiated the Summer Townet (STN) Survey in 1959 and have since conducted annual surveys, except in 1966. Data were collected bimonthly from 32 historic stations ranging from the San Pablo Bay to the eastern Delta. Sampling currently takes place from June through August. In 2009, 5 supplemental stations, located in the Sacramento Deep Water Ship Channel (SDWSC), were temporarily added to the sampling regime. These stations were not sampled in 2010, but were permanently added in 2011 along with 3 more supplemental stations in Cache Slough (CS) to more adequately describe Delta Smelt habitat (Figure 1). Data collected from the STN Survey are useful in approximating fish abundance, and have proven to be effective in gauging the overall health of the estuary (see Baxter and others, 2010).

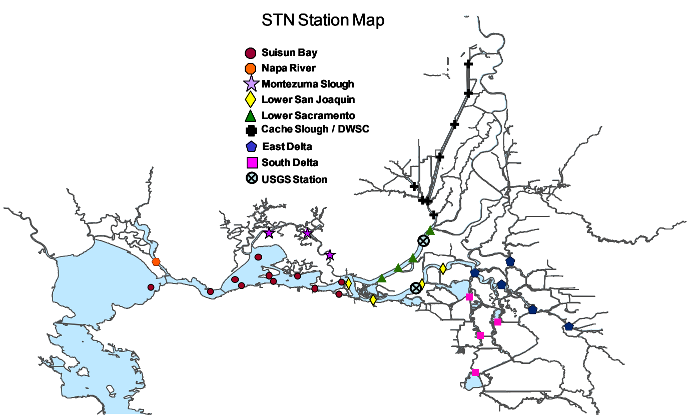

Figure 1 Summer Townet Survey stations by region in the Sacramento - San Joaquin Estuary (Note: USGS stations are not sampled by Summer Townet)

Microcystis aeruginosa is a toxic cyanobacteria found worldwide. However, *M. aeruginosa* blooms in the Sacramento-San Joaquin Delta region are a relatively recent occurrence, documented observations by research groups began in 1999 (Lehman and others, 2005). Even at low levels, *M. aeruginosa* may affect estuary health by negatively impacting the food web or through direct toxicity. As a low quality food, *M. aeruginosa* can reduce growth and survival rates of zooplankton (Tillmanns and others 2008, Ger and others 2009). Due to toxin accumulation at higher trophic levels, *M. aeruginosa* has been shown to negatively impact fish health through direct toxicity, promotion of liver cancer, and reduction in food quality and quantity (Ibelings and Chorus 2007, Brooks and others 2011). Furthermore, the toxic microcystins released by *M. aeruginosa* upon cell lysis have been linked to animal poisonings worldwide, including cattle deaths in Switzerland (Mez and others 1997), bird mortalities in Canada (Park and others 2001), and adverse health effects on humans (Chorus and Bartman, 1999).

Concern stemming from increased observations of *M. aeruginosa* at historic STN stations led to the collection of *M. aeruginosa* data. The STN crewmembers have gathered data on *M. aeruginosa* presence since 2007, and a formal system to visually rank presence was instated in 2008. In this paper, I summarize STN observations from 2008 through 2012 to depict relative density rankings monthly across years, regionally within the upper estuary, and across scales of salinity, Secchi depth, and water temperature.

Methods

In all years here reported, the STN survey sampled on alternate weeks, beginning in early June and continuing through late August. During each survey week, visual observations of *M. aeruginosa* were collected at 32 (2008-2010) or 40 (2011-2012) stations. This includes 32 core stations ranging from the eastern San Pablo Bay to Rio Vista on the Sacramento River and to Stockton on the San Joaquin River (Figure 1). The same observations were also collected at 8 supplemental stations in Cache Slough (2011 onward) and the SDWSC (2009 and 2011 onward) (Figure 1). In 2008 a visual scale was implemented ranking presence and density of *M. aeruginosa* colonies from 1 to 5 (Figure 2). On this scale, a ranking of 1 indicated the absence of visible colonies and a ranking of 5 indicated a continuous mat of visible colonies. Following protocol, at each station crewmembers searched for *M. aeruginosa* presence by looking over the side of the boat. They then ranked its presence according to the visual scale (Figure 2). In addition to a visual scan of the surface water, crewmembers also looked for *M. aeruginosa* presence in the plankton sample collected once per station by a mesozooplankton net. Plankton sample presence was recorded to attempt providing a more sensitive means of detections because the nets sample throughout the water column and because *M. aeruginosa* has the ability to regulate buoyancy using gas vacuoles (Jacoby and others, 1999) and thus may have been present elsewhere in the water column when it was not evident at the surface. However, data collected from the mesozooplankton net did not improve detections of *M. aeruginosa*; therefore these data were not reported.

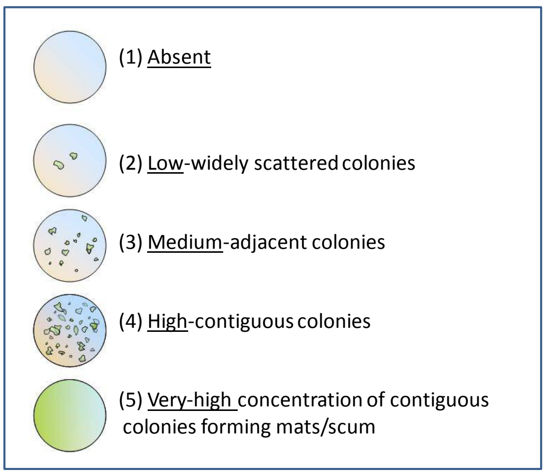

Figure 2 *Microcystis aeruginosa* density ranking key for Summer Townet and Fall Midwater Trawl Surveys

To assess *M. aeruginosa* presence and density, I looked at the total count of *M. aeruginosa* observations as the sum of counts of each ranking 1-5. There was a maximum of 80 observations each month in 2011 and 2012 (2 per month at each of the 40 stations), and a maximum of 64 observations each month in 2009 and 2010 (2 per month at each of the 32 core stations). In 2008 the 32 core stations were sampled on alternate weeks, although 3 surveys were conducted in July and one in August. Data collected from 2007 were removed from analysis as no protocol had been instated at this time and data collections were not consistent enough for comparison. Occasionally observations were not taken at a station; all such null values were removed from analysis; however, the frequency of null values in the data set was low (7 total, 3 in 2008 and 4 in 2009). To describe the temporal, spatial, and environmental distribution of *M. aeruginosa* observations, I tallied the 5 observational rankings in several ways: 1) by month for each year; 2) for all years combined, by embayment; 3) for all years combined, by 1.0 ºC temperature intervals; and 4) for all years combined, by 20.0 cm Secchi depth intervals. Over half the salinity observations were taken in 0.0 - 1.0 ppt, so salinity observations were portrayed in 2 ways to facilitate comparison: 1) data were converted to percentages of positive observations (i.e., sum of ranks 2-5 divided by sum of ranks 1-5) combined by 1 ppt salinity intervals; and 2) data were portrayed in $\log_{10}$ transformation to more clearly reveal the observed ranks of *M. aeruginosa* in each salinity range.

To describe flow rates, I used average monthly flow statistics generated by USGS (http://nwis.waterdata.usgs.gov). The statistics were generated from daily-mean data and were compiled from 1994 – 2007. I then calculated the average flow during the STN study months (June – August) for 2 USGS stations: one on the Sacramento River at Rio Vista and one on the San Joaquin River at Jersey Point (Figure 1). These stations were chosen because their placement on each river allows for flow comparison between the 2 rivers with little outside influence.

Results

In most years, *M. aeruginosa* density increased from June through August (Figure 3). Presence typically peaked in July, but the frequency of rankings > 2 peaked in August (Figure 3). The highest number of positive observations was seen in July 2012, whereas the greatest frequency of high rankings was observed in 2008. There were only 3 observations with a ranking of 5, all occurred in 2008 (1 in July, 2 in August).

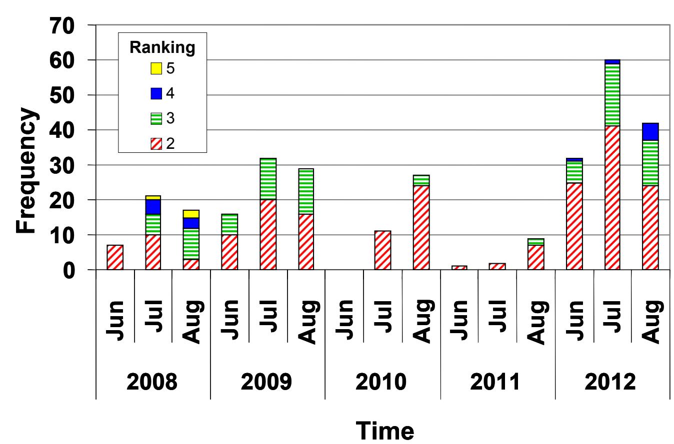

Figure 3 Frequency of *Microcystis aeruginosa* density rankings by month collected June through August during the Summer Townet Survey, 2008-2012. The frequency of non-detection observations (rank 1) is not shown.

Colonies of *M. aeruginosa* became more prevalent with rising temperatures (Figure 4). Although 71.4% of samples were collected in water with temperatures below 22.0 °C, within this range *M. aeruginosa* was only observed in 21.7% of the samples. Conversely, only 28.6% of samples were collected in waters warmer than 22.0 °C; however, within this range *M. aeruginosa* was observed in 53.2% of these samples.

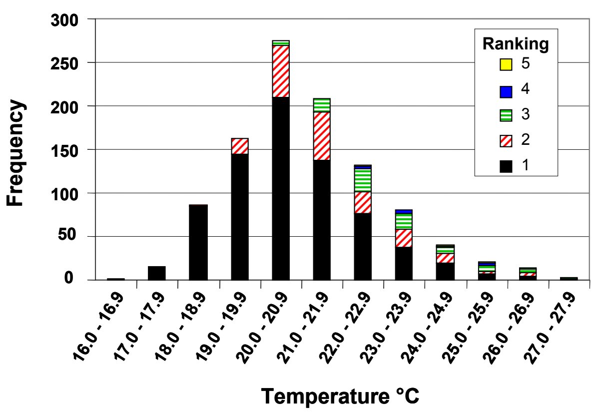

Figure 4 Frequency of *Microcystis aeruginosa* density rankings by water temperature intervals (1°C), collected 2008-2012 during the Summer Townet Survey

Across a salinity gradient, the highest percentage of positive observations occurred between 1.0 and 1.9 ppt (39%) (Figure 5A). There was a dip in the percentage in the range of 3.0-3.9 ppt where only 11% of samples showed *M. aeruginosa* presence, followed by peak within the range of 5.0-5.9 ppt (29%). After this second peak, the percentage of positive observations gradually declined. No *M. aeruginosa* was observed at salinities of ≥ 13.0 ppt. Most rankings > 2 were observed between 0.0 – 0.9 ppt (Figure 5B). There were only 6 observations with rankings > 2 in salinities higher than 1.0 ppt, and no observations with rankings > 2 in salinities higher than 6.0 ppt. Note that relatively few observations occurred at salinities of > 1.0 ppt (less than 50 observations per each 1.0 ppt increment, except from 2.0-3.0 ppt where n = 57).

Based on the relative frequency of medium to high observational rankings, the concentration of *M. aeruginosa* was highest in the south and east Delta (Figure 6). Low concentrations were observed in the DWSC-CS region (starting in 2011 and again in 2012) and Montezuma Slough (Figure 6). There has been no reported presence of *M. aeruginosa* in the Napa River (not shown), which is represented by only one station.

M. aeruginosa was observed once Secchi depths exceeded 30 cm (Figure 7). However, moderate to high density rankings were not a high proportion of observations until Secchi depths approached and surpassed 1 m (Figure 7).

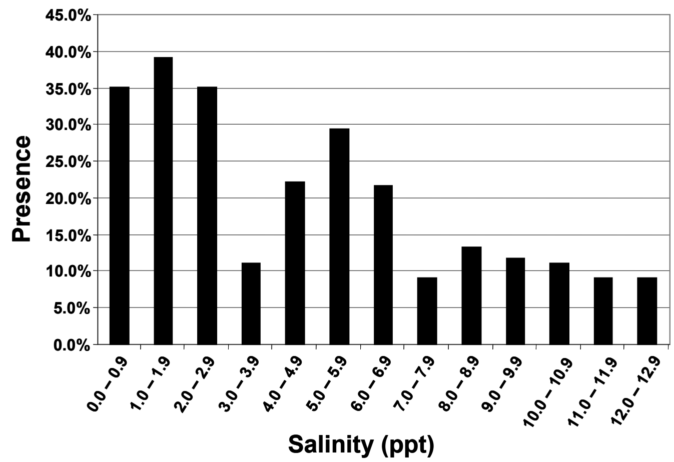

Figure 5A Observations of *Microcystis aeruginosa* by 1 ppt salinity interval, collected 2008-2012 during the Summer Townet Survey as a percent presence (i.e., all positive ranks combined)

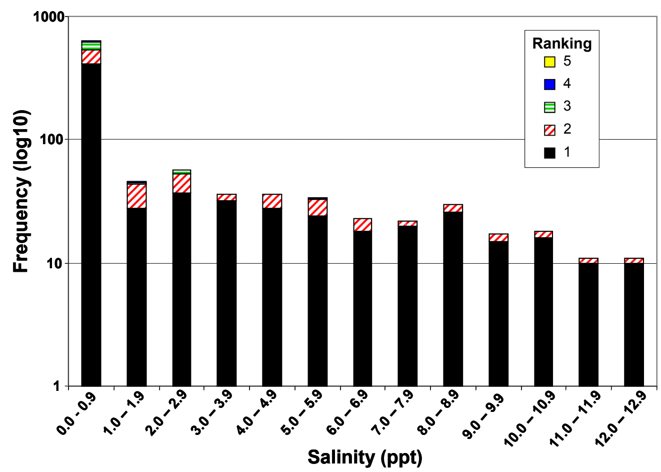

Figure 5B Observations of *Microcystis aeruginosa* by 1 ppt salinity interval, collected 2008-2012 during the Summer Townet Survey as a frequency of density rankings in log_{10} transformation

Discussion

M. aeruginosa has been shown to favor high temperatures (24 - 35 °C, Ganf, 1974), low salinities (0 – 10 ppt, Tonk, 2007), and low-flow vertically stable environments (Lehman and others, 2008). These distributional restrictions are consistent with the present results. Such constraints seem to have strongly influenced its presence throughout the Sacramento-San Joaquin Delta during the STN survey period: the highest frequencies of *M. aeruginosa* were observed in inland areas during mid-to-late summer, where temperature was highest and both salinity and vertical mixing were lowest.

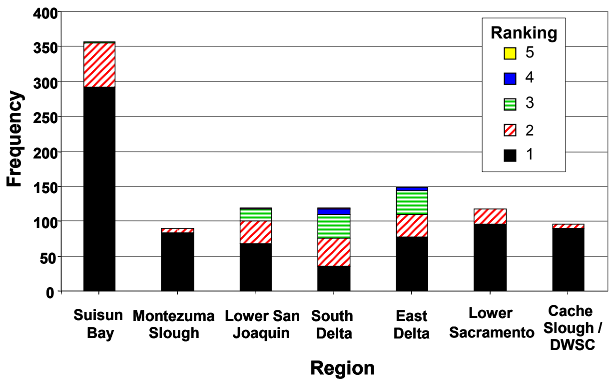

Figure 6 Frequency of *Microcystis aeruginosa* density ranking by region, collected 2008-2012 during the Summer Townet Survey

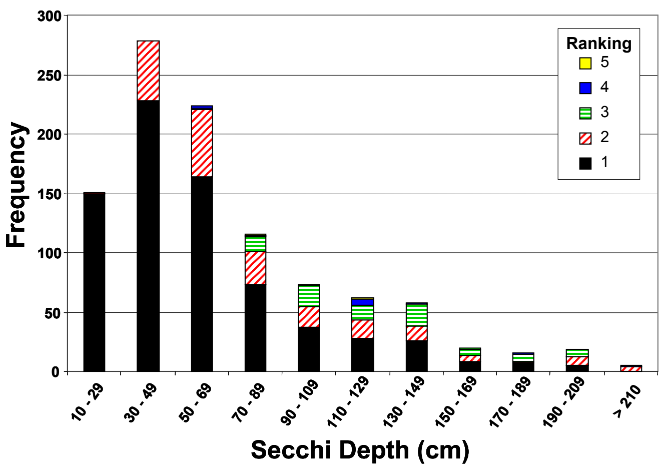

Figure 7 Frequency of *Microcystis aeruginosa* density ranking by Secchi depth interval (20 cm), collected 2008-2012 during the Summer Townet Survey

Gorham (1964) indicated a correlation between water temperature and the toxicity level of *M. aeruginosa*. In a lab setting, van der Westhuizen and Eloff (1985) found that *M. aeruginosa* cells were most toxic at 20 °C, yet toxicity was not markedly reduced until temperatures exceeded 28 °C. Of the 301 STN samples collected containing *M. aeruginosa*, 283 were taken within the range of 20.0 - 28.0 °C, suggesting that high toxicity levels may have characterized the cells of the *M. aeruginosa* collected during the STN study period. In this estuary, Lehman and others (2008) reported *M. aeruginosa* was dominant within this range as well, and remarked on a correlation between temperature and toxicity levels. Climate change models project warmer air temperatures in central California (Baxter and others 2010). A rise in water temperature may further favor *M. aeruginosa* development in the future.

The STN data showed that *M. aeruginosa* concentration decreased with increasing salinity following a peak at 1.0 – 1.9 ppt, and the maximum salinity range with *M. aeruginosa* presence was between 12.0 – 12.9 ppt (Figure 5). These findings are consistent with prior research showing *M. aeruginosa* has a constant growth rate up to approximately 10.0 ppt, followed by zero growth at 12.5 – 15.0 ppt (Tonk, 2007). However, the absence of colonies in salinities ≥ 13.0 ppt and the low number of observations with ranking > 2 in salinities ≥ 1.0 ppt suggest that *M. aeruginosa* is unable to survive within this suggested zero growth range in the Sacramento – San Joaquin Delta. The STN findings also are consistent with suggestions that *M. aeruginosa* may benefit from a slightly brackish environment, as observed in prior studies that noted an increase in *M. aeruginosa* growth rates with increasing salinity up to 1.5 ppt (Prinsloo and Pieterse, 1994).

The highest positive frequencies and rankings of *M. aeruginosa* observations were seen in the south and east Delta and lower San Joaquin River; however, distribution may be expanding north over time. In the lower Sacramento River, *M. aeruginosa* presence was observed every year from 2008-2012 at the three southernmost stations, with the exception of 2011. In 2011, it is possible that high outflows pushed *M. aeruginosa* colonies downriver. *M. aeruginosa* was first observed at all lower Sacramento River stations in 2012. Moving north, in CS no *M. aeruginosa* was noted in 2011, but all stations had small presence in 2012. Further north, *M. aeruginosa* was seen at the southernmost station of the SDWSC in 2012, but has not been seen further north. Although distribution appears to be expanding north, it is likely that expansion is limited by high flow rates in the Sacramento River. The 12 year average flow rate from June - August at Rio Vista on the Sacramento River was 14,047 cfs; the average flow rate at Jersey Point on the San Joaquin River was 3,475 cfs (http://nwis.waterdata.usgs.gov). Similarly, Lehman (2008) noted low levels *M. aeruginosa* occurrence and high flow rates in the lower Sacramento River. High flow may be detrimental to *M. aeruginosa* colonies; increased mixing may lessen access to light and restrict the necessary residence time for this slow-growing species (Reynolds, 1997).

We found a positive association between the proportion of rank 2-5 *M. aeruginosa* observations to total observations and Secchi depth. Low flow has shown to promote colony formation in the Sacramento-San Joaquin Delta (Lehman, 2008). With the ability to regulate buoyancy (Jacoby and others, 1999), *M. aeruginosa* is able to actively move to the surface in a stable water column; there they have been shown to out-compete other phytoplankton for light (Huisman and others, 2004) and decrease light availability for plankton below the surface (Lehman, 2009). Furthermore, a shift in species composition from larger to smaller zooplankton has been associated with increases in *M. aeruginosa* colonies (Lehman, 2009). This shift may be detrimental to the health of the estuary by reducing food quality at the base of the food web (Baxter and others, 2010).

Conclusion

It is clear that *M. aeruginosa* has found a suitable niche in the Sacramento – San Joaquin Delta. The present *M. aeruginosa* observations and associated density rankings derived from the STN have shown that high temperatures, relatively clear water and low salinities favor growth, which is consistent with past research. In this study area, fluctuations in salinity due to tidal influence and river outflows may give *M. aeruginosa* a competitive edge over species with more constrained salinity tolerances. In addition, the high temperatures seen during the summer months may promote high levels of toxic constituents within these organisms, which could be detrimental to wildlife. High water clarity, as seen in much of this region, may enable this species to out compete other, more palatable zooplankton species, which could further alter the food web base. Continued monitoring and increased understanding of this species may prove useful in further understanding the state of the Bay-Delta region. In the following article (Morris and Civiello, this issue), we discuss *M. aeruginosa* trends in the Delta through fall and briefly discuss how *M. aeruginosa* data collected from each of these studies compare.

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Microcystis aeruginosa status and trends during the Fall Midwater Trawl Survey and a comparison to trends in the Summer Townet Survey

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Introduction

A bloom of the toxic cyanobacteria *Microcystis aeruginosa* has been observed annually in the Sacramento – San Joaquin Delta since 1999 (Lehman and others 2005). This invasive species may pose a threat to the health of the estuary via direct toxification (Chorus and Bartram 1999), competition for resources (Tillmanns and others 2008), and in extreme cases may pose a threat to livestock and human health (Chorus and Bartram 1999). Concern stemming from increased occurrence of *M. aeruginosa* during fish surveys, particularly the Summer Townet (see Morris, this issue), led to the initiation in 2007 of a formal protocol for visually detecting *M. aeruginosa* and ranking its density. In the previous article, Morris (this issue) examined trends in *M. aeruginosa* bloom formation from June through August, as seen in the Summer Townet Survey (STN). In the present article we examine *M. aeruginosa* bloom formation from September through December, as seen in the Fall Midwater Trawl Survey (FMWT), and compare the findings of the two surveys.

The California Department of Fish and Wildlife (CDFW) initiated the FMWT survey in 1967 and has since conducted surveys annually, except in 1974 and 1979. CDFW created the FMWT survey to determine the relative abundance and distribution of age-0 Striped Bass in the estuary, but also collected data regarding other fish and invertebrate species. The list of data collected now includes visual detection and density ranking of *M. aeruginosa*. The FMWT survey covers a broad range within the upper San Francisco Estuary and observational results can help delimit *M. aeruginosa* range and habitat conditions. During the FMWT survey, 122 stations are sampled once per month from September through December. The sampling area ranges from San Pablo Bay to Hood on the Sacramento River, and to Stockton on the San Joaquin River (Figure 1). Additional stations were added to the Sacramento Deep Water Ship Channel (SDWSC) and Cache Slough (CS) in the late 2000s to improve information on Delta Smelt distribution (Figure 1); these non-core stations are not used for abundance index calculation.

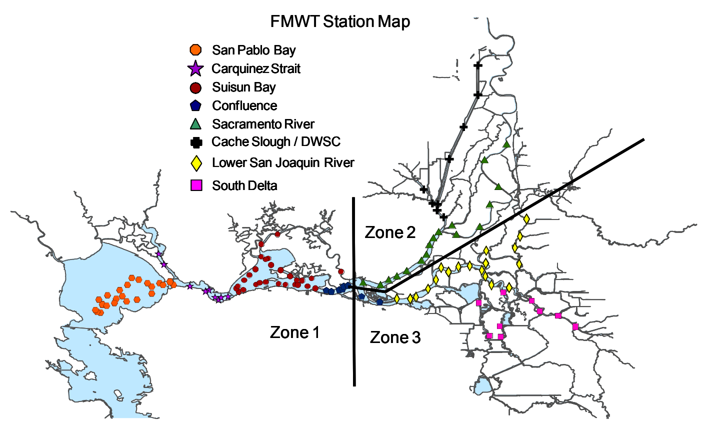

Figure 1 Fall Midwater Trawl Survey stations by zones, with regions denoted in legends. Regions per zone are as follows: Zone 1: San Pablo Bay, Napa River, Suisun Bay, Montezuma Slough and confluence; Zone 2: Sacramento River, Cache Slough and Deep Water Shipping Channel; Zone 3: lower San Joaquin River, south Delta and east Delta.

Methods

The FMWT crew began recording the visual presence and ranking relative density of *M. aeruginosa* in 2007. *M. aeruginosa* density was ranked on a 1-5 scale with 1 being an absence of visible colonies and 5 being a contiguous mat or scum (Figure 2). Since 2007, once per month at each station crewmembers looked into the water column for presence of *M. aeruginosa* and ranked density according to the visual ranking scale.

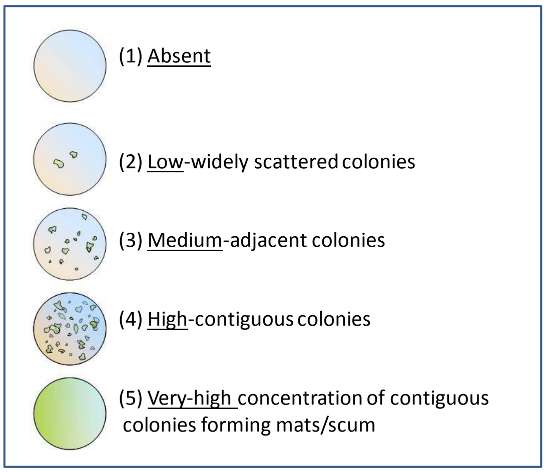

Figure 2 *Microcystis aeruginosa* density ranking key for Summer Townet and Fall Midwater Trawl surveys

To assess patterns in *M. aeruginosa* presence and density, we tallied the total count of *M. aeruginosa* observations as well as total counts of each visual density ranking. There was a maximum of 122 observations each month (one observation per station). All null values (observation inadvertently not taken) were removed; the frequency of occurrence of null values was low, with no more than 10 missing records in any given year.

To describe the temporal distribution of *M. aeruginosa* observations, we tallied the 5 observational rankings by month for each year. Unlike *M. aeruginosa* reported in STN surveys (Morris, this issue), there were few observations in ranks 3 or 4, and none in rank 5. For this reason, to describe spatial and environmental distribution of *M. aeruginosa* we converted tallies to percentages of positive observations (i.e., sum of ranks 2-5 divided by sum of ranks 1-5) to facilitate comparison. This was done in several ways; for all years combined by: 1) embayment; 2) 1 ºC temperature intervals; 3) 1 ppt salinity intervals; and 4) 0.20 m Secchi depth intervals.

To gain a more comprehensive view of *M. aeruginosa* trends, we compared data from FMWT and STN (Morris, this issue). To compare *M. aeruginosa* data from both studies, data were analyzed as a percentage of positive observations within each given environmental parameter. The STN and FMWT index regions vary, so to simplify geographic comparison of the data, the study area was split into 3 zones: Zone 1) the salty portion of the sampling area including San Pablo Bay, the Napa River, Suisun Bay, Montezuma Slough and the confluence; Zone 2) stations northeast of the confluence including the Sacramento River, Cache Slough and the DWSC; and Zone 3) stations southeast of the confluence including the San Joaquin River and the east and south Delta.

Results

FMWT Data

During the September through December period, positive *M. aeruginosa* observations were fairly infrequent, peaking at 45 observations in September 2011 (Figure 3). Across years, the number of *M. aeruginosa* observations showed no clear trend from September through November. No *M. aeruginosa* was seen in December, except at 2 stations in 2011. The greatest number of observations with ranking > 2 was seen either in September or October of each year. Only one observation of a > 2 ranking was noted following the month of October, a ranking of 3 in November of 2008.

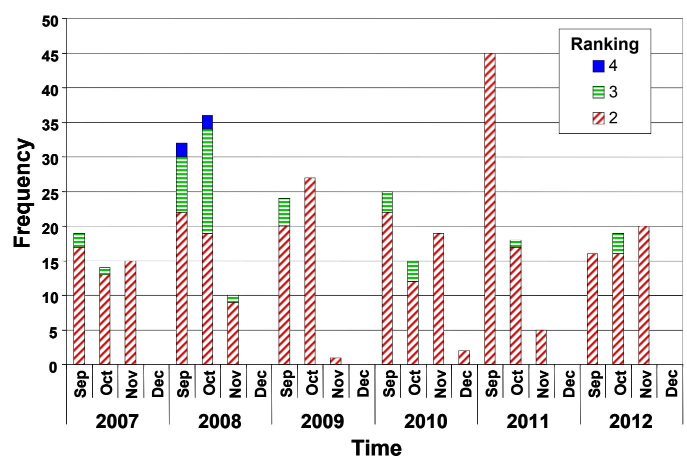

Figure 3 Frequency of *Microcystis aeruginosa* rankings by month, September through December, collected during the Fall Midwater Trawl Survey, 2007-2012. A visual density of rank 5 was not observed during this period. The frequency of non-detection observations (rank 1) is not shown.

The proportion of positive *M. aeruginosa* observations rose with increasing temperature (Figure 4). *M. aeruginosa* was seen in > 45% of samples taken from waters with a temperature of 22 °C and higher; yet was only seen in < 25% of samples taken in waters with a temperature below 21 °C. The proportion of positive *M. aeruginosa* observations was consistently > 20% between the salinity range of 0.0 and 4.9 ppt, but dropped sharply at salinities ≥ 5.0 ppt (Figure 5). There were no observations at salinities ≥ 11.0 ppt.

The highest percentages of positive *M. aeruginosa* observations were seen in the south Delta and the lower San Joaquin River, followed by the confluence (Figure 6). All observations with > 2 rankings came from these 3 areas as well. Low percentages (≤ 6%) were observed in all other areas, and no positive observations were recorded in San Pablo Bay (Figure 6). Positive observations of *M. aeruginosa* were made in every Secchi depth interval, but the proportion of positive *M. aeruginosa* observations rose sharply between Secchi depths of 1.0 and 1.4 m and remained about 30% in deeper intervals (Figure 7).

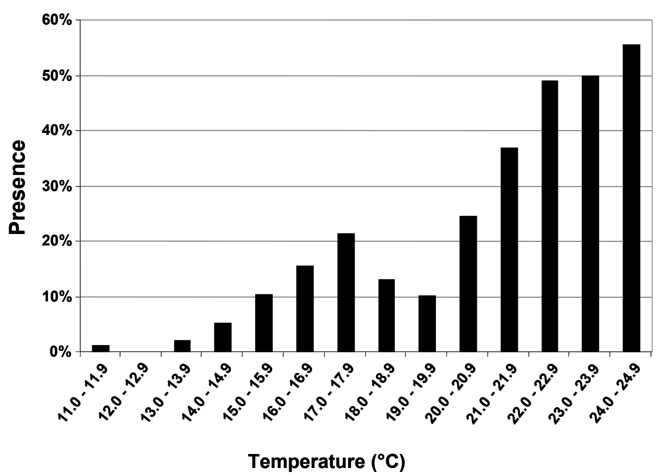

Figure 4 Frequency of positive *Microcystis aeruginosa* observations as a percentage of the overall frequency of water temperature observations per 1.0 °C temperature intervals, collected September through December during the Fall Midwater Trawl Survey, 2007-2012

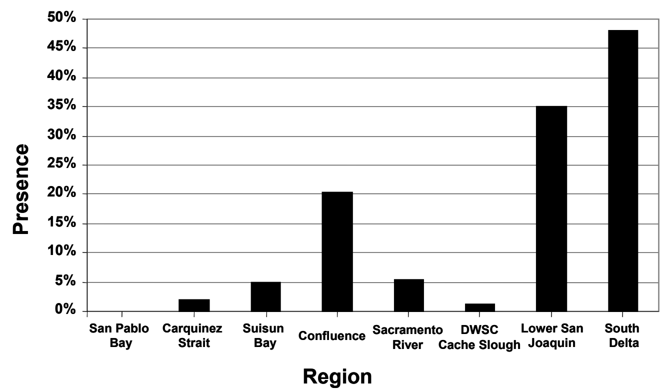

Figure 6 Frequency of positive *Microcystis aeruginosa* observations as a percentage of the overall frequency of observations per region, collected September through December during the Fall Midwater Trawl Survey, 2007-2012

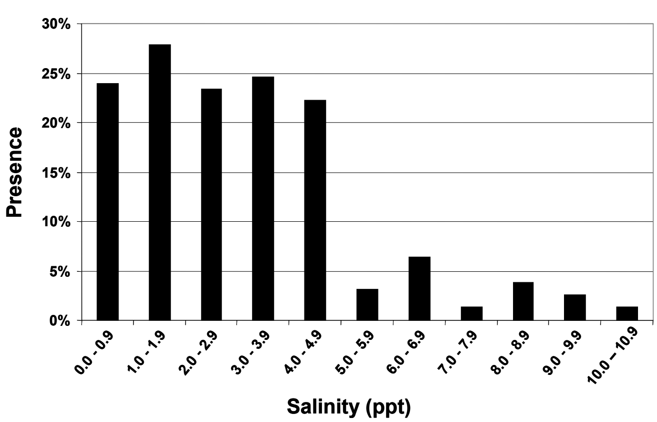

Figure 5 Frequency of positive *Microcystis aeruginosa* observations as a percentage of the overall frequency of salinity observations per 1.0 ppt salinity intervals, collected September through December during the Fall Midwater Trawl Survey, 2007-2012

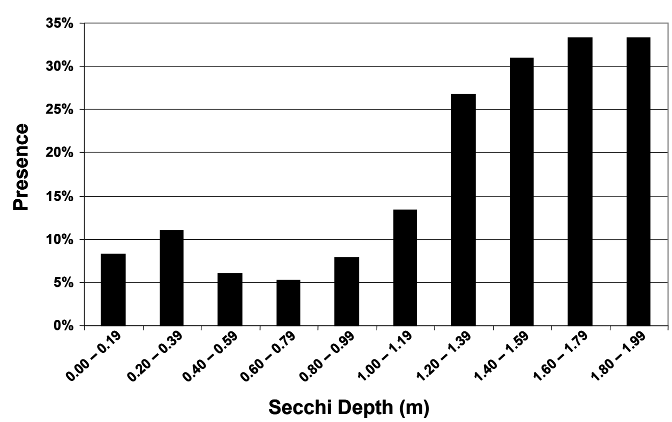

Figure 7 Frequency of positive *Microcystis aeruginosa* observations as a percentage of the overall frequency of Secchi depth observations per 0.20 m depth intervals, collected September through December during the Fall Midwater Trawl Survey, 2007-2012

Comparison of STN and FMWT Data

When data from the two projects were directly compared, *M. aeruginosa* presence was described across a wider range of environmental conditions. Average temperatures were higher during the STN study (80 stations, sampled June – August), and both average salinity and average Secchi depth were higher during the FMWT study (122 stations, sampled September – December). Rankings > 2 were observed more frequently during STN (104 observations with ranking > 2) than during FMWT (45 observations with ranking > 2) and the total number of positive *M. aeruginosa* observations showed no clear differences between the two studies, however FMWT surveyed 42 additional stations each month.

Although the water temperatures encountered by the FMWT were lower than those encountered by STN, the percentage of positive *M. aeruginosa* observations in much of the overlapping temperature range matched very closely between the two studies, with a positive pattern between percentage of presence and water temperature (Figure 8). Data from both studies showed a peak in the percentage of *M. aeruginosa* present within the salinity range of 1.0 -1.9 ppt (Figure 9). At high salinities, however, STN positive observations dropped off sharply then returned to a second peak in the 5.0-5.9 interval, whereas FMWT data showed a slight undulating decline prior to a sharp drop off in percentage of presence at 5.0 ppt. There was a general trend of increased percentage of presence with increased Secchi depth for both studies (Figure 10). Percentages of presence tended to be lower within each salinity and Secchi range for FMWT samples compared to those for STN.

Geographically, results from both studies showed a similar pattern: highest percentages of positive observations were seen in Zone 3 and low percentages were seen elsewhere (Figure 11). Percentages of positive observations were slightly lower in Zone 2 than in the higher salinity area of Zone 1.

Discussion

FMWT Data

The environmental conditions observed during the FMWT study period (September–December) were not best suited for the proliferation of *M. aeruginosa*. Infrequent observation of *M. aeruginosa* during the study period was likely due in part to the relatively lower temperatures observed. Commonly decreased positive observations and virtual absence of rankings > 2 in November, combined with few, but mostly no positive observations in December (n=2), indicates that *M. aeruginosa* began to die off in the late fall, and was likely absent from the system by early winter.

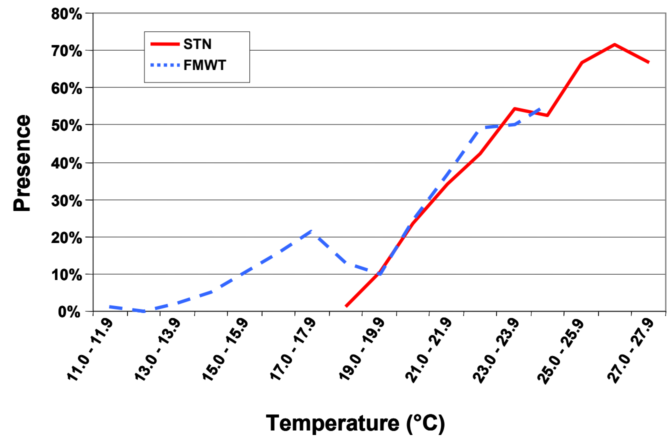

Figure 8 Frequency of positive *Microcystis aeruginosa* observations as a percentage of the overall frequency of water temperature observations per 1.0 °C temperature intervals, collected June through August during Summer Townet, 2008 through 2012, and September through December during Fall Midwater Trawl, 2007 through 2012

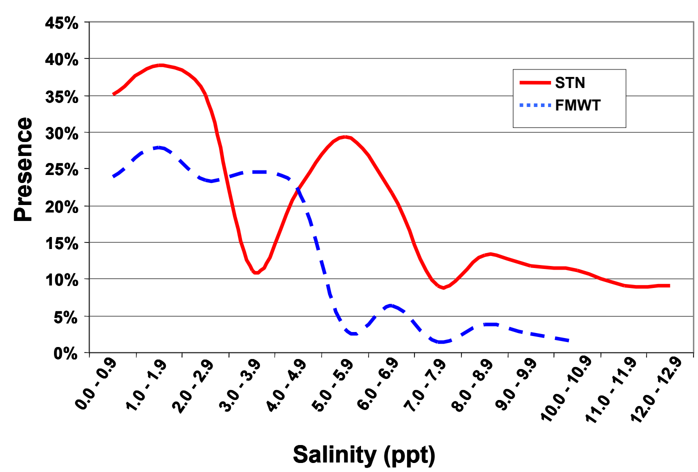

Figure 9 Frequency of positive *Microcystis aeruginosa* observations as a percentage of the overall frequency of salinity observations per 1.0 ppt salinity intervals, collected June through August during Summer Townet, 2008 through 2012, and September through December during Fall Midwater Trawl, 2007 through 2012

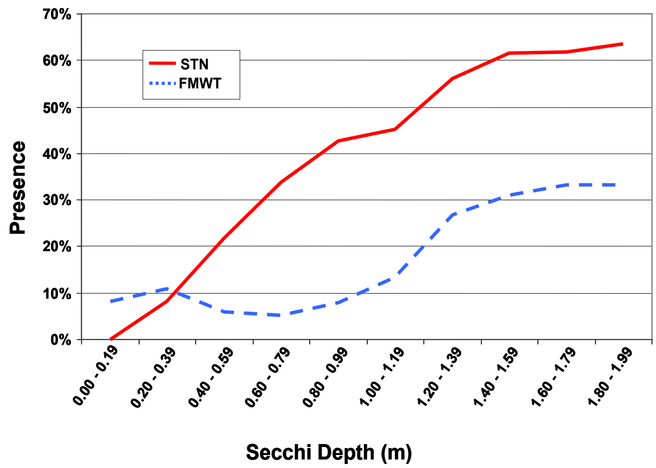

Figure 10 Frequency of positive *Microcystis aeruginosa* observations as a percentage of the overall frequency of Secchi depth observations per 0.20 m depth intervals, collected June through August during Summer Townet, 2008 through 2012, and September through December during Fall Midwater Trawl, 2007 through 2012

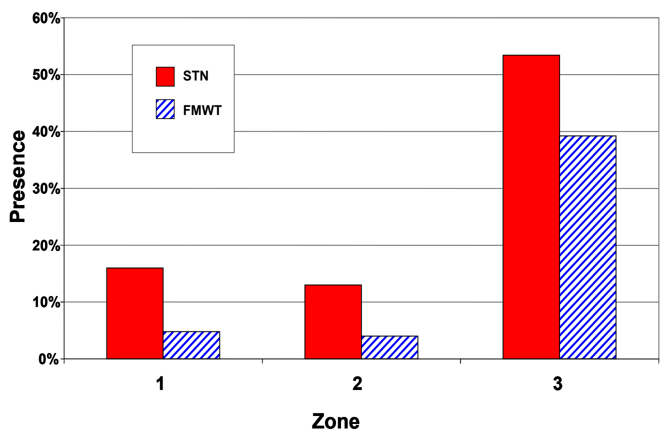

Figure 11 Frequency of positive *Microcystis aeruginosa* observations as a percentage of the overall frequency of observations per region. Data collected June through August during Summer Townet, 2008 through 2012, and September through December during Fall Midwater Trawl, 2007 through 2012

Highest growth rates of *M. aeruginosa* have been observed in the range of 24-35 °C (Ganf, 1974), which is above the water temperatures observed during FMWT. However, the percentage of positive observations during FMWT rose sharply between 20-23 °C and remained ≥ 50% of samples taken at higher temperatures, which follows prior findings that water temperatures of 20 °C are required for bloom initiation (Jacoby and others, 1999).

Based on our geographic and salinity scaled results, it seems clear that *M. aeruginosa* thrived in the lower San Joaquin River and south Delta, particularly at the freshwater-brackish water interface and somewhat beyond. Having the ability to not only tolerate but do well in brackish water (Figure 5) creates an overlap in habitat with several fish species (Kimmerer and others, 2009), particularly Delta Smelt (Feyrer and others, 2007 and 2010). Thus, these fishes are likely to be near the blooms and any associated toxicity. Our observations suggest a dramatic drop off at salinities higher than 4.9 ppt (Figure 5). It is unclear whether this decline might be related to the interaction of salinity and declining temperatures or some other factor. Prior research has suggested that *M. aeruginosa* is most severely affected at salinities higher than 8 ppt (Tonk 2007), well beyond the salinity where we observed the decline, but close to the highest salinity range in which we detected *M. aeruginosa*.

M. aeruginosa has been observed throughout the upper San Francisco Estuary with the exception of San Pablo Bay. The highest numbers of observations and the highest number of rankings > 2 were seen in the lower San Joaquin, the south Delta, and the San Joaquin River portion of the confluence, which are all characterized by low salinities. Observations in the Sacramento River, Cache Slough and DWSC were much less frequent, and in these areas no rankings > 2 were noted. It is possible that the habitat in these regions is less favorable to *M. aeruginosa* growth.

Comparison of STN and FMWT Data

By comparing data collected from both studies, a more complete picture of *M. aeruginosa* in the Sacramento–San Joaquin Delta emerges. Distribution throughout the estuary showed clear patterns with each environmental and spatial parameter. Positive presence of *M. aeruginosa* was associated with abiotic conditions characterized by: 1) high temperatures; 2) fresh to brackish water; and 3) high water clarity, all of which predominated in the lower San Joaquin River, south Delta regions.

Data collected from the two studies showed a parallel increase of the percentage of positive *M. aeruginosa* observations across a temperature gradient (Figure 8). Similar findings have been reported in this system (Lehman and others, 2008). This indicates that temperature had a large influence on *M. aeruginosa* presence. Additionally, increases in both presence and rankings seemed to correlate with higher temperatures (20.0–28.0 °C). Temperatures are often seen within this range within the study area, which may be of some concern, as previous research has suggested that temperatures > 20 °C may contribute to higher toxicity levels of *M. aeruginosa* colonies (Gorham 1964).

Data collected from both studies indicated a peak in the proportion of *M. aeruginosa* within the salinity range of 1.0–1.9 ppt. This suggests that colonies may benefit from a slightly brackish (i.e., oligohaline) environment or that downstream transport is somewhat delayed in this region concentrating colonies (see low salinity zone in Kimmerer 2004). The steep decline in presence at 4.9 ppt in FMWT data was not observed from STN data (Figure 9), though there was a similar decline at higher salinity in the STN data. One reason for the variable pattern of presence across salinity intervals may be that very few STN stations are located in high salinity areas; hence the total number of samples collected was very limited in salinity intervals above 4.9 ppt (n < 10 for each salinity interval above 4.9 ppt). Therefore, FMWT data may be more representative of these high salinity regions (n > 45 for each salinity interval above 4.9 ppt). Alternately, as discussed above, *M. aeruginosa* survival at higher salinities may be further limited by cooling water temperatures in fall. Van der Westhuizen and Eloff (1985) found that *M. aeruginosa* growth rate was substantially reduced at 16°C compared to higher temperatures. If *M. aeruginosa* remains largely unaffected by salinities up to 4.9 ppt in the Sacramento – San Joaquin Delta, the wide tolerance range may give the organism a competitive edge over less tolerant species.

An association between the percentage of positive *M. aeruginosa* observations and an increasing Secchi depth was also noted in both studies (Figure 10). As a slow growing species, longer residence time associated with low flows and high water clarity favor *M. aeruginosa* growth (Reynolds, 1997). With the ability to regulate buoyancy (Jacoby and others, 1999) *M. aeruginosa* is able to rise to the surface in a stable water column (Lehman 2008) where they outcompete other phytoplankton for light (Huisman 2004).

Geographically, both studies showed the highest levels of *M. aeruginosa* in Zone 3 (Figures 1 and 11). In this area, *M. aeruginosa* was present in over 50% of samples gathered during STN, and in almost 40% of samples gathered during FMWT. These findings are consistent with prior research on distribution patterns which noted highest *M. aeruginosa* levels were found in the San Joaquin River in 2003 (Lehman and others 2005). Lower percentages were seen elsewhere, yet percentages seen in the generally colder, saltier regions of Zone 1 were slightly higher than those seen in high flow Zone 2 (Figure 1). This suggests that growth originated in the lower San Joaquin River or south Delta region and was dispersed or transported downstream into the confluence and Suisun Bay. Such *M. aeruginosa* transport has been reported in other estuaries (Robson and Hamilton 2003).

Conclusion

M. aeruginosa has been observed throughout most of the Sacramento – San Joaquin Delta, with predominance in the warm, clear waters of the San Joaquin and south Delta. The high temperatures, relatively low salinities, and clear waters often seen in this estuary provide a suitable habitat for *M. aeruginosa* to thrive. In addition, the response of this species to long-term environmental changes may provide a competitive advantage over less tolerant species in this dynamic environment. *M. aeruginosa* has the potential to weaken the base of the food web by serving as a poor food source (Tillmanns and others 2008), by out-competing native or beneficial phytoplankton species through competition of resources (Lehman and others 2009), and has been shown to be fatal to two species of calanoid copepods that are an important food source in the Delta (Ger and others, 2009). *M. aeruginosa* can also negatively impact resident fish species by creating a toxic environment (Baxter and others 2010). Extremely high concentrations, like those observed in 2008, has led to health warnings and has the potential to directly harm fish species, particularly those with widespread distribution in the central and southern Delta such as Striped Bass and Threadfin Shad, through toxicity effects (Baxter and others, 2010). Due to the potential detrimental impacts to the numerous organisms that live in and utilize the Delta, continued monitoring of *M. aeruginosa* levels is critical.

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