Interagency Ecological Program for the San Francisco Estuary

IEP NEWSLETTER

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Of Interest to Managers

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Using the terminology "Status and Trends" to describe the spring issue is becoming somewhat outdated because, for various reasons, projects now submit these types of articles year-round (e.g., fish salvage is reported in winter, San Francisco Bay Study, Spring Kodiak, and Smelt Larva Survey results in summer or fall). Nonetheless, several articles in this issue fit the status and trends label and several historically 'status and trends'-type articles were modified or expanded to include Fall Low Salinity Habitat study results. More about this below…

Dan Yamanaka and **Reza Shahcheraghi** contributed the single highlights article on Delta Water Project Operations in the first quarter of 2012. They report a dry winter quarter with limited water exports.

The status and trends section didn't receive an article for 2011 flows and exports. However, 2011 was characterized as a "wet" year in both the Sacramento and San Joaquin river systems (http://cdec.water.ca.gov/cgi-progs/iodir/WSIHIST), and flows remained high in both systems into July and then increased again during September and October as a result of dam releases to achieve flood control space. Such high, consistent outflows and associated conditions produce a variety of biological effects, some of which will be discussed in subsequent articles.

River flows influence the salinity field location within the estuary, which in turn has a strong effect on the benthos community. **Heather Fuller** reviews water-year types for recent years to put her 2011 benthic community results into context. Importantly, the 2011 densities of clams in the Estuary Monitoring Program Suisun Bay stations declined substantially from 2010 densities, and virtually all of this difference was due to reductions in *Potamocorbula amurensis* (was *Corbula amurensis*) abundance in summer and fall. This should have been a good sign for lower trophic level production.

High river flows facilitate salmonid survival and migration within the system. **Christian McKibbin** shows how tightly emigration timing of juvenile salmon is tied to river flows. He presents mid-season counts for water year 2012 from the Knights Landing rotary screw trap and notes that the juvenile Chinook salmon catch increased substantially over 2011, but in 2011 high spring flows provided salmon an alternate migration route through the Sutter Bypass (rather than past the traps); this was not the case in 2012 except for 2 days in March.

Jason Azat's summary of adult Chinook Salmon returns to Central Valley rivers in 2011 shows that fall-run stocks rebounded from lows in the late 2000s. Unfortunately, adult spring-run returns were flat, and late-fall-run- and winter-run Chinook salmon returns continued to decline.

Fall Low Salinity Habitat (FLaSH) was identified in the Delta Smelt Biological Opinion (BiOp; USFWS 2008) as an important component of critical habitat and deemed necessary to avoid jeopardy. The BiOp Reasonable and Prudent Alternative included an action to improve fall LSH (see details in the FLaSH Introduction) and recognized that questions remained on the efficacy of the fall habitat action, so the Service implemented a formal adaptive management process wherein it would review new scientific information when provided and make changes to the action when warranted based on the best available scientific information. The fall action called for X2 at 74 km during September and October of "wet" water-years and X2 at 81 km during the same period of "above normal" water-years; these X2 locations placed the LSZ entirely or substantially, respectively, in Suisun Bay, a location hypothesized to benefit delta smelt. Although this action was challenged in court, fortuitous hydrological and water supply circumstances in 2011 created a situation where the fall X2 location target for a wet water year – 74 km – was virtually achieved as result of typical flood control and water management actions. Anticipating such a possibility, IEP managers and agency and academic researchers worked to organize an investigative response. The FLaSH studies were implemented coincident with the last Summer Townet field survey (late August) and continued during the Fall Midwater Trawl survey period, September through December. Since no additional delta smelt take was authorized for the FLaSH studies, fish measures focused on catches from the Summer Townet and Fall Midwater Trawl. I provide a more detailed FLaSH introduction prior to 3 articles summarizing some FLaSH results for the 2011 zooplankton community, fish abundance, distribution and size, and delta smelt diet. These articles either expand upon traditional content (fishes) or take the place of historical status and trends article (zooplankton) for this newsletter issue. For zooplankton, look for a traditional status and trends article in a later issue this year.

April Hennessy examined zooplankton responses in fall 2011 in comparison to fall abundances in the most recent wet year, 2006, and in the years preceding each, 2005 and 2010. Her results show that fall 2011 was good for many delta smelt prey.

Upper estuary pelagic fishes generally responded favorably to environmental conditions in 2011 according to **Dave Contreras**, **Katherine Osborn**, **Kathryn Hieb**, **Randy Baxter**, and **Steven Slater**. In particular, delta smelt abundance increased substantially over recent years.

Fall typically provides relatively poor feeding conditions for delta smelt (Lott 1998. IEP Newsletter Vol 11 (1): 14-19; Slater and Baxter manuscript). **Steve Slater** found this was not the case in fall 2011, when delta smelt appeared well fed and used a broad variety of prey (particularly late in the fall), including mysids and amphipods in addition to well known copepod prey.

The single contributed paper investigated new technologies as indirect means of characterizing phytoplankton communities. Identification of phytoplankton to species is often important to recognize environmental change and particularly to recognize potential food value; however, species identification based on microscopy is time consuming and expensive, thus limiting sample sizes and limiting our ability to detect changes in the community at relevant temporal and spatial scales. **Erica Kress**, **Alexander Parker**, **Frances Wilkerson**, and **Richard Dugdale** report on efforts to augment and contrast microscope counts with those using new technologies (e.g. spectrofluorometry and flow cytometry) to indirectly monitor phytoplankton communities over broader temporal and spatial scales. The authors found sizable differences in some measures, but generally similar overall trends in results comparing direct and indirect methods. They conclude that employing new technologies may provide sufficient benefits in increased sampling capacity at decreased cost to offset the more coarse measures provided by these new technologies.

IEP QUARTERLY HIGHLIGHTS

DELTA WATER PROJECT OPERATIONS

January to March 2012

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

Most of the Delta inflows during these months were a combination of contributions from the upstream reservoir releases and other in-basin accretions originated within Sacramento and San Joaquin Rivers basins.

The Sacramento River flow at Freeport (SACRV) ranged between 250 cms and 1,290 cms and the San Joaquin River at Vernalis (SJRV) ranged between 35 cms and 60 cms. Net Delta Outflow Index (NODI) peaked to a high of 1,450 cms and receded to 150 cms during the 3 month period (Figure 1).

The combined CVP and SWP Projects' export was as low as 50 and peaked as high as 175 cms (Figure 2).

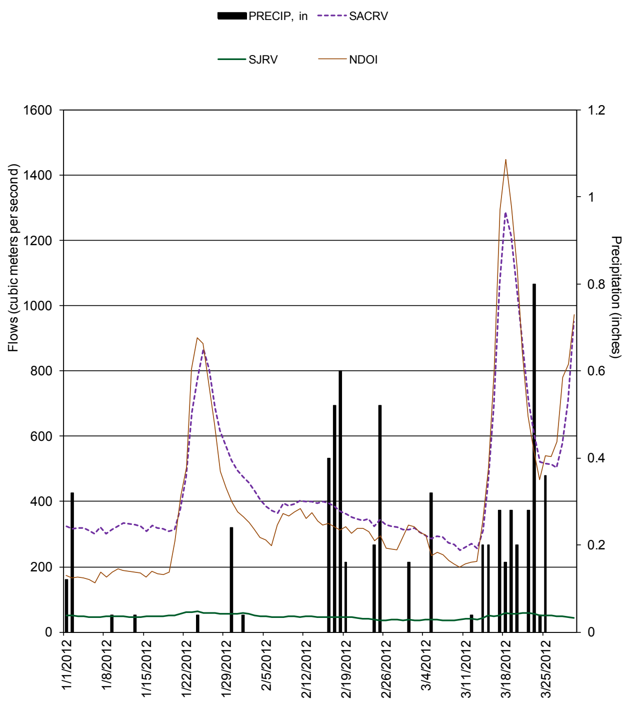

Figure 1 Sacramento River, San Joaquin River, Net Delta Outflow, and Precipitation, January 1 through March 31, 2012

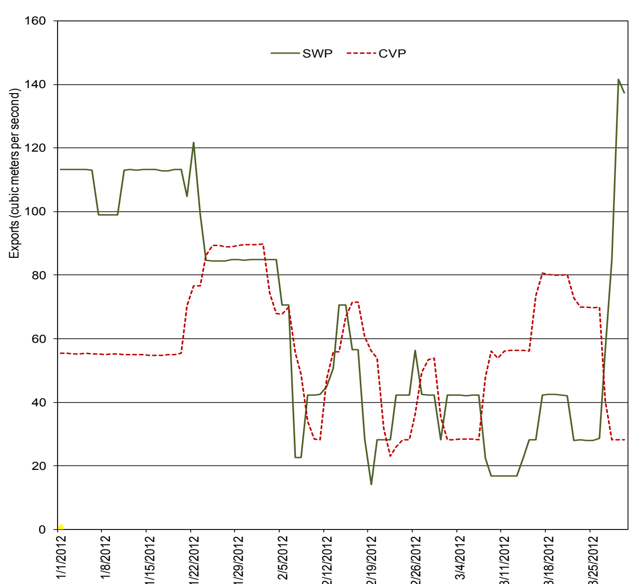

Figure 2 State Water Project and Central Valley Project Exports, January 1 through March 31, 2012

Bay-Delta Standards Contained in D-1641

CRITERIA	*Jan 2012*	*Feb 2012*	*Mar 2012*
FLOW/OPERATIONAL			
Fish and Wildlife			
Export/Inflow Ratio	65%	35%	
Minimum Outflow - mon.	4500 cfs		
- 7 day average	3500 cfs		
Habitat Protection Outflow, X2		7,100 - 29,200 cfs or X2 days	
Salinity Starting Condition		Meet EC<= 2.64 at Collinsville for 1-day	
River Flows:			
@ Rio Vista - min. mon. avg.			
- 7 day average			
@ Vernalis: Base - min. mon. avg.		710 cfs or 1140 cfs	
- 7 day average		568 cfs or 912 cfs	
Delta Cross Channel Gates	Dec-Jan may be closed up to a total of 45 days	Closed	
WATER QUALITY STANDARDS			
Municipal and Industrial			
All Export Locations	250 mg/l Chlorides		
Contra Costa Canal	Cl <= 150 mg/l for 175 days		
Agriculture			
Southern Delta	30-day running average EC <= 1.0mS		
Fish and Wildlife			
San Joaquin River Salinity			
Suisun Marsh Salinity	12.5 EC	8.0 EC	

Water Year Classification: (Based on forecast, 01/01/2012)

SRI (40-30-30 @ 50%) = 6.9 MAF (Below Normal)

SJV (60-20-20 @75%) = 2.0 MAF (Critical)

Figure 3 Bay-Delta Standards contained in D-1641

Status and Trends

Benthic Monitoring, 2011

Heather Fuller (DWR), hlfuller@water.ca.gov

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 2011, and highlight some of the differences seen in the communities between 2010 and 2011.

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 0.053 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.

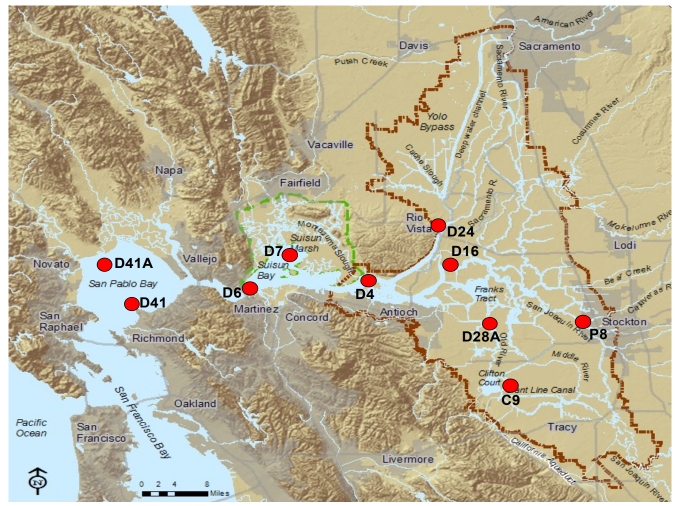

Figure 1 Locations of the Environmental Monitoring Program's (EMP) benthic monitoring stations

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 square meters, to get an abundance of organisms per square meter. The densities for all phyla were then plotted month by month to depict seasonal patterns in benthic communities.

Results

The 2011 water year was considerably wetter than the four preceding years (Table 1). Higher than average flows in the winter and spring of 2011 were expected to affect both benthic organism abundances and benthic community composition.

Five new species were added to the benthic species list in 2011, including two species of crabs (Table 2). These species are not necessarily new to the upper San Francisco estuary, but were collected for the first time in 2011 by benthic monitoring component of the EMP. It should also be noted that *Corbula amurensis* now con-

Table 1 Percent of average flows and official water year classification for water years (WY) 2007-2011

Water Year	*Sacramento Valley % of average flows (WY Type[a])*	*San Joaquin Valley % of average flows (WY Type[a])*
2007	74% (D)	60% (C)
2008	62% (C)	63% (C)
2009	69% (D)	83% (D)
2010	85% (BN)	85% (AN)
2011	128% (W)	170% (W)

[a] Water Year Type Classification: W=Wet, AN=Above Normal, BN=Below Normal, D=Dry, C=Critical. All data are from CDEC.

sidered, once again, to be in the genus *Potamocorbula* (Huber 2010), and will be referred to as *Potamocorbula amurensis* in this and future EMP publications.

Ten phyla were represented in the benthic fauna collected in 2011: Cnidaria (jellyfish, corals, sea anemones, and hydrozoans), Platyhelminthes (flatworms), Nermertea (ribbon worms), Nematoda (roundworms), Nematomorpha (horseshoe/gordian worms), 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 2011.

Of the 211 benthic species collected in 2011, 10 represented 81% of all organisms collected. These include several amphipods, the Asian clams, and several worms (Table 3). 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.

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 2011 was consistently made up of sand each month. Mollusca was the most abundant phylum at D24 in all months (Figure 2), accounting for 71% of all organisms collected in 2011. Nearly all (97%) of the mollusks found at D24 in 2011 were *Corbicula fluminea*. Annelids (dominated by *Varichaetadrilus angustipenis* and *Limnodrilus hoffmeisteri*) and Arthropods (dominated by *Gammarus daiberi*) were also commonly found at D24 in 2011 (Figure 2). The benthic community found at D24 in 2011 was very similar to the community found there in 2010.

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 2011, the substrate composition of D16 varied from month to month; in some months it was primarily sand, in some it

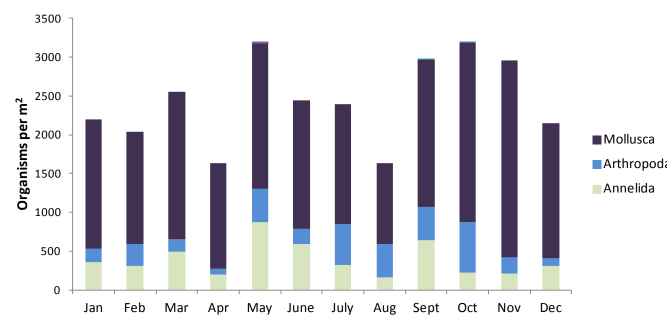

Figure 2 Abundance of benthic organisms, grouped by phyla, collected at station D24 (Sacramento River at Rio Vista) by month, 2011. Very rare phyla (defined as fewer than 100 individuals per square meter total for the year) were omitted from this figure.

Table 2 Location, collection month, and lowest taxonomic identification of taxa collected by the benthic monitoring component of the EMP for the first time in 2011

Site Name	*Location*	*Month collected*	*Family*	*Genus*	*Species*	*Common Name*
D41	San Pablo Bay	February	Cancridae	*Cancer*	*anthonyi*	yellow crab
D41	San Pablo Bay	May	Cancridae	*Cancer*	*branneri*	furrowed rock crab
D24	Rio Vista	June	Pseudironidae	*Pseudiron*	*"centralis"*	flatheaded mayfly
C9, D28A	Clifton Court, Old River	August, November	Chironomidae	*Cryptochironomus*	*species D*	chironomid
D41	San Pablo Bay	September	Unknown	Unidentified nudibranch	*species A*	nudibranch

Table 3 Most abundant species collected by the benthic monitoring component of the EMP in 2011

Species	*Organism Type*	*Station(s) at which the species was abundant*	*Month(s) in which the species was abundant*	*Total Count for 2011[a]*
Potamocorbula amurensis	Asian clam	D6, D7, D41A	July-Dec	31061
Varichaetadrilus angustipenis	Tubificidae worm	C9, D4	Abundant year round	29385
Limnodrilus hoffmeisteri	Tubificidae worm	C9, D4, P8	March-Dec	21365
Americorophium stimpsoni	Amphipod	C9, D4, D7, P8	May-Dec	16678
Americorophium spinicorne	Amphipod	D4	Abundant year round	16325
Manayunkia speciosa	Sabellidae polychaete worm	P8	Feb-July	13515
Gammarus daiberi	Amphipod	D4, P8	June-Dec	10932
Corophium alienense	Amphipod	D7	Jan-May, Sept-Dec	10343
Corbicula fluminea	Asian clam	D24, D16, D28A, P8, C9, D4	Abundant year round	9887
Ampelisca abdita	Amphipod	D41A, D41	Sept-Dec	8282

[a] Total number of individuals collected by the benthic monitoring program at all stations in all months 2011 (the four replicate grabs collected at each station each month were summed)

was primarily fines (clay and/or silt), and in other months it was a mixture of both. Arthropoda was the most abundant phylum (34% of all organisms collected) in most months from February-September, except May in which Annelida was most abundant. In January and from September through December Mollusca dominated (44% of all organisms collected; Figure 3). The most abundant arthropods at D16 in 2011 were *Americorophium spinicorne* and *Gammarus daiberi*, the most abundant mollusk was *Corbicula fluminea*, and the most abundant annelid was *Varichaetadrilus angustipenis*.

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. Annelida, Arthropoda, and Mollusca were the three most abundant phyla at D28A in 2011, with 54%, 25% and 20% of total organisms collected, respectively (Figure 4). The most common annelid was *Varichaetadrilus angustipenis* (23% of all annelids collected), the dominant arthropod was the ostracod *Cyprideis sp. A* (34% of all arthropods collected), and the dominant mollusk was *Corbicula fluminea* (37% of all mollusks collected). The number of arthropods collected at D28A in 2011 was half the number of arthropods collected there in 2010.

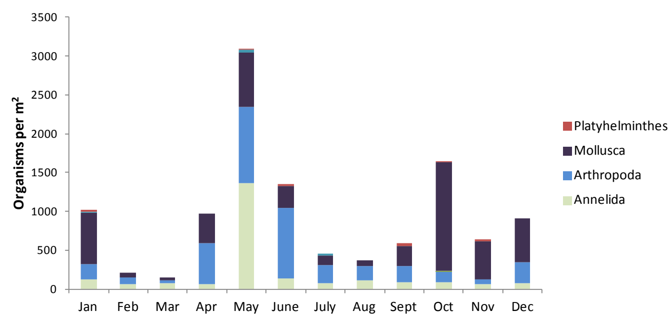

Figure 3 Abundance of benthic organisms, grouped by phyla, collected at station D16 (San Joaquin River at Twitchell Island) by month, 2011. Very rare phyla (defined as fewer than 100 individuals per square meter total for the year) were omitted from this figure.

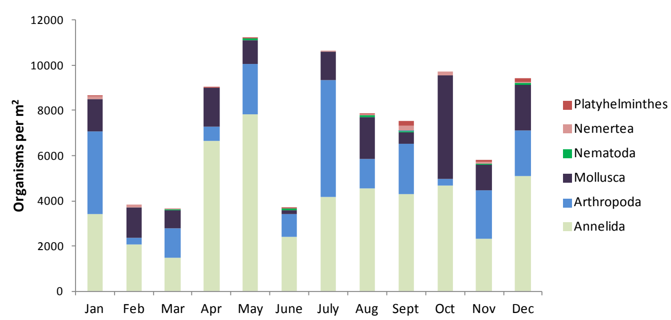

Figure 4 Abundance of benthic organisms, grouped by phyla, collected at station D28A (Old River) by month, 2011. Very rare phyla (defined as fewer than 100 individuals per square meter total for the year) were omitted from this figure.

South Delta (P8, C9)

The benthic monitoring program took samples 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 sand and fines (silt or clay) with some organics, though the amount of each varied slightly throughout the year. Annelida was the most abundant phyla at this station for all months in 2011 except August, accounting for 67% of all organisms collected (Figure 5). The dominant annelid was *Manayunkia speciosa*, which accounted for 42% of all organisms in all phyla collected at P8 in 2011. In July-October Arthropoda abundances increased substantially compared to previous months; Arthropoda was the most abundant phylum in August 2011. The number of arthropods collected at P8 in 2011 was nearly 6 times the number collected there in 2010. The most abundant arthropod was *Americorophium stimpsoni*, accounting for 57% of all arthropods collected.

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 clay. Annelida was by far the dominant phylum in all months (Figure 6), accounting for 86% of all organisms collected. *Limnodrilus hoffmeisteri* and *Varichaetadrilus angustipenis* were the dominant annelids at C9 in 2011, accounting for 39% and 35% of the total annelids collected, respectively. The number of annelids collected at C9 in 2011 was more than three times the number of annelids collected there in 2010.

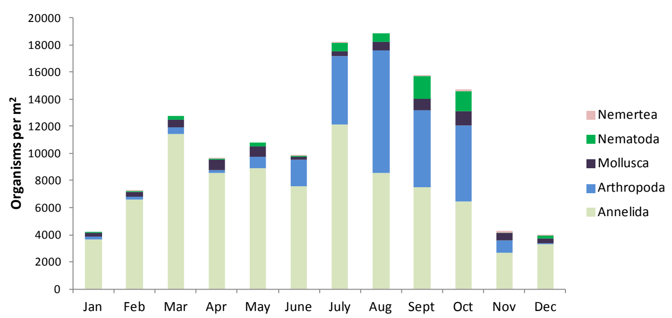

Figure 5 Abundance of benthic organisms, grouped by phyla, collected at station P8 (San Joaquin River at Buckley Cove) by month, 2011

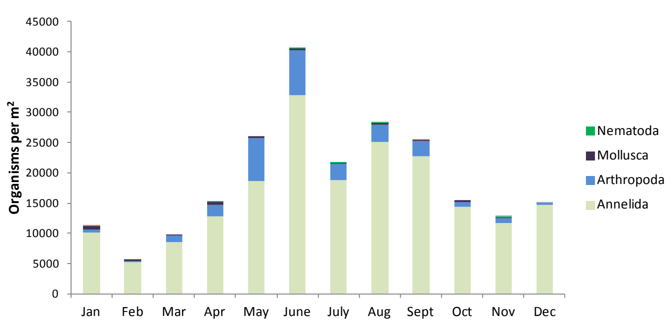

Figure 6 Abundance of benthic organisms, grouped by phyla, collected at station C9 (Clifton Court) by month, 2011. Very rare phyla (defined as fewer than 100 individuals per square meter total for the year) were omitted from this figure.

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 and silt) dominated the sediment sample, though in August the sample was primarily sand. The percent organic matter was greatest in April and September, making up 30-40% of the sediment sample, whereas percent organics ranged from 3-15% in other months. Arthropoda was the most abundant phylum in March and in May-December, accounting for 59% of all organisms collected. Annelida was the most abundant phylum in all other months (Figure 7), and accounted for 34% of all organisms collected. *Americorophium spinicorne* was the most abundant arthropod at this station in 2011 (52% of all arthropods collected), whereas *Varichaetadrilus angustipenis* was the most abundant annelid (64% of all annelids collected).

Suisun Bay (D6 and D7)

The benthic monitoring program samples 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). Mollusca

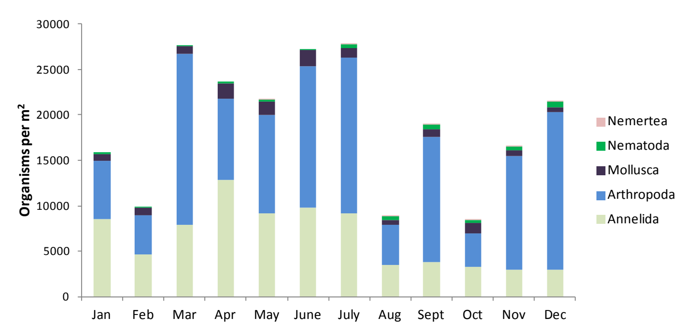

Figure 7 Abundance of benthic organisms, grouped by phyla, collected at station D4 (Confluence) by month, 2011

was by far the dominant phylum in all months at this station (Figure 8), accounting for 88% of all organisms collected. With the exception of one individual, all mollusks collected at D6 in 2011 were *Potamocorbula amurensis*. The number of mollusks at D6 decreased substantially in the summer months, and then increased in fall and winter. The total number of mollusks collected in 2011 at D6 was about 25% lower than those collected there in 2010. A difference in seasonal trends between 2010 and 2011 was noted; far fewer mollusks were collected in the summer and early fall of 2011 than in the summer and early fall of 2010. This trend was likely tied to the extremely high flows in the spring of 2011.

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). Arthropoda was the most abundant phylum in all months except October (Figure 9) and accounted for 75% of organisms collected in 2011. *Corophium alienense* was the dominant arthropod at D7 in 2011, accounting for 75% of arthropods collected.

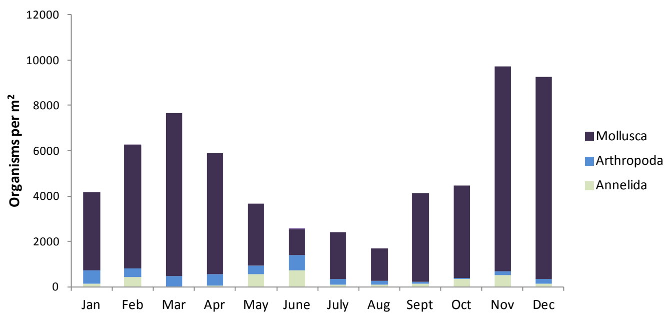

Figure 8 Abundance of benthic organisms, grouped by phyla, collected at station D6 (Suisun Bay) by month, 2011. Very rare phyla (defined as fewer than 100 individuals per square meter total for the year) were omitted from this figure.

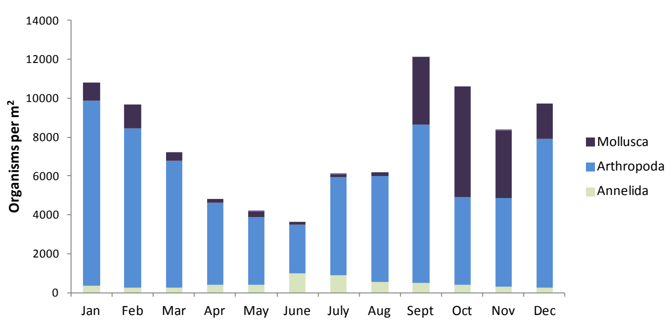

Figure 9 Abundance of benthic organisms, grouped by phyla, collected at station D7 (Grizzly Bay) by month, 2011. Very rare phyla (defined as fewer than 100 individuals per square meter total for the year) were omitted from this figure.

Mollusca (made up almost exclusively of *Potamocorbula amurensis*) was slightly more abundant than Arthropoda in October, and September-December saw substantially increased numbers of mollusks compared to previous months. Overall, however, the number of mollusks collected at D7 in 2011 was one third the number of mollusks collected at D7 in 2010.

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 in most months, accounting for 72% of total organisms collected in 2011 (Figure 10). Arthropoda abundances were particularly high in April, May, August, September and November. The most common arthropod was *Ampelisca abdita* which accounted for 40% of all arthropods collected in 2011, though *Nippoleucon hinumensis* was also fairly abundant, particularly in April and May. In 2010, D41 had an exceptionally high abundance of phoronids in September (11,180 per m^2). Although phoronids were present in a few months in 2011, no month had an abundance of the magnitude found in September 2010.

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-May and November and December was Arthropoda (accounting for 35% of

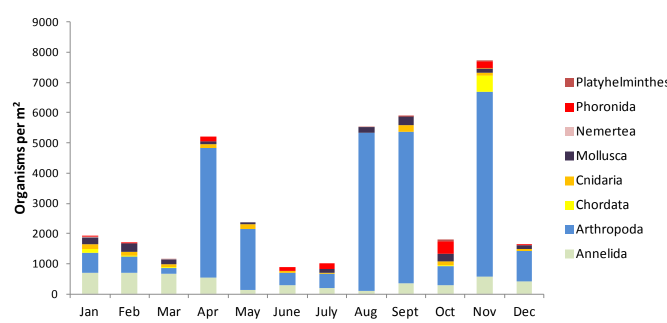

Figure 10 Abundance of benthic organisms, grouped by phyla, collected at station D41 (San Pablo Bay) by month, 2011. Very rare phyla (defined as fewer than 100 individuals per square meter total for the year) were omitted from this figure.

organisms collected in 2011). The dominant arthropod was *Ampelisca abdita* (69% of arthropods collected). Mollusca (almost exclusively *Potamocorbula amurensis*) was by far the most abundant phylum in June through October (Figure 11) at D41A, accounting for 62% of the organisms collected in 2011. Twice as many *Potamocorbula amurensis* were collected in 2011 at D41A as were collected in 2010, and the 2011 average annual abundance of *Potamocorbula amurensis* at D41A (4,976 individuals per m^2) was the highest seen since 2000 (10,600 individuals per m^2).

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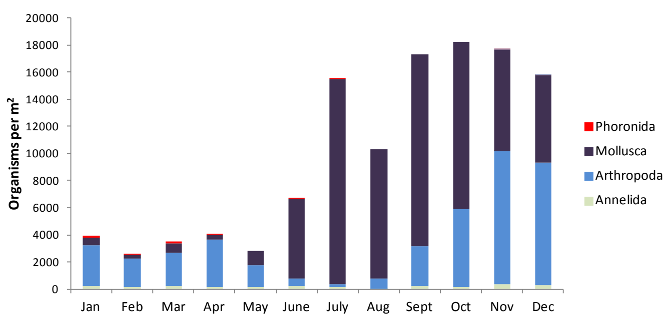

Figure 11 Abundance of benthic organisms, grouped by phyla, collected at station D41A (San Pablo Bay) by month, 2011. Very rare phyla (defined as less than 100 individuals per square meter total for the year) were omitted from this figure.

Juvenile Salmonid Emigration Monitoring in the Sacramento River at Knights Landing

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Introduction

The California Department of Fish and Game (DFG) continues to monitor juvenile anadromous salmonid emigration in the Sacramento River near the town of Knights Landing (RM 89.5) using paired 8-foot rotary screw traps. The project started its 16th consecutive sampling season (Snider and Titus, 1998) on October 6, 2011 and is scheduled to continue through the end of June 2012. The purpose of the project is to help develop information on temporal distribution, composition (race and species), and relative abundance of juvenile Chinook salmon (*Oncorhynchus tshawytscha*) and steelhead trout (*O. mykiss*) emigrating from the upper Sacramento River to the Sacramento-San Joaquin Delta. All naturally spawned (in-river produced and non-adipose fin clipped) fish captured by the rotary screw traps (RST) at Knights Landing are assumed to be produced in the upper Sacramento River and its tributaries, as the sampling site is above the confluence with lower, large tributaries such as the Feather and American rivers.

The upper Sacramento River supports endangered winter-run Chinook salmon and threatened spring-run Chinook salmon. As juveniles of these races move downstream toward the Sacramento-San Joaquin Delta, Knights Landing RSTs collect emigration timing data and provide this information on a real time basis to water management groups and fisheries management agencies. Real time data reporting allows for early warning of protected salmon races moving into the Delta which allows for proper water management strategies such as the closing of the Delta Cross Channel gates to keep juvenile salmonids out of the central Delta, as well as reduction in Delta water exports to limit salmonid entrainment near water export pumping facilities.

Rotary Screw Trap Catch

This report sumarizes the Knights Landing Rotary Screw Trap Program operation for the period of October

6, 2011 through April 24, 2012. The paired, 8-foot RSTs were fished continuously over a 24 hour period, 7 days a week. They were checked by DFG employees for catch on a daily basis during peak salmonid emigration periods. All fish that were caught by the Knights Landing RSTs were identified to species and measured to the nearest fork length in millimeters. Steelhead trout were measured to the nearest millimeter fork length, weighed to the nearest gram, and recorded by stage: alevin, fry, parr, silvery parr or smolt. Chinook salmon data was similarly recorded, but fish were separated by race: fall-run, spring-run, winter-run and late fall-run.

During this reporting period, 13,054 naturally spawned Chinook salmon were sampled by the RSTs at Knights Landing in 8,468.5 hours of trapping. Of these captured Chinook salmon 12,247 (93.8%) were fall-run, 694 (5.3%) were spring-run, 105 (0.8%) were winter-run, and 9 (.06%) were late-fall run. Twelve naturally produced steelhead were also captured during this time.

Hatchery produced salmonids from both Coleman National Fish Hatchery as well as Livingston Stone National Fish Hatchery upstream of Knights Landing were sampled by the RSTs. Coleman Hatchery removed the adipose fin from approximately 25% of their hatchery produced fall-run Chinook salmon, 100% of their late fall-run Chinook salmon and applied a corresponding proportion of coded wire tags (cwt) which provide information on the origin, release date and year-class of each fish. The Livingston Stone Hatchery placed a cwt in every winter-run Chinook salmon and also marked every fish by the removal of the adipose fin. A percentage of adipose clipped Chinook salmon produced by these hatcheries was collected by the Knights Landing RSTs and taken to a DFG laboratory for the extraction and reading of each cwt. So far this sampling season, 68 experimental, hatchery produced late fall-run Chinook salmon and 4 hatchery produced fall-run Chinook salmon were caught by the RSTs. One hundred fifty hatchery produced steelhead trout were also caught. Hatchery steelhead sampled by the RSTs were released back into the Sacramento River after processing.

Salmonid catch rates at the Knights Landing sampling site have been similar to years past, where emigrating salmonids were sampled by the RSTs at a greater rate during periods of increased flows in the Sacramento River. During peak flows, catch rates of salmonids increased, suggesting emigration timing to be correlated with high flow events. This sampling season, there have four significant spikes in flow in the Sacramento River near Knights Landing, which provided four corresponding increases in catch rates of Chinook salmon (Figures 1a, 1b).

Catch rates of Chinook salmon were also greater during periods of increased water turbidity (Figure 2). Nephelometric turbidity units (NTU) were measured at the RSTs on a daily basis during the sampling period. When turbidity increased, emigrating juvenile Chinook salmon were less likely to see the RSTs and avoid entrainment.

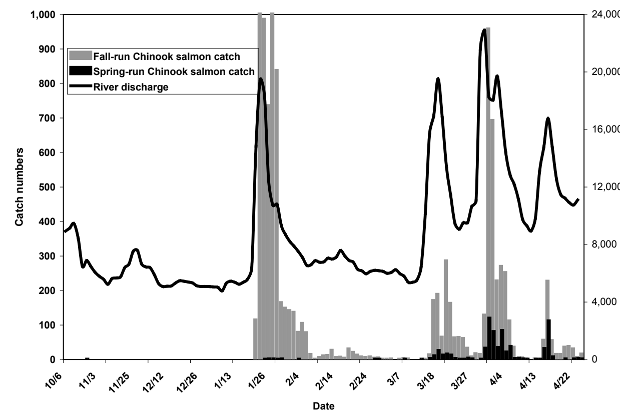

Figure 1a Juvenile fall-run and spring-run Chinook salmon catch by timing with associated river flow, Knights Landing rotary screw traps, Sacramento River, October 6, 2011 through April 24, 2012. Fall-run catch of Chinook salmon on dates January 24 and 27, 2012 totaled 2070 and 1515 respectively.

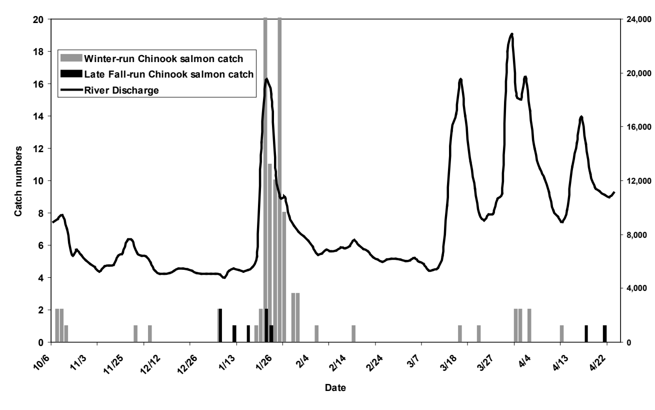

Figure 1b Juvenile winter-run and late fall-run Chinook salmon catch by timing with associated river flow, Knights Landing rotary screw traps, Sacramento River, October 6, 2011 through April 24, 2012. Spring-run catch of Chinook salmon on dates January 24 and 27, 2012 totaled 26 and 21 respectively.

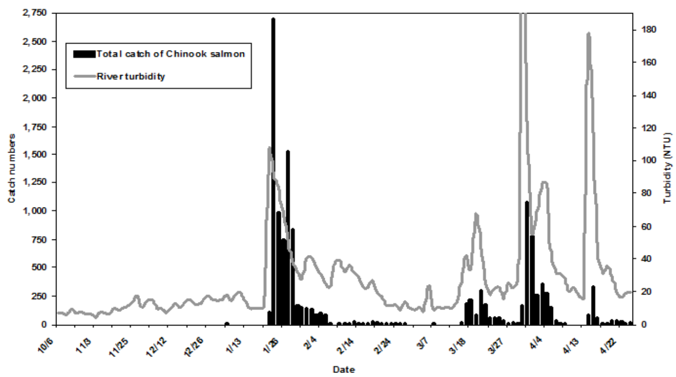

Figure 2 Sacramento River turbidity evaluated at Knights Landing rotary screw traps, measured in nephelometric turbidity units (NTU) and total catch of Chinook salmon including all races: fall-run, spring-run, winter-run and late fall-run, October 6, 2011 through April 24, 2012. The turbidity value on March 30, 2012 was 246.5 NTU.

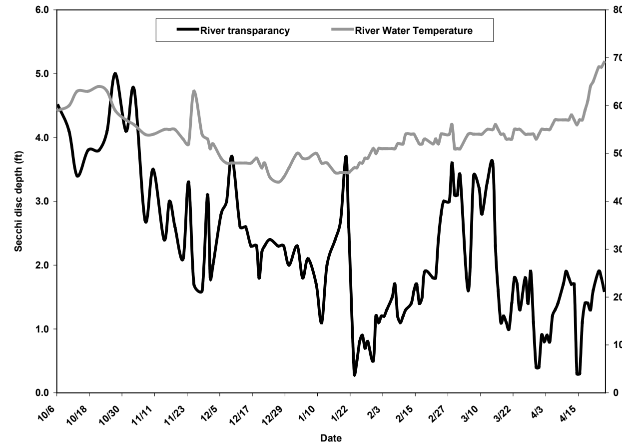

Figure 3 Temperature and water transparancy, measured daily at the rotary screw traping site, near Knights Landing in the Sacramento River, October 6, 2011 through April 24, 2012

Environmental Parameters

During the reporting period, flows in the Sacramento River near Knights Landing, ranged from 4,783 cubic feet per second (cfs) on January 6, 2012 to 22,888 cfs on March 30, 2012 (http://cdec.water.ca.gov[1]). Water temperatures at the sampling site have ranged from 44 degrees Fahrenheit (F) on December 26, 2011 to 68 °F on April 22, 2012. Secchi disk readings at the sampling site have varied between 60 inches of water transparency on October 27, 2011 to 4 inches on April 15, 2012 (Figure 3). Similar to transparancy, turbidity at the RST site has varied, from 4.5 NTU in the early portion of the trapping season on November 3, 2011, to 246.5 NTU on March 30, 2012.

Discussion

A total of 13,054 Chinook salmon have been captured so far this season, which is a sizably greater number in comparison to last season's total sampling effort producing 6,983 Chinook salmon (Vincik, 2011). Ignoring other environmental factors that may influence this dissimilarity, little precipitation this season and corresponding low flows in the Sacramento River compared to last season has contributed to better catch rates. In times of excessive river flow, flood control diversions upstream from Knights Landing (Mouton Weir, Colusa Weir and Tisdale Weir) spill, allowing fish to bypass the sampling site by entering the Sutter Bypass rather than remaining in-river. The Sacramento River only crested the Tisdale Weir on March 29 and 30 this season (http://cdec.water.ca.gov[2]), which would suggest the majority of emigrating salmonids stayed in-river and passed by the sampling site.

The remaining portion of this sampling season (spring-early summer 2012) at Knights Landing should show an increase in the number of captured adipose fin-clipped salmon corresponding with the upcoming annual releases of Chinook salmon from Coleman National Fish Hatchery. Coleman Hatchery will release approximately 12 million fall-run Chinook salmon into Battle Creek, tributary to the Sacramento River, upstream from Knights Landing. The Knights Landing RST project will continue operations until the end of June 2012, or whenever water temperatures exceed 72 °F, or if there is no catch of juvenile salmonids for several days in a row. An annual report produced by DFG describing project results will be produced after the sampling season concludes.

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1 Sacramento River at Wilkins Slough, near Knights Landing flow data from http://cdec.water.ca.gov/river/upsacto3Stages.html

2 Sacramento River at Tisdale Weir stage data from http://cdec.water.ca.gov/cgi-progs/queryF?s=TIS

Central Valley Chinook Salmon Harvest and Escapement

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California Ocean Harvest

The Pacific Fishery Management Council (PFMC) develops ocean harvest regulations to protect federally listed Central Valley winter- and spring-run Chinook salmon. The regulations also meet National Marine Fisheries Service (NMFS) conservation objectives for Sacramento River System and Klamath River fall-run Chinook salmon escapements. The PFMC limited California commercial and recreational ocean fisheries in 2010, and closed the commercial fishery completely in 2008 and 2009, primarily due to the low abundance estimate of Sacramento River fall-run Chinook salmon.

The estimated harvest in California ocean waters was 118,803 Chinook salmon in 2011, more than six times the 29,897 in 2010 (PFMC, 2012). This is the highest since 2007, but 21% of the 40-year average ocean harvest of 564,630 (Figure 1).

California Central Valley Harvest

The California Fish and Game Commission (FGC) develops inland harvest regulations to protect federally listed Central Valley winter- and spring-run Chinook salmon. The regulations also meet NMFS conservation objectives for Sacramento River System fall-run Chinook salmon escapements. The FGC limited Central Valley recreational fisheries from 2008 through 2010, due to the low abundance estimate of Sacramento River fall-run Chinook salmon.

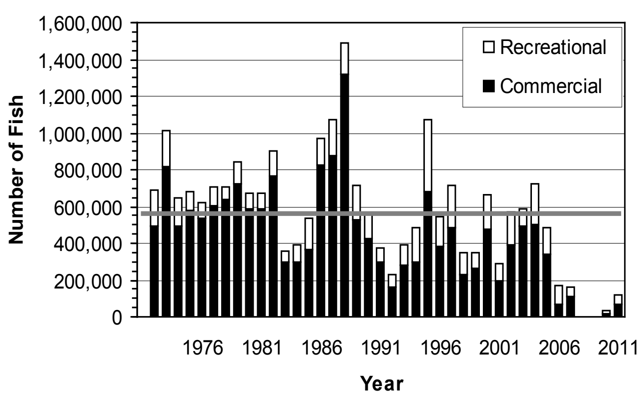

Figure 1 California commercial and recreational Chinook salmon ocean catch from 1972 to 2011, showing the 40 year average (gray line)

The estimated harvest in Central Valley waters was 62,230 Chinook salmon in 2011, nine times the harvest of 6,936 in 2010. The harvest of late-fall run was 1,730 in 2011, only 3% more than the 1,687 in 2010. The harvest of winter-run was again zero in 2011, the same as in 2010. The harvest of spring-run was 140 in 2011, about three times the 43 in 2010. The harvest of Sacramento fall-run was 57,833 in 2011, more than 11 times the 5,050 in 2010. The harvest of San Joaquin fall-run was 2,183 in 2011, about 16 times the 134 Chinook salmon in 2010.

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 2011, the escapement estimate for Chinook salmon returning to hatcheries and natural areas of California's Central Valley was 242,167 fish, the highest since 2006, and 79% of the 40-year average of 306,588 (Figure 2). The late-fall-run escapement was 8,418, the winter-run escapement was 827, the spring-run escapement was 5,033, and the fall-run escapement was 227,889 Chinook salmon.

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 8,418 in 2011, the lowest on record since 1997 and 65% of the 40-year average of 12,922 (Figure 3). Escapement to the Sacramento River was 3,741. Escapement to Battle Creek was 4,677. Most of the late-fall run in Battle Creek were counted at Coleman National Fish Hatchery, where the fish were propagated.

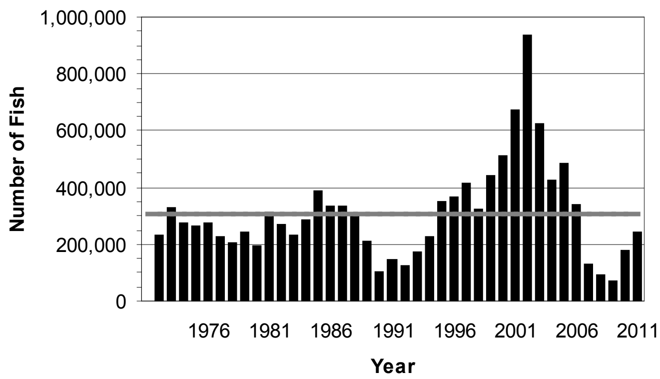

Figure 2 Annual Chinook salmon escapement to the California Central Valley from 1972 to 2011, showing the 40 year average (gray line)

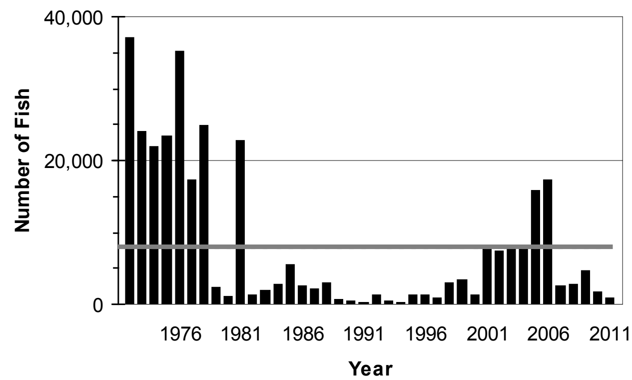

Figure 4 Annual winter-run Chinook salmon escapement to the Sacramento River from 1972 to 2011, showing the 40 year average (gray line)

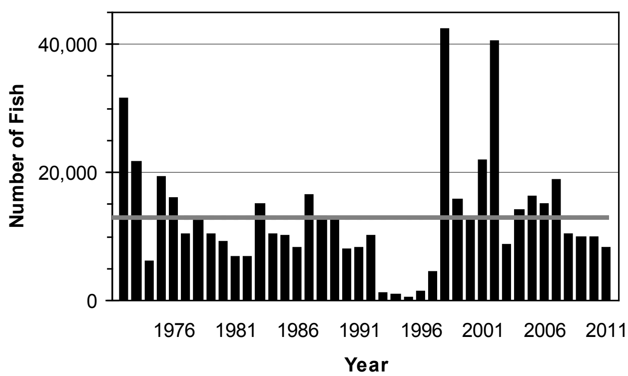

Figure 3 Annual late-fall-run Chinook salmon escapement to the Sacramento River System from 1972 to 2011, showing the 40 year average (gray line)

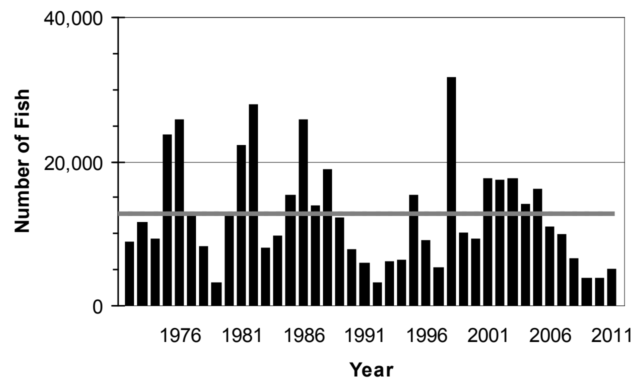

Figure 5 Annual spring-run Chinook salmon escapement to Sacramento River Tributaries from 1972 to 2011, showing the 40 year average (gray line)

Winter-run Escapement to the Sacramento River

The estimated escapement of winter-run Chinook salmon to the Sacramento River was 827 in 2011, the lowest escapement since 1994, and 10% of the 40-year average of 8,010 (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 5,033 in 2011, 133% of the 3,792 in 2010, but 40% of the 40-year average of 12,525 (Figure 5). Most of these fish were from Butte Creek and the Feather River hatcheries, with estimates for these locations of 2,130 and 1,969 Chinook salmon, respectively.

Fall-run Escapement to the Sacramento River System

The estimated escapement of fall-run Chinook salmon to the Sacramento River and its tributaries was 205,096 in 2011, the highest since 2006, but 83% of the 40-year average of 273,100 (Figure 6).

Escapement to the Sacramento River and its tributaries upstream of Red Bluff Diversion Dam (RBDD) was 74,314, 72% of the 40-year average of 103,341 Chinook salmon. Escapement to the Sacramento River and its tributaries between RBDD and Princeton Ferry was 3,227, 14% of the 40-year average of 22,638 Chinook salmon. Escapement to Sacramento River tributaries between Princeton Ferry and Sacramento was 127,555, 99% of the 40-year average of 128,689 Chinook salmon.

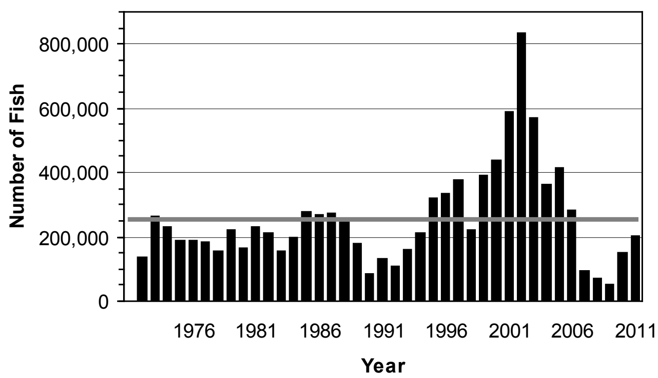

Figure 6 Annual fall-run Chinook salmon escapement to the Sacramento River System from 1972 to 2011, showing the 40 year average (gray line)

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 22,793 in 2011. This is 220% of the 10,358 in 2010, the highest since 2004, and 124% of the 40-year average of 18,432 (Figure 7).

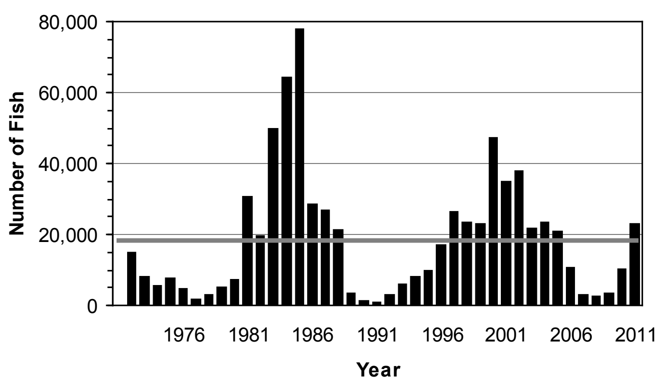

Figure 7 Annual fall-run Chinook salmon escapement to the San Joaquin River system from 1972 to 2011, showing the 40 year average (gray line)

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Burkes, R., CDFG, NCR, personal communication.

Burr, K., Fishery Foundation of California (FFC), personal communication.

Cozart, M., CDFG, San Joaquin Valley and Southern Sierra Region (SJVSSR), personal communication.

Del Real, S., East Bay Municipal Utilities District. Fisheries and Wildlife Division, personal communication.

Garman, C., CDFG, Sacramento Valley and Central Sierra Region (SVCSR), Chico Office, personal communication.

Hartwigsen, K., California Department of Water Resources, Division of Environmental Services, personal communication.

Kastner, A., CDFG, SVCSR, Feather River Hatchery, personal communication.

Kennedy, T., FFC, personal communication.

Killam, D., CDFG, NCR, Sacramento River Salmon and Steelhead Assessment Project (SRSSAP), personal communication.

Mahoney, L., USFWS, RBFWO, personal communication.

Massa, D., Pacific States Marine Fisheries Commission, Yuba River Accord Monitoring and Evaluation, personal communication.

Null, R., USFWS, RBFWO, personal communication.

Phillips, J., CDFG, NCR, personal communication.

Tsao, S., CDFG, SJVSSR, personal communication.

Fall Low Salinity Habitat (FLaSH)

Introduction

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In Fall 2011, a number of studies were implemented by the U.S. Bureau of Reclamation in cooperation with the Interagency Ecological Program to investigate hypotheses about the importance of low salinity habitat (LSH, defined as 1-6 ppt) and its distribution to the ecology of the upper San Francisco Estuary, and specifically the biology of delta smelt. These studies were motivated by a US Fish and Wildlife Service Biological Opinion (BiOp) in 2008 on the operations of the Central Valley Project and State Water Project. The BiOp concluded that aspects of those operations jeopardize the continued existence of delta smelt, a federal and state listed species, and adversely modify delta smelt critical habitat. One component of the BiOp's Reasonable and Prudent Alternative (RPA) called for the adaptive management of fall Delta outflow following "wet" and "above normal" water-years to alleviate jeopardy to delta smelt and adverse modification of delta smelt critical habitat. Specifically, in wet water-years the RPA called for X2 to be located at 74 km during September and October and during above normal water-years to be located at 81 km. These X2 locations increased the amount of LSH and were hypothesized to position it in putatively favorable locations in Suisun Bay as compared to X2 $\geq$ 85 and located in the Delta. IEP agencies and academic collaborators implemented studies in fall 2011 to document habitat, food web and fish responses to the exceptionally high outflow conditions that located X2 at about 75 km during September and October. The BiOp notes that pertinent information from these studies (and those in the future) would then be reviewed to assess the efficacy of the current fall action, and through the adaptive management process, modify it as needed.

Many of the Fall Low Salinity Habitat (FLaSH) studies initiated in fall/winter 2011/2012 focused on delta smelt and its use of LSH in September and October. These studies contrasted habitat, zooplankton and fish measures from LSH with those from Cache Slough/Sacramento Deepwater Ship Channel (CS/SDWSC) region (initial contrast), with the intent of ultimately identifying whether the location of fall LSH, in Suisun Bay or the western Delta, improved delta smelt health, growth or subsequent fecundity and egg quality (ultimate contrast); investigators also examined measures from samples at >6 ppt and < 1 ppt habitats outside LSH and the CS/SDWSC region. As part of the overall study plan, water quality, zooplankton and fish sampling in 2011 began in late August with the Summer Townet Survey and continued through the Fall Midwater Trawl Survey sampling period, September through December (reported here). Additional sampling continued through the winter and spring during Spring Kodiak Trawl sampling period to capture the final measures of delta smelt health, fecundity and egg quality; these results will be reported elsewhere.

In the following section, initial FLaSH results from zooplankton monitoring, fish monitoring and delta smelt diet projects are presented and contrasted with those from 2010 (previous dry year) and 2005 and 2006, the most recent previous dry year/wet year combination. Due to limited time for data analysis and reporting, these contrasts were deemed the most logical and effective. Additional information can be found in the FLaSH report that will be posted to the web late fall 2012.

Fall 2011 Upper San Francisco Estuary Zooplankton

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Introduction

Zooplankton in the upper San Francisco Estuary (SFE) are an important food for larval and juvenile fishes of many species and adults of planktivores, such as delta smelt and threadfin shad. The California Department of Fish and Game's Zooplankton Study has been sampling zooplankton in the upper SFE since 1972 as a means of monitoring abundance and distribution of fish food resources. Recently 2 long-term fish monitoring surveys, the Summer Townet (STN) and Fall Midwater Trawl (FMWT), started zooplankton sampling concurrent with pelagic fish sampling to better assess fish food resources in summer and fall. The 2011 Fall Low Salinity Habitat study or FLaSH, conducted zooplankton sampling in conjunction with the long-term fish monitoring surveys mentioned above as a means to analyze the biotic habitat factor fish food in the low salinity zone (LSZ) in fall. Zooplankton biomass and distribution from 2011, a wet year with relatively high flows in fall, was compared to 2006, another wet year, and to the drier years 2005 and 2010.

Methods

Fall 2011 zooplankton biomass and distribution were reported from zooplankton samples collected by the STN (Figure 1) in August, and the FMWT (Figure 2) September through December. Two gear types were used for collecting zooplankton: 1) a mesozooplankton net targeted zooplankton 0.5-3.0 mm long, including cladocerans, copepodids (immature copepods), and adult copepods; and 2) a macrozooplankton net for sampling zooplankton 1-20 mm long, including mysid shrimp.

Biomass is reported as biomass-per-unit-effort (BPUE) in micrograms of carbon per cubic meter of water sampled. Biomass for copepods and cladocera was calculated from catch-per-unit-effort (CPUE) by multiplying CPUE by carbon weights for each taxon. Current carbon weights for some copepods were provided by Wim Kimmerer of the Romberg-Tiburon Center for Environmental Studies (Kimmerer et al. 2011), while values found in the literature were used for other copepods and cladocera. Mysids biomass was calculated from length-weight equations developed by Jim Orsi at The Department of Fish and Game.

The 2011 zooplankton biomass data were grouped by surface salinity (ppt >6, 1-6, and <1) for most stations and compared to the "Cache Slough/Sacramento Deep Water Ship Channel" (CS/SDWSC) geographical region; CS/SDWSC salinities were always <1. Average monthly biomass for fall 2011 was calculated for each region and salinity group.

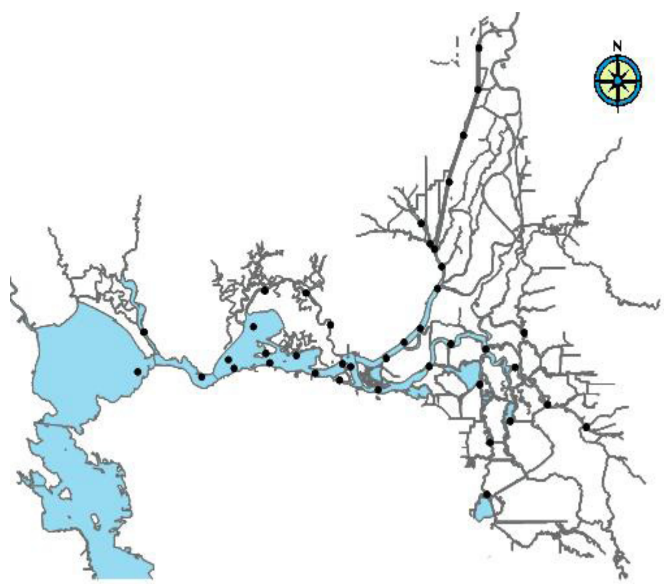

Figure 1 Summer Townet Survey zooplankton station map

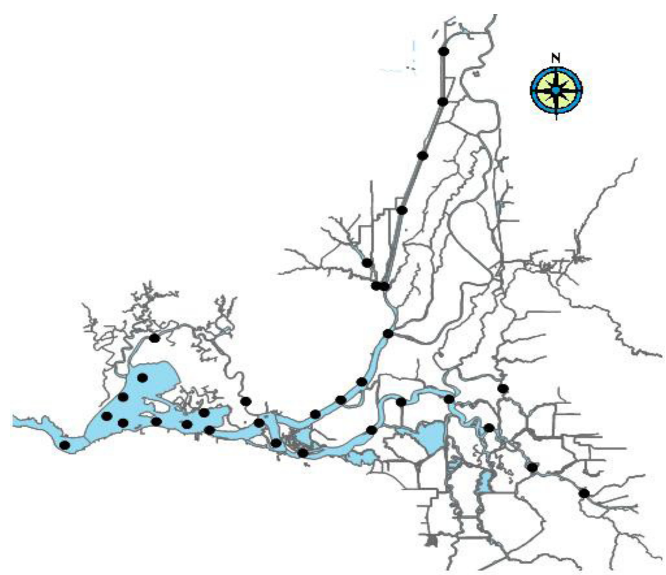

Figure 2 Fall Midwater Trawl zooplankton station map

Interannual comparisons were made using August through December Zooplankton Study (Figure 3) data. Data from core stations (those sampled consistently since study inception) where salinity measurements fit within the LSZ group (1-6 ppt) were used for these comparisons. Total mesozooplankton biomass from the Zooplankton Study was calculated from the total copepod and cladocera (all life stages) biomass at each station. These totals were then averaged by month and year for interannual comparisons.

Copepods

Adult calanoid copepod biomass was highest in 2011 in the CS/SDWSC region from August through November, before dropping off in December (Figure 4). *Pseudodiaptomus forbesi* and *Sinocalanus doerrii* were the most abundant calanoid copepods in the CS/SDWSC area. From September through November 2011 adult calanoid copepod biomass was second highest in the LSZ, where *Acartiella sinensis* was the most abundant species.

Calanoid copepodid (immature copepod) biomass was highest in the CS/SDWSC and freshwater (<1 ppt) areas and lowest in the LSZ in fall 2011, indicating that most successful calanoid copepod reproduction was occurring in upstream areas (Figure 5). Copepodid biomass declined throughout fall and was lowest in December in all areas, except >6 ppt where *Acartia* spp. copepodids were found.

Cyclopoid copepod biomass sampled by the mesozooplankton net was much lower than calanoid copepod biomass in fall 2011 (Figure 6). A small peak in cyclopoid copepod biomass occurred in the LSZ in November 2011 during an algal bloom. However, this peak may not have resulted from a true increase in numbers, but from algae partially clogging the net mesh causing retention of smaller species and life stages such as *Limnoithona tetraspina* and cyclopoid copepods.

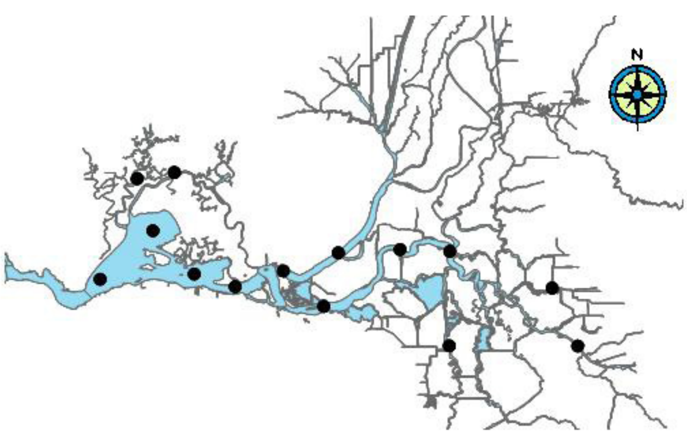

Figure 3 Zooplankton Study map of core stations

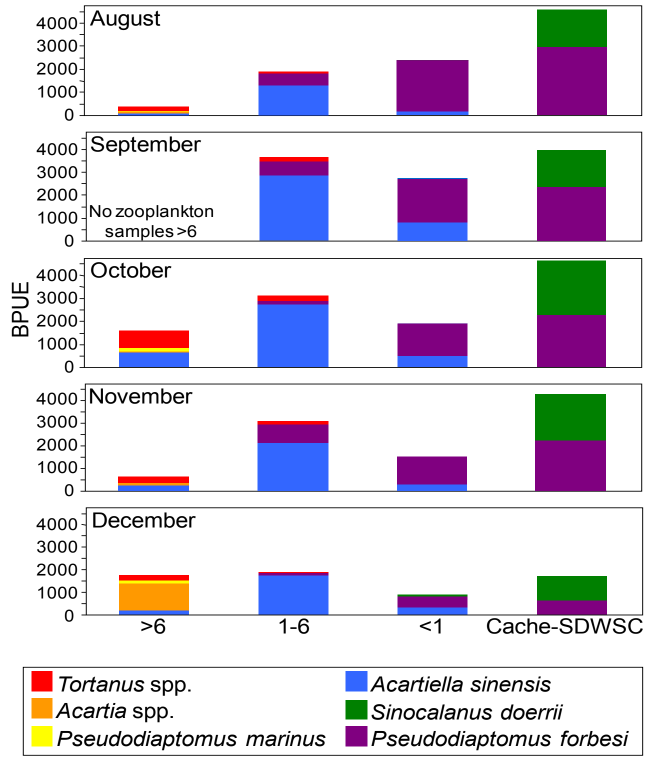

Figure 4 Adult calanoid copepod biomass (mean BPUE in µg of carbon*m^{-3}) August-December 2011

Cladocera

Cladocera biomass in fall 2011 was highest in the CS/SDWSC region in August and declined thereafter (Figure 7). *Diaphanosoma* spp. was the most abundant cladoceran in the CS/SDWSC region from August through October.

Total Mesozooplankton Biomass in LSZ

Mean August through December zooplankton biomass was higher in 2011 than in 2005, 2006, and 2010. When examined on a monthly basis, 2011 LSZ mesozooplankton biomass was higher than those of the comparison years for each respective month, except November 2006 (Figure 8). Over a longer period of comparison, 1990-2011, monthly 2011 LSZ mesozooplankton biomass was higher than in recent years, except for October, which was comparable to recent years (Figure 9). August and September 2011 mesozooplankton biomass in the LSZ was higher than it

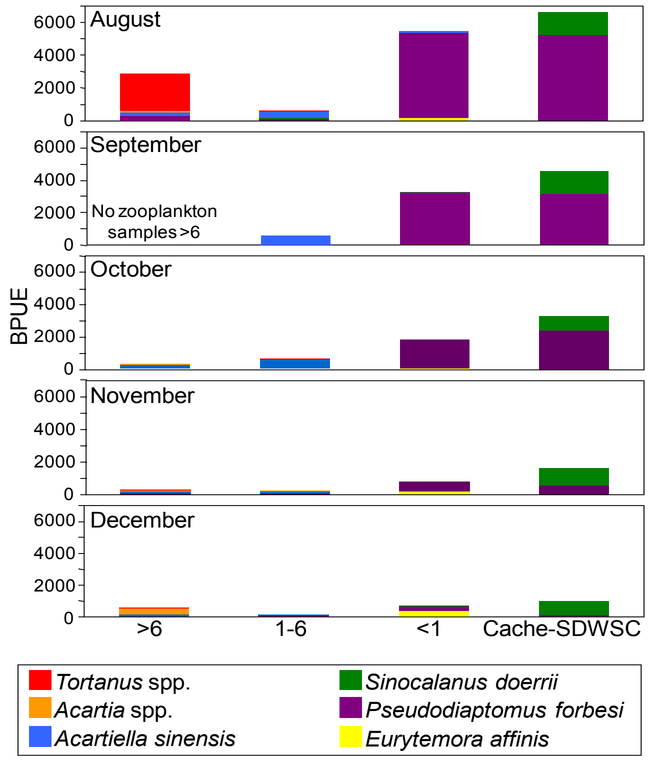

Figure 5 Calanoid copepodid biomass (mean BPUE in µg of carbon*m^{-3}) August- December 2011

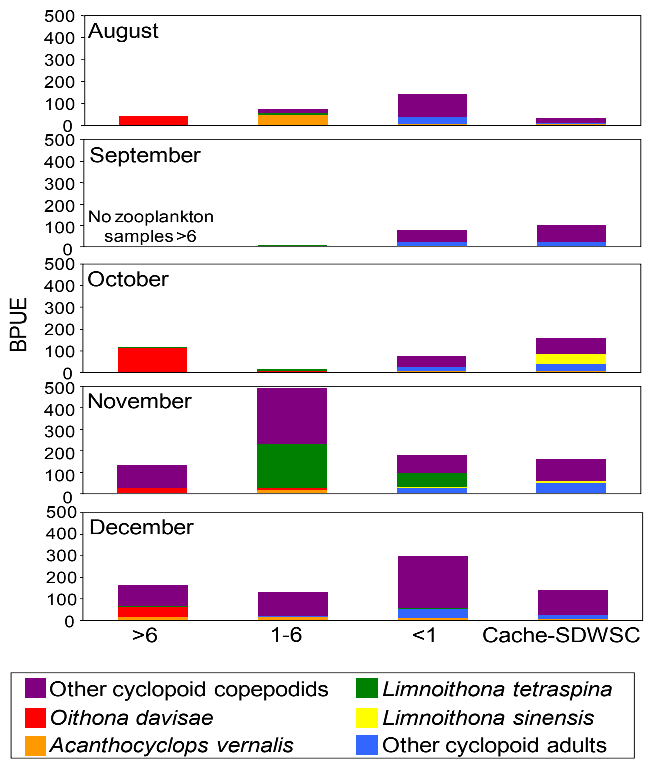

Figure 6 Cyclopoid copepod biomass (mean BPUE in µg of carbon*m^{-3}) August-December 2011

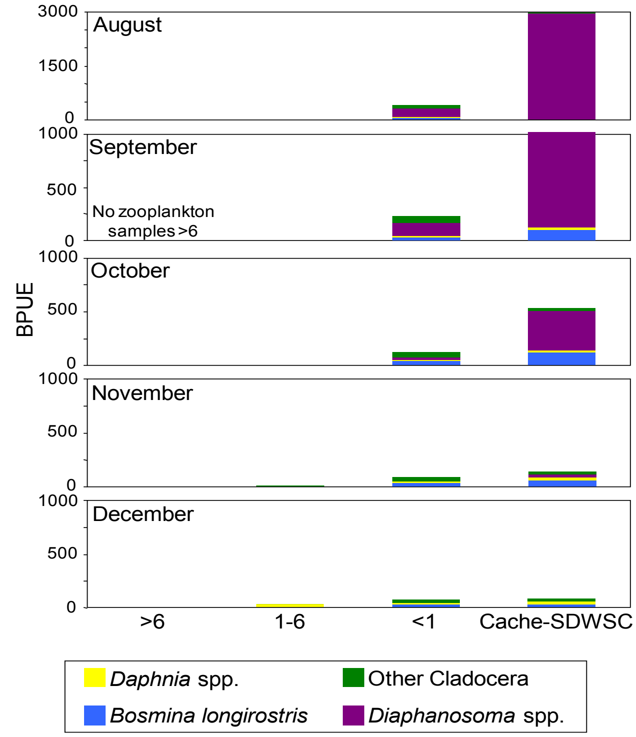

Figure 7 Cladocera biomass (mean BPUE in µg of carbon*m^{-3}) August-December 2011

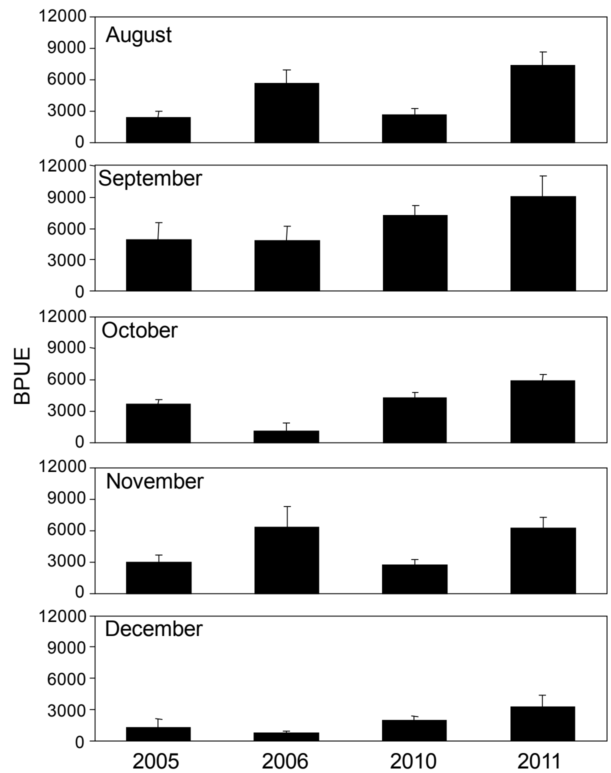

Figure 8 Total mesozooplankton (all life stages of copepods and cladocera) biomass (mean BPUE in µg of carbon*m^{-3}) (+1SE) in the LSZ August-December 2005, 2006, 2010, and 2011

has been since the 1990s. The highest November mesozooplankton biomass in the LSZ coincided with some of the highest outflow years, 1997 (early rainfall and low outflow in fall), 2006, and 2011.

Mysids

Mysids, historically an important prey for upper San Francisco Estuary fishes, have generally declined since monitoring began. Seasonally mysids are usually most abundant in spring and summer, before declining in fall and winter (Hennessy 2011). Mysid biomass in fall 2011 was highest in the CS/SDWSC region in November, when it was more than three times higher than the next highest biomass (Figure 10). *Hyperacanthomysis longirostris* was the most abundant mysid in every salinity zone and region in 2011, although very small numbers of other mysids were also present. Compared monthly, August and September 2011 mysid biomass in the LSZ was not higher than 2005, 2006, and 2010, while October through December 2011 mysid biomass was higher than in the comparison years (Figure 11). Over a longer period of comparison, 1990-2011, although mysid biomass in the LSZ was slightly higher in 2011 than in recent years, it was still much lower than the 1990s (Figure 12).

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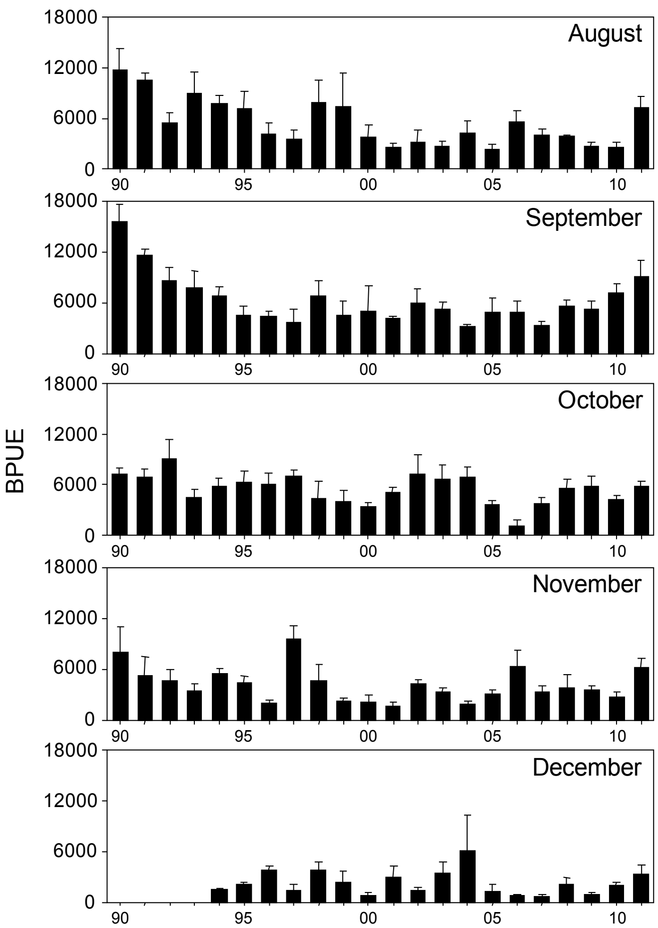

Figure 9 Total mesozooplankton (all life stages of copepods and cladocera) biomass (mean BPUE in µg of carbon*m^{-3}) (+1SE) in the LSZ August-December 1990-2011

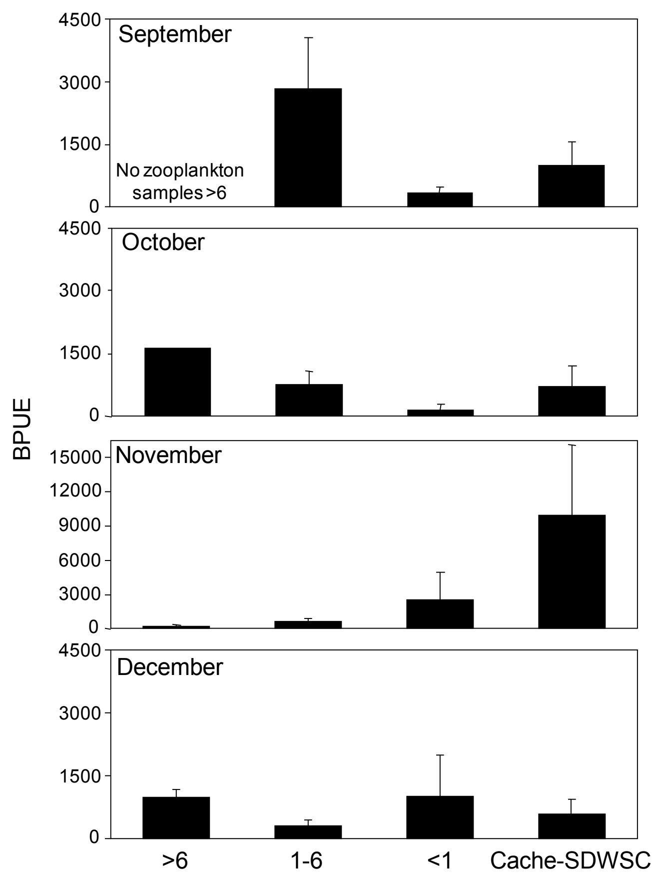

Figure 10 Mysid biomass (mean BPUE in µg of carbon*m^{-3}) (+1SE) September-December 2011

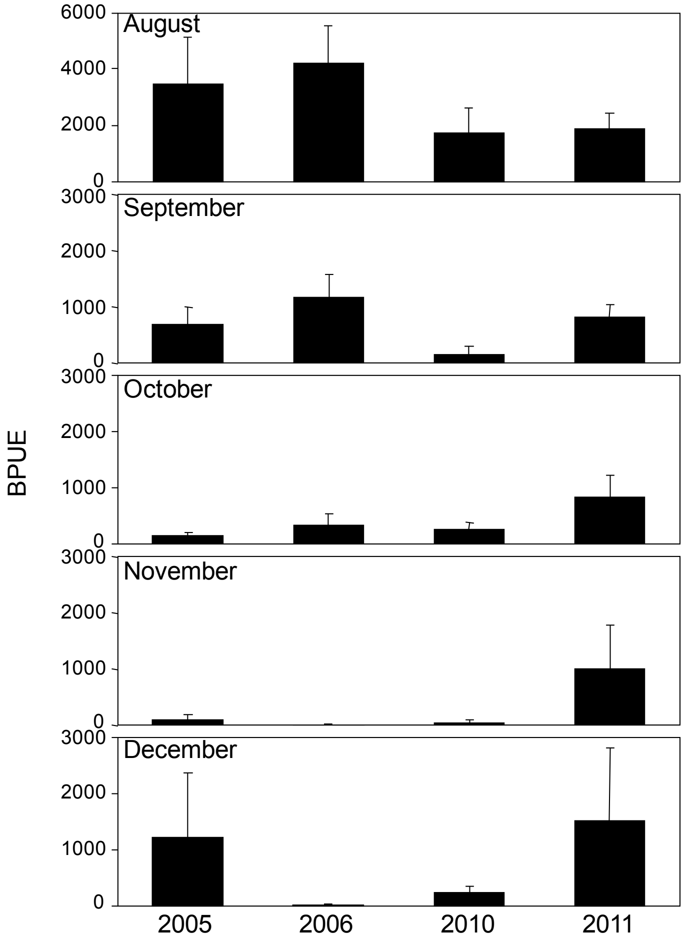

Figure 11 Mysid biomass (mean mBPUE in µg of carbon*m^{-3}) (+1SE) in the LSZ August-December 2005, 2006, 2010, and 2011

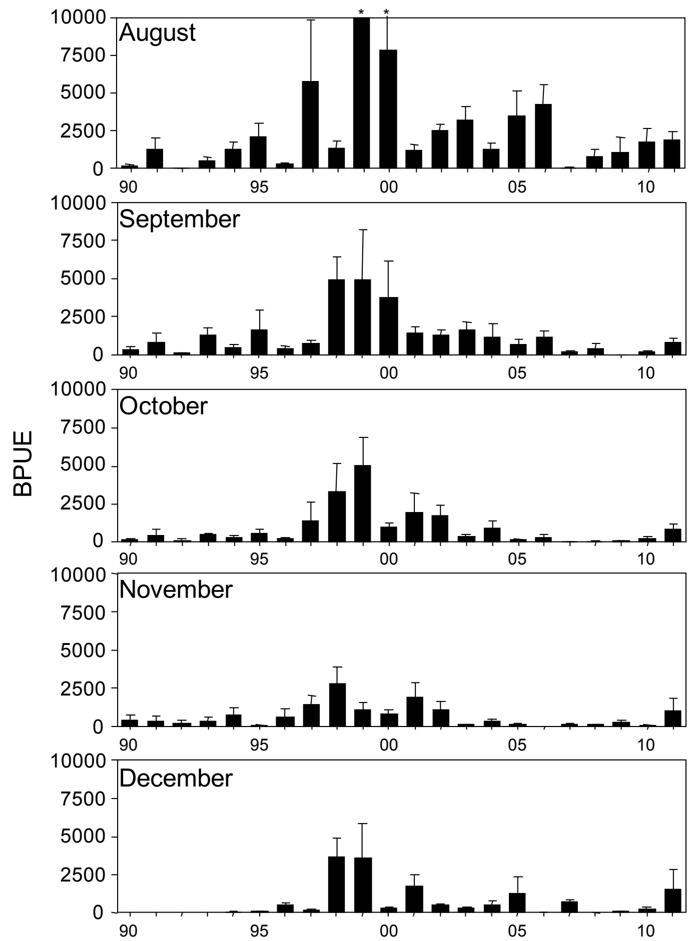

Figure 12 Mysid biomass (mean BPUE in µg of carbon*m^{-3}) (+1 SE) in the LSZ August through December 1990-2011. *August 1999 mean 26,995 with standard error 22,593, and August 2000 standard error 4,787.

2011 Status and Trends Report for Pelagic Fishes of the Upper San Francisco Estuary

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Introduction

The 2011 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 20mm 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).

The low salinity zone, defined as 1-6 ppt, is believed to provide crucial habitat for delta smelt in autumn, and may also be important to other pelagic fishes as the interface between salt and fresh water tends to be particularly nutrient rich. The Fall Low Salinity Habitat (FLaSH) studies were initiated in fall 2011 to comply with the Delta Smelt Biological Opinion (USFWS 2008), and to investigate whether the location of the low salinity zone affected September and October rearing conditions for delta smelt. The low salinity zone in fall runs from Suisun Bay in wet years, to the lower Sacramento and San Joaquin rivers in dry years, When low salinity habitat occurs downstream in Suisun Bay it is thought to be more beneficial to rearing conditions than when it occurs upstream in the Sacramento and San Joaquin rivers. As the low salinity zone can only occur in one place at a time, we could not compare location directly. Therefore, we used the Cache Slough/ Sacramento Deep Water Ship Channel (CS/SDWSC) region as a constant for comparison to low salinity habitat in both wet and dry years. To further evaluate the benefit of Suisun Bay as the low salinity zone, we also examined delta smelt health and diet. Since no additional delta smelt take could result from FLaSH studies, fishes collected by the STN and FMWT were individually preserved in liquid nitrogen to assess health, diet, and condition (see Delta Smelt Regional Feeding Patterns in Fall 2011, Slater, this issue). Finally, to further support FLaSH findings, we chose to also examine young of the year American shad, which remain relatively abundant and may therefore evidence the importance of low salinity habitat more readily, threadfin shad, which were once abundant in freshwater, and young of the year striped bass, which have historically co-occurred with delta smelt. Abundance trends and distribution patterns for these 4 species were examined by salinity zone: <1, 1-6, and >6 ppt and compared to abundance and distribution values for the CS/SDWSC region.

Methods

Abundance and Abundance vs Outflow

We will now briefly discuss the methods for the 4 studies that contribute to our report on the pelagic fishes listed in the introduction. The 20mm 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 2011. Three tows are completed at each of the 48 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 SDWSC. The survey name comes from the size (20 mm) that the survey gear targets, which corresponds to when delta smelt are readily identifiable and counted at the State Water Project and Central Valley Project fish facilities.

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.

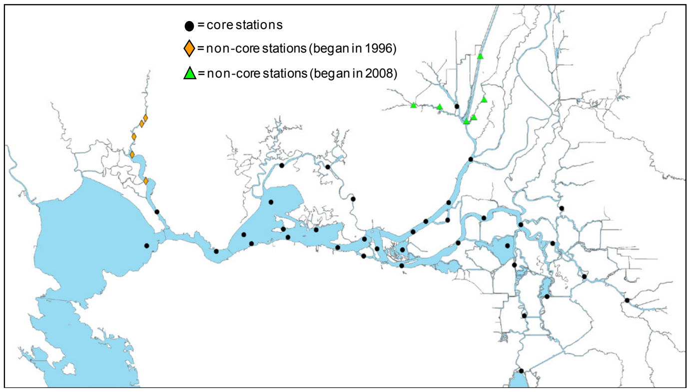

Figure 1 20mm Survey station map

The Summer Townet Survey began in 1959. The data has 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 (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, CDFG 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 CS/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 CS/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 38.1mm 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.

The Fall Midwater Trawl Survey began in 1967. Surveys have been conducted annually in all years, except for 1974 and 1979. The California Department of Fish and Game (CDFG) established the FMWT survey to examine age-0 striped bass mortality by determining their 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 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.

Since 1994, USFWS has conducted beach seine sampling weekly at approximately 40 stations in the Delta

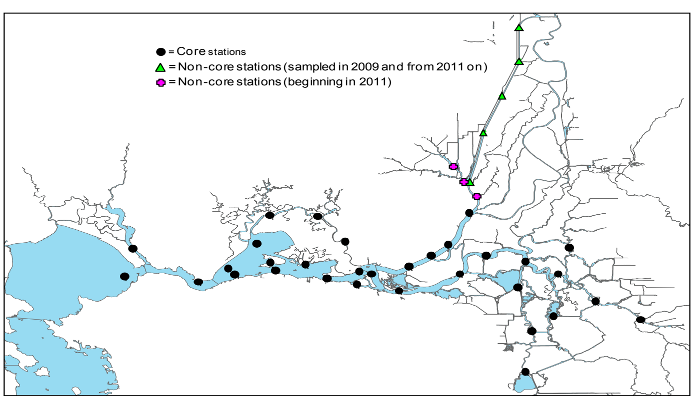

Figure 2 Summer Townet Survey station map

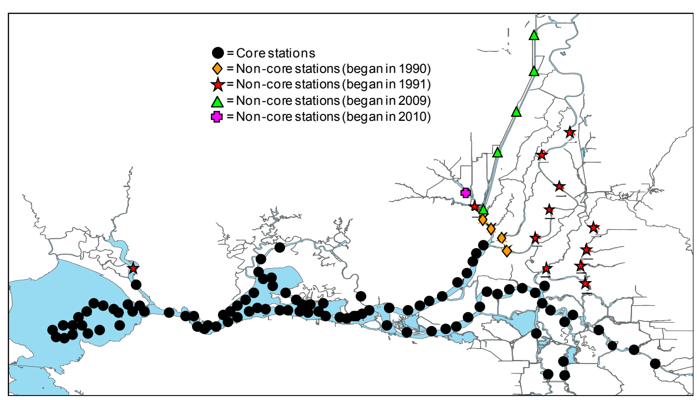

Figure 3 Fall Midwater Trawl Survey station map

and the Sacramento and San Joaquin rivers (Brandes and McLain 2001). 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, and to just downstream of the Tuolumne River confluence (hereafter referred to as the Tuolumne confluence) on the San Joaquin River, are used to calculate the annual age-0 splittail abundance index. Stations are grouped into 10 regions, and the annual index is calculated as the sum of regional mean catch per seine haul for May and June sampling. For graphical presentation, rather than showing each regional contribution, the regions were grouped and summed in 3 categories – 5 regions in the Delta, 3 in the Sacramento River, and 2 in the San Joaquin River – that recognize their contributions to the overall index.

Many upper estuary fish species increase in abundance with increased freshwater flows through the estuary (Stevens and Miller 1983, Jassby et al. 1995, Kimmerer 2002). We examined outflow effects on abundance by log transforming species annual abundance indices and mean outflow measures, which were derived by grouping flow data from a critical seasonal period in each species' life. We then regressed abundance on outflow. Although the exact mechanism(s) behind this relationship remains unknown, it could be influenced by any or all of the following factors: 1) an increase in low salinity habitat, 2) greater dispersal and transportation of larvae and juveniles to favorable habitat, 3) stimulation of the food web, resulting in an increased food supply, or 4) reduction in predation and other top down effects. Delta outflow data, reported as daily outflow in cubic feet per second (cfs) at Chipps Island, was acquired from the Department of Water Resources Dayflow database. It is available online at: http://www.water.ca.gov/dayflow/.

Longfin smelt and American shad especially demonstrated a direct relationship between outflow and abundance (Sommer et al. 2007). For these species, daily outflow values were averaged by month, then averaged again for a series of months representing important periods in their respective life histories. The outflow means and abundance indices were $\log_{10}$ transformed. The transformed abundance indices were then regressed on the transformed outflow means and plotted. We present abundance versus outflow plots divided into three important time periods: the years leading up to the establishment of *Potamocorbula amurensis* in the estuary in 1988, the years after 1988 establishment, and the last decade. These plots jointly depict how the relationship between outflow and abundance has changed over time.

We used data sets from the STN and FMWT surveys to describe abundance trends and distribution patterns for a subset of the upper estuary pelagic fishes: American shad, threadfin shad, delta smelt, and age-0 striped bass, as part of the FLaSH studies. These studies focused on delta smelt and its use of low salinity habitat (1-6 ppt) in September and October in contrast with use of the CS/SDWSC region, with the intent of identifying whether increases in fall low salinity habitat improve delta smelt health, growth, or subsequent fecundity and egg quality (USFWS 2011). As part of the overall study plan, sampling in 2011 began in late August with STN and continued through the fall period with FMWT sampling (reported here) and into the winter and spring with Spring Kodiak Trawl sampling to capture the final measures of health, fecundity, and egg quality to be reported elsewhere.

Salinity Distributions

The FLaSH studies focused on 1-6 ppt salinity range and contrasted it with salinities above and below, as well as habitat in the upstream CS/SDWSC region. Therefore, STN and FMWT stations were categorized into 3 downstream salinity groups (<1, 1-6, and >6 based on the surface specific conductance) and 2 regions: CS/SDWSC and all other downstream station locations (Other). During portions of this paper region "Other" will be discussed in general geographic terms (i.e., San Pablo Bay, etc.). For all survey data presented, the salinity in CS/SDWSC remained <1 ppt.

To evaluate abundance and distribution by salinity, STN survey 6 (second survey in August) catch was summed for delta smelt and age-0 striped bass for each salinity group and CS/SDWSC. FMWT Catch Per Unit Effort (CPUE = (catch/tow volume)*10,000) for American shad, threadfin shad, delta smelt, and age-0 striped bass was calculated for each station. The CPUE was then averaged across September through December for each salinity group and CS/SDWSC and plotted.

Water year 2011 was wet and had high outflows into fall, resulting in a large low salinity zone located in Suisun Bay. We compared general geographic and salinity distributions of fishes from this year with the most recent previous wet year, 2006 and the two preceding dry years, 2005 and 2010.

December Mean Lengths

Size attained at the end of the first growth period is important to winter survival of many fishes, and is related to delta smelt fecundity (see Bennett 2005). To assess end of the year size, December mean lengths for the FMWT were plotted for years 1975, 1977, 1978, 1980-2011. December mean length was chosen as this is when delta smelt are largest and most susceptible to gear retention. The end of the year age-0 striped bass mean length is also presented.

Apparent Growth

Length frequency data was compiled for delta smelt and age-0 striped bass. Fish were measured in the field in millimeters (mm) fork length (FL), up to 50 per species per tow. When only a portion of the species total catch was measured, an adjusted length frequency was calculated by multiplying the frequency at each length by the quotient of the total catch divided by the total measured.

Apparent growth was calculated for delta smelt and age-0 striped bass using only FMWT length data. For each species, fork lengths for each survey were grouped by 3mm intervals and analyzed in FiSAT II to derive monthly means using the NORMSEP method. For each species, these monthly mean lengths were assigned to the survey date of greatest catch, then regressed on calendar day for each year to obtain a daily growth rate (slope of the relationship) from September through December. When mean FL for a given month was greater than the following month or did not follow general growth trends (sometimes the case when few fish were caught), that month was removed from the regression. Regression results were only reported for years with at least three acceptable data points.

Results

American shad

American shad were 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 2011 FMWT American shad (all ages) index was 1.3 times greater than in 2010, but only 39% of the 2006 index, and 51% of the 2005 index (Figure 4). 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 2011, but from September through November were most common from the CS/SDWSC downstream through Suisun Bay. By December, American shad catches had decreased; 70% of this reduced catch was downstream from the Confluence.

Over all fall months (Sept-Dec) in 2005, 2006, 2010, and 2011 American shad were most numerous in the CS/SDWSC region (Figure 5). However, they were well dispersed throughout the estuary as they migrated to the ocean. Outside the CS/SDWSC region, American shad were mostly found at <1 ppt in 2005 and 2006, at >6 ppt in 2010, and at 1-6 ppt in 2011 (Figure 5). Generally, American shad densities decreased as salinity increased.

The American shad index increased from 2010 to 2011; however abundance remained relatively low. This was surprising, given the high spring outflow of 2011. American shad abundance has been directly related to delta outflow during the spring spawning and early rearing period of April through June (Figure 6; Stevens and Miller 1983). For unknown reasons this relationship became

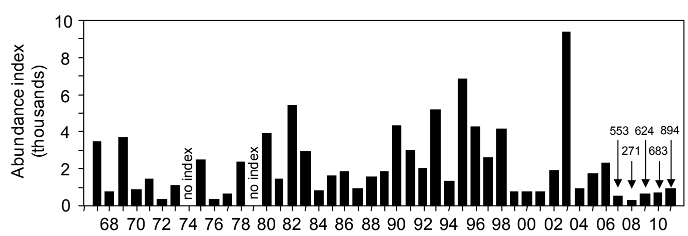

Figure 4 Annual abundance indices of American shad (all sizes) from the Fall Midwater Trawl Survey, 1967-2011

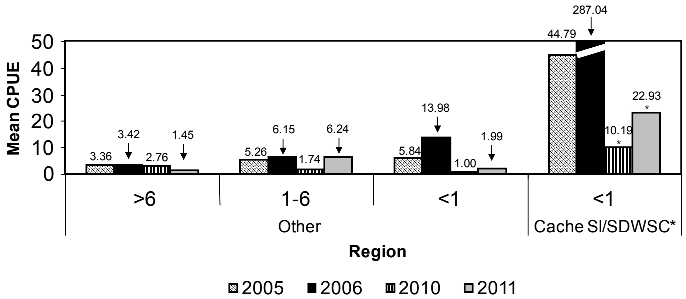

Figure 5 Fall Midwater Trawl American shad (all ages) mean September through December CPUE by salinity group and region for FLaSH years 2005-2006 and 2010-2011

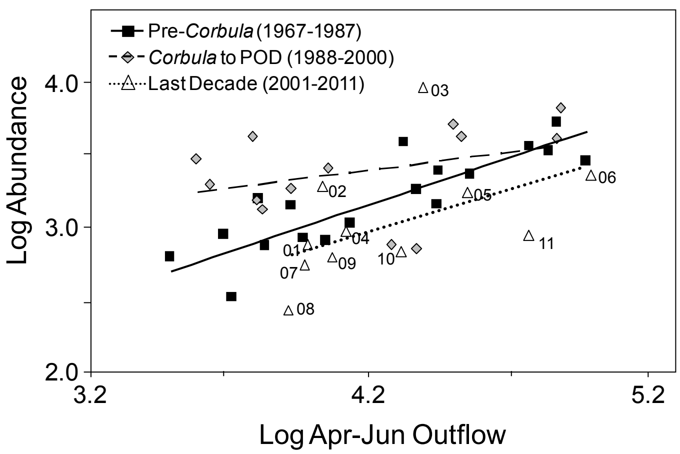

Figure 6 Fall Midwater Trawl Survey American shad (all ages) abundance index vs. mean April through June outflow relationships pre-Potamocorbula amurensis introduction (1967-1987, solid line), post-Potamocorbula amurensis introduction (1988-2000, dashed line), and recent years including the pelagic organism decline period (2001-2011, dotted line). Abundance and outflow data were $\log_{10}$ transformed. Regression from 1988-2000 was significant (P<0.05).

stronger after the introduction of the overbite clam, *Potamocorbula amurensis*, in the late 1980s (Kimmerer 2002). During the last decade (2001-2011) abundance has been more variable and has responded more dramatically to changes in outflow (Figure 6). However, since 2006, the American shad abundances have been lower than expected for the given flows.

Threadfin Shad

Threadfin shad were introduced to reservoirs in the watersheds of the Sacramento and San Joaquin rivers in the late 1950s and quickly became established in the Delta. Although they're found throughout the estuary, 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 2011 FMWT threadfin shad (all ages) index was 1.9 times the 2010 index, but only 10% of the 2006 index, and 8% of the 2005 index (Figure 7). Since 2002, shad abundance has been below the study period mean, but demonstrated a slight upward trend through 2007 before dropping off precipitously in 2008 and remaining extremely low since due to poor catches in the San Joaquin River.

In 2005, threadfin shad were most common in <1 ppt (Figure 8), particularly in the south Delta (data not presented), but catch there has since dwindled to a few fish. More recent trends show that the majority of catch occurs upstream in the CS/SDWSC region (Figure 8). In 2006 and 2010, threadfin shad catch was high in CS/SDWSC (Figure 8). Threadfin shad were sparse from Suisun Bay through the lower San Joaquin River and South Delta, from September through December in 2011, but remained common in CS/SDWSC. By December, their distribution had expanded downstream into San Pablo Bay.

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

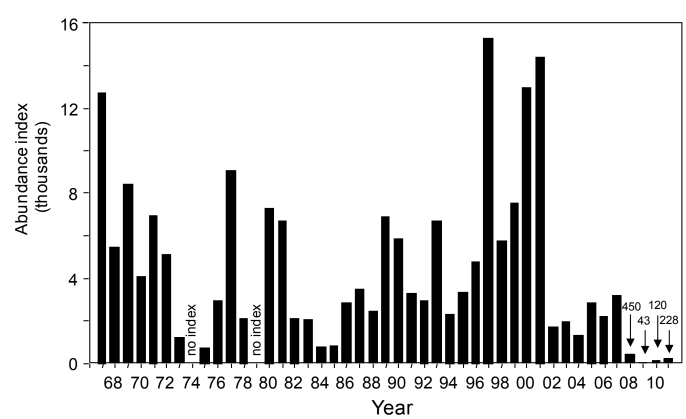

Figure 7 Annual abundance indices of threadfin shad (all sizes) from the Fall Midwater Trawl Survey, 1967-2011

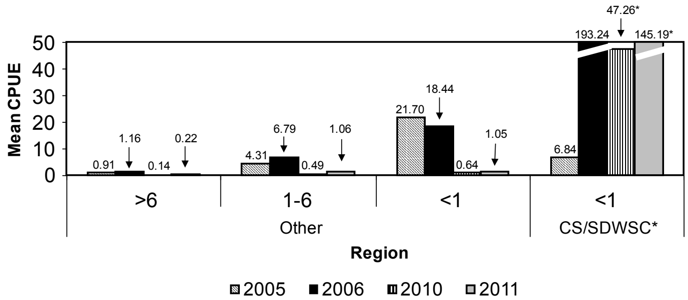

Figure 8 Fall Midwater Trawl threadfin shad (all ages) mean September through December CPUE by salinity group and region for FLaSH years 2005-2006 and 2010-2011

because they typically live for 1 year, reside primarily in the interface between salt and fresh water and possess low fecundity. It was thought they had a limited diet, but that is no longer the case (see Slater in this issue). In addition, females have low fecundity and only produce 1,200 to 2,600 eggs on average (Moyle et al. 1992). This low fecundity may be partially offset by the ability of some females to produce more than 1 batch of eggs per spawning season (Bennett 2005).

The 2011 20mm Survey delta smelt index increased by 2.1 times from 2010 (Figure 9A). This makes the 2011 index the highest on record since 2006. The 20mm Survey began in March; delta smelt larvae were already present in the lower Sacramento River. By the end of April, delta smelt catches were highest in the Napa River, but also occurred in Suisun Bay and the SDWSC, and to a lesser extent in San Pablo Bay, the Confluence, and Lindsey and Cache sloughs. This pattern of larval delta smelt catch continued through mid-May, and the distribution expanded into the lower Sacramento River. During the later part of May through June, catches were highest in Suisun Bay, although catches continued to a lesser extent in the Napa River, the SDWSC, and Lindsey Slough, and from the Confluence through Cache Slough. By July, catch was still highest at Suisun Bay, with a continued presence of delta smelt from the Confluence through the SDWSC and Cache Slough.

The 2011 STN age-0 delta smelt index was 2.8 times that of 2010 (Figure 9B); it was also a 5.5 fold increase from 2006, and 7.3 times the 2005 index. Like 20mm, the STN 2011 index was the highest since 2004, but remains low compared to the majority of indices recorded for the survey. Delta smelt catch in 2011 was comparable in June (surveys 1&2, n = 351) and July (surveys 3&4, n = 324), but declined in August (surveys 5&6, n = 113). Delta

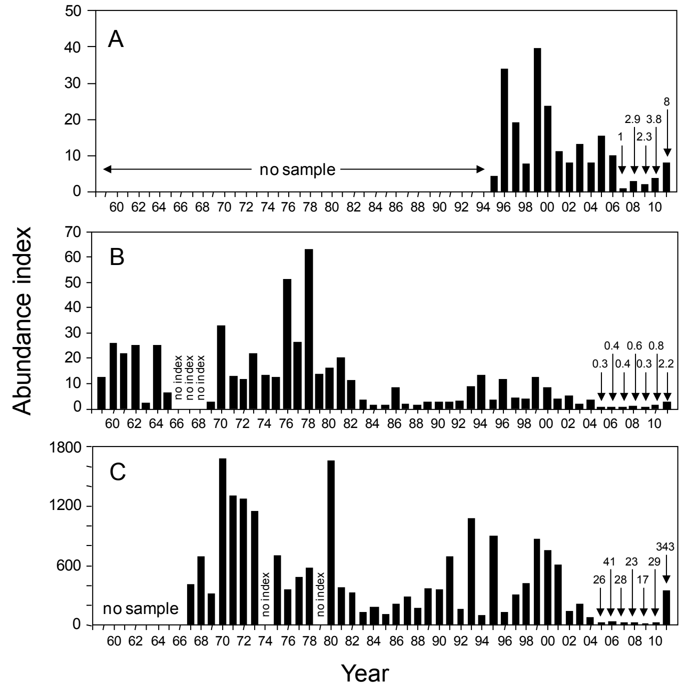

Figure 9 Annual abundance indices of delta smelt from: A) 20mm Survey (larvae and juveniles, 1995-2011), B) Summer Townet Survey (juveniles, 1959-2011), C) Fall Midwater Trawl Survey (subadults, 1967-2011)

smelt catch was greatest in Suisun Bay and Cache Slough in June. In July and August, catch was highest in Suisun Bay, with lesser catches in the CS/SDWSC.

As STN survey 6 occurs at the end of summer, it was used as a precursor to FLaSH. Catch in 2011 (n = 70) was concentrated CS/SDWSC (n = 42), and to a lesser extent in the low salinity waters of Suisun Bay (n = 24). These numbers were strongly affected by a relatively high catch of 38 delta smelt in Cache Slough. Catches in 2006 (n = 5) and 2010 (n = 5) occurred in <1 ppt in the lower Sacramento River and in low salinity habitat in Suisun Bay. In 2005 they were captured in salinities <1 ppt in the Lower Sacramento River (n = 4) and > 6 ppt in Suisun Bay (n = 22). The CS/SDWSC regions were not sampled in 2005, 2006, or 2010.

The 2011 FMWT delta smelt index was 11.8 times the 2010 index, 8.4 times the 2006 index, and 13.2 times the 2005 index. This makes the 2011 FMWT delta smelt index the highest in a decade (Figure 9C). During September in 2011, delta smelt were collected from Carquinez Strait through the Confluence and Cache Slough. In October, they were collected in Suisun Bay, the Confluence, and Cache Slough. By November, they were caught in the SDWSC, persisted in the Confluence, and reappeared in Carquinez Strait. In December, smelt were collected from Suisun Bay through SDWSC and in the San Joaquin River. A large catch (n=109) in the lower Sacramento River drastically increased the year's index. The 2011 geographic distribution did not differ much from years 2005, 2006, and 2010, as smelt appeared to be centrally located from Suisun Bay through the lower Sacramento River. In addition, they were consistently present in the CS/SDWSC region, except during 2006.

In the low outflow year 2005, delta smelt were most common at Cache Slough but were also common in low salinity habitat (Figure 10). In the wet year 2006, smelt were most common at low salinities, but present in the other salinity ranges, although none were caught in the CS/SDWSC region. During the low outflow year 2010, they were most common in the CS/SDWSC region, but were also caught downstream at all salinity ranges. During the high outflow year of 2011, delta smelt were slightly more numerous in the <1 ppt zone than in 1-6 ppt habitat (Figure 10). This was due to the aforementioned single large catch in December, which occurred slightly upstream of the 1-6 ppt range. Smelt were also common in the CS/SDWSC region, in contrast to 2006 when none were collected. Generally, smelt were most consistently caught in CS/SDWSC region or low salinity habitat (Figure 10).

The 2011 mean December fork length of delta smelt was lower than 2010, but higher than 2005 or 2006 (Figure 11). Mean December FL from 1975-1988 is higher than the following years (Figure 11). The mean December FL may be lower after 1988 due to food competition from the overbite clam, *Potamocorbula amurensis*, which was first detected in 1986 (Kimmerer et al. 1994).

Growth rates of delta smelt from September through December have fluctuated through time. The overall mean

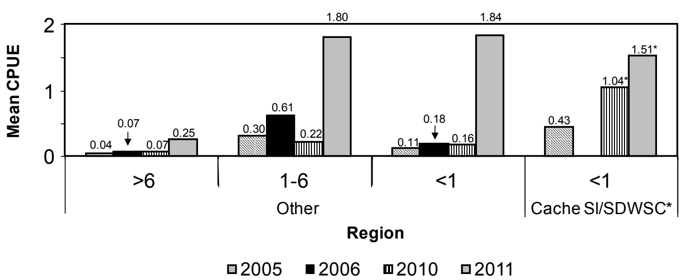

Figure 10 Fall Midwater Trawl delta smelt (all ages) mean September through December CPUE by salinity group and region for FLaSH years 2005-2006 and 2010-2011

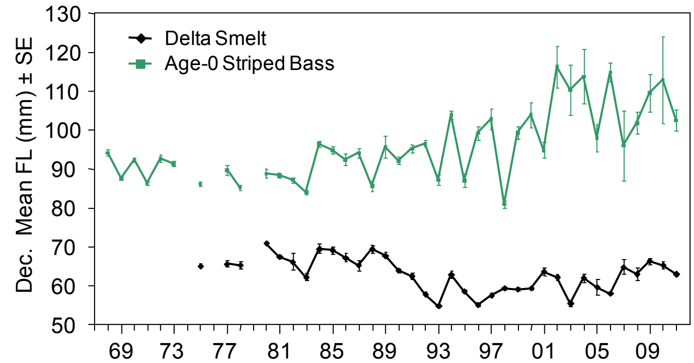

Figure 11 Fall Midwater Trawl delta smelt and age-0 striped bass mean December fork lengths (± 1 SE)

growth rate was about 0.10 mm/day (Figure 12). The 2011 apparent growth rate, at 0.12 mm/day, was among the highest in a decade and slightly above the overall average. It was the same growth rate in 2006 (0.12 mm/day) and higher than the 2010 (0.09 mm/day) growth rate. No growth rate was calculated for 2005 because mean fork length for each month did not follow a clear growing pattern.

Longfin smelt

Longfin smelt are short-lived, anadromous fish that spawn in freshwater in winter and spring and rear 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). A strong positive relationship between longfin smelt abundance and winter-spring outflow has long been observed (Stevens and Miller 1983).

Longfin smelt diet once contained a high proportion of the mysid, *Neomysis mercedis* (Feyrer et al. 2003). However, *N. Mercredis* has only been a fraction of the diet since it experienced a precipitous decline, coinciding with the 1987 establishment of *P. amurensis*. After losing one of their main food sources, longfin smelt abundance also dropped off. The declines of *N. mercedis* and longfin smelt mirror declines in phytoplankton and zooplankton, which Kimmerer attributed to grazing by *P. amurensis* (2002). Siegfried and Kopache (1980) found that *Neomysis* spp. feed primarily on diatoms, rotifers, and copepods, food resources shared with *P. amurensis* (Kimmerer

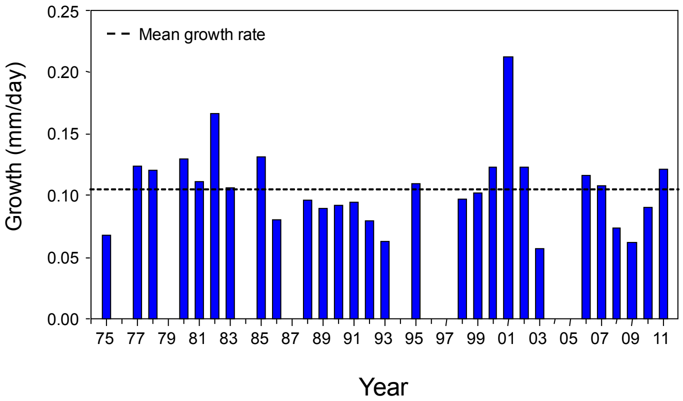

Figure 12 Fall Midwater Trawl delta smelt apparent growth rates (mm/day) based on September through December data. Dotted line represents the mean apparent growth rate for all years

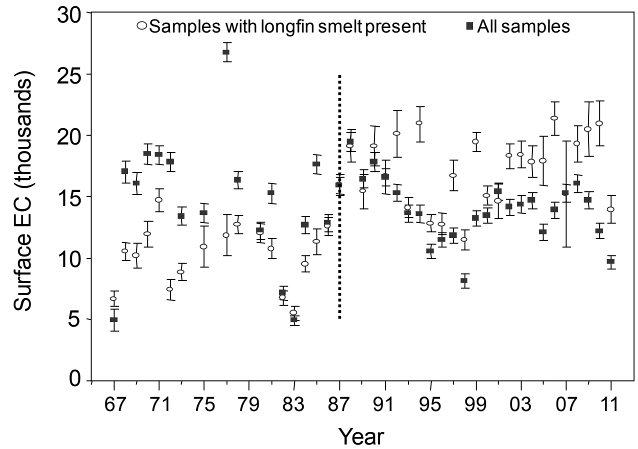

Figure 13 Fall Midwater Trawl Survey mean (±1 SD) surface water electrical conductivity (EC) for samples with longfin smelt present (open circles) and all samples (black squares). Dotted line represents the year P. amurensis was discovered.

and Orsi 1996). It is therefore thought that *N. mercedis* declined due to food competition from *P. amurensis* (Kimmerer and Orsi 1996). Beginning in 1989, longfin smelt relocated to relatively higher salinity waters, presumably to find food sources less impacted by *P. amurensis* (Figure 13). This pattern remained consistent through 2011 and was similar to the recent downstream shift in northern anchovy (*Engraulis mordax*) distribution reported by Kimmerer (2006), who argued that competition for food with *P. amurensis* explained the shift.

The 2011 FMWT longfin smelt abundance index for all ages increased by 2.5 times from 2010 (Figure 14). We had relatively low catches of longfin smelt in September (n = 28) and October (n = 13) in San Pablo and Suisun bays, as well as in Carquinez Strait (September only). Catch then increased in November (n = 74) as longfin smelt began emigrating upstream to spawn. By November longfin smelt ranged from San Pablo and Suisun bays through the lower Sacramento and San Joaquin rivers. In December catch increased substantially (n = 217), and distribution expanded into the SDWSC, although longfin smelt remained most concentrated in and around Suisun Bay.

The 2011 FMWT longfin smelt abundance index increased in response to high winter/spring outflows in 2011 (Figure 14). However, the FMWT longfin smelt abundance-outflow relationship shifted downward after the introduction of *P. amurensis* and again during the last decade, 2001-2011 (Figure 15). The 2011 index was lower than expected given the high winter/spring outflow, and may be partially attributed to the relatively weak 2009-year class, parents of the 2011-year class. Mac Nally et

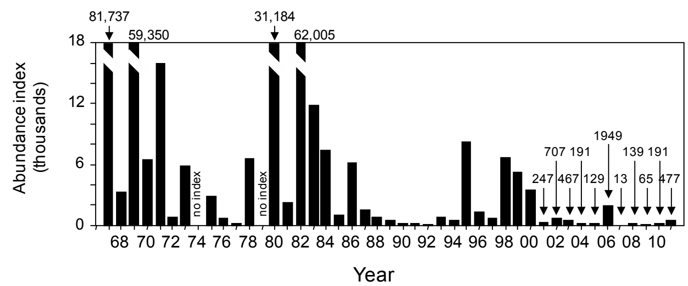

Figure 14 Annual abundance indices of longfin smelt (all sizes) from the Fall Midwater Trawl Survey, 1967-2011

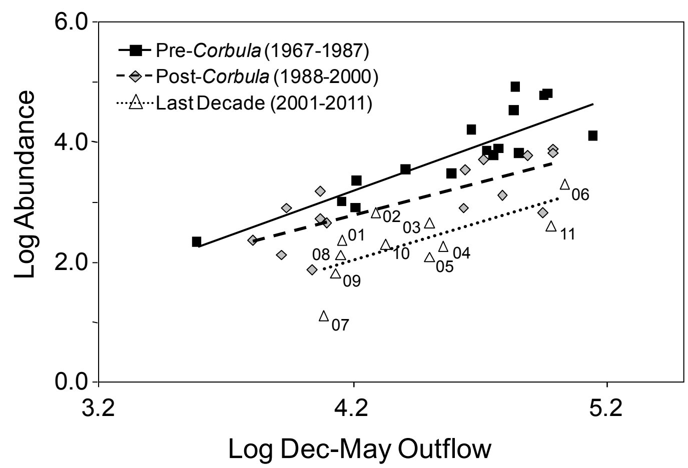

Figure 15 Fall Midwater Trawl Survey longfin smelt (all sizes) abundance index vs. mean December through May outflow relationships for pre-Potamocorbula amurensis introduction (1967-1987, solid line), post-Potamocorbula amurensis introduction (1988-2000, dashed line), and pelagic organism decline years (2001-2011, dotted line). Abundance and outflow data was log_{10} transformed. Regression from 1967-1987 was significant (P<0.05).

al. (2010) described the FMWT longfin smelt abundance trend as a long-term decline punctuated by abundance increases associated with high outflow periods. They also detected that abundance was most significantly influenced by outflow.

Wakasagi

Wakasagi were 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 35 wakasagi, more than half of them in 2011 in the CS/SDWSC region, coincident with expansion of trawling in that region. In 2009, 7 wakasagi were captured, 4 at new SDWSC stations and the rest at historic stations in the upper estuary. The SDWSC was not sampled in 2010, and no wakasagi were caught at any stations. In 2011, 23 wakasagi were collected: 2 in Montezuma Slough and the rest from newly implemented stations at Cache Slough and SDWSC (Table 1).

Few wakasagi have been caught (n = 43) by the FMWT survey through 2011. Prior to 2009, wakasagi were collected sporadically (n = 9) in Grizzly Bay, Montezuma Slough, and the lower Sacramento River (Table 2). Starting in 2009, the FMWT began to consistently sample the CS/SDWSC region and the region produced consistent low catches of wakasagi each year; catches have been less consistent elsewhere (Table 2). In 2011, wakasagi were found in salinities of less than 1.2 ppt, but in temperatures ranging from 9.1ºC to 25.5ºC; at the upper temperature range marginally above delta smelt tolerance (Swanson et al., 2000).

Splittail

Splittail are endemic to the San Francisco Estuary and its watershed. Adults migrate upstream during increased

Table 1 Summer Townet Survey wakasagi total catch 1959 to 2011 (regions where no wakasagi were caught removed)

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

Table 2 Fall Midwater Trawl Survey wakasagi catch from index stations occurring from 1967 to 2011 (regions where no wakasagi were caught removed)

Year	*Suisun Bay*	*Confluence*	*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

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, Consumnes, Napa and Petaluma rivers, as well as Butte 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 current trawl sampling areas.

The 2011 splittail age-0 beach seine index (USFWS data) was about 5.5 times the 2010 index and set a new record (Figure 16A). Recent abundance has been low (e.g., 2007-2009) with very little contribution from the San Joaquin River; however decent San Joaquin River spring runoff in 2010 and very good runoff in 2011 were reflected in substantially improved abundance from the river (Figure 16A). Unlike the FMWT, the beach seine detected some recruitment in all sampling years (Figure 16). In many low outflow years (e.g., 2001, 2003, 2007-2009) the Sacramento River contributed a higher proportion of the abundance index than in other years.

The 2011 FMWT splittail (all ages) index increased to 15 (Figure 16B). All splittail were caught in September at Carquinez strait and Suisun Bay. Although the splittail index increased, it should be noted this is due to catching just a few fish (n = 10). Recent splittail indices have been low, and it is not uncommon to catch only 1 or 2 fish during the entire survey year. However, these 2011 increases in the USFWS and FMWT indices coincide with a record high salvage of splittail at the Tracy Fish Collection Facility and near record high salvage at the Skinner Delta Fish Protective Facility (Aasen, 2012). Together these indices reflect both good floodplain inundation in the Sacramento and San Joaquin rivers and an increase in the abundance of mysids (see Hennessey in this issue). Other than detritus, mysids are an important food source for splittail in fall (Feyrer et al. 2002).

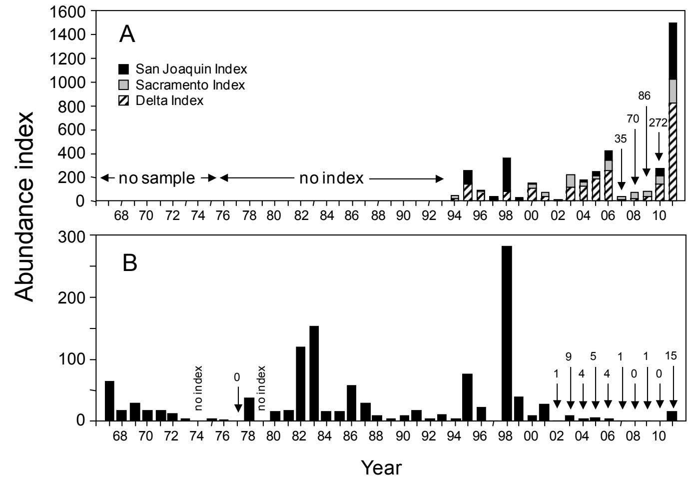

Figure 16 Annual abundance indices of splittail from: A) USFWS beach seine (juveniles), 1994-2011; B) Fall Midwater Trawl Survey (all sizes), 1967-2011

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 near-shore ocean, and migrate up rivers to spawn in spring. Juveniles rear in the fresh and brackish waters of the estuary. The population of legal-size fish in the San Francisco Estuary declined during the late 1970s and remained low until 1995 when it inexplicably increased, peaking in 2000 (Figure 17). Since the abundances for year 2004, 2005, and 2007 remain provisional, it is too early to tell whether the decline observed after 2000 was interrupted by a brief increase in 2004 (Figure 17). The most recent population estimate is low (Figure 17).

Age-0 striped bass abundance began to decline in the mid-1970s if not sooner (Figure 18). STN and FMWT indices declined in the late 1990s, and again early 2000s; indices have remained low since (Figure 18) despite a

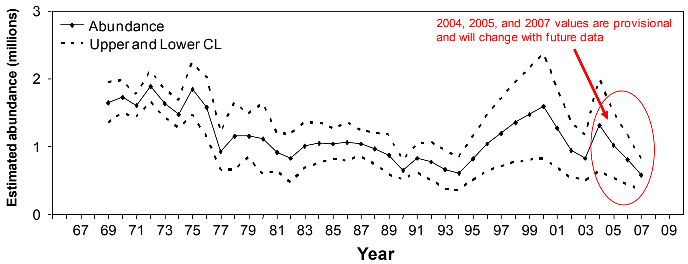

Figure 17 Estimated Abundance of Striped Bass Age ≥ 3 in the San Francisco Estuary from DFG Mark-Recapture Data. Note: values for 1995, 1997, 1999, 2001, and 2006 are mean of estimates from the immediate previous and following year.

putative recovery in the adult population. However, spring adult sampling has shown females comprised only a small proportion of the spawning run (~10%) since the early 1990s (Jason DuBois, personal communication 2008). Such low female numbers likely contributed to the low juvenile abundance indices. 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 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. Based on our understanding of the factors controlling striped bass abundance in the estuary, the adult population increases leading up to 2000 and again in 2004 were unexpected and remain unexplained. UC Davis researchers, in collaboration with IEP Biologists, are experimenting with population models to examine many of these issues.

For FLaSH, we compared abundance, distribution and apparent growth rates for striped bass in the high outflow year 2011 with the last wet year, 2006 and the two preceding dry years, 2005 and 2010. The 2011 STN age-0 striped bass 38.1-mm index was 1.7 times that of 2010, but still low compared to historical values (Figure 18A). The index was 5.2 times that of 2006, and 2.9 times that of 2005. This year's index was set during surveys 5 and 6 in August. Catch of striped bass juveniles peaked at over 1000 fish in early July, and then dropped over the course of the survey to a late August catch of 32 fish. In June, most fish were caught in Suisun Bay, with the highest catches occurring in Montezuma Slough. This trend

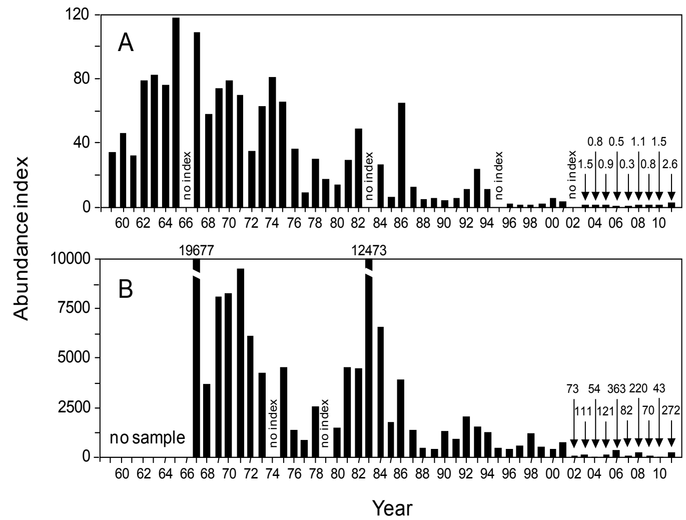

Figure 18 Annual abundance indices of age-0 striped bass from: A) Summer Townet, 1959-2011; B) Fall Midwater Trawl Survey, 1967-2011

continued through August, with occasional large catches in Grizzly Bay, the lower Sacramento River and Montezuma Slough. Only 2 age-0 striped bass were caught in the lower San Joaquin River over the course of the field season.

STN survey 6 total catch in 2006 was similar to 2011, however the distribution varied between the two years (not shown in Figure). In 2006, survey 6 catch was concentrated at <1 ppt in the lower Sacramento River (n = 15) and in low salinity waters in Suisun Bay and the Confluence (n = 19). During 2011, no striped bass were caught during survey 6 in the Sacramento River, just like the previous year. Catch was still concentrated in the low salinity waters of Suisun Bay (n = 22), with 1 fish caught at low salinity in the Confluence. Striped bass were also collected in the CS/SDWSC region (n = 8). Both 2005 and 2010 were dryer years with lower survey 6 catch (n = 11 & 12, respectively) than the wetter years that immediately followed. In these dryer years, striped bass were mainly caught at low salinity in Suisun Bay (n = 6 and 10, respectively). In 2005, striped bass were also collected at <1 ppt in the lower Sacramento River (n = 2) and at >6 ppt in Suisun Bay (n = 3). In 2010, two fish were caught at <1 ppt in the lower San Joaquin River.

The 2011 FMWT age-0 striped bass index was 6.3 times greater than in 2010 index, 74% of the 2006 index, and 2.2 times the 2005 index. Although this was a substantial increase from last year's index, it remains low when compared to the historical record (Figure 18B). In September, bass were collected from Carquinez Strait up through Cache Slough. By October, their distribution had contracted, and they were only collected in Suisun Bay and the Confluence. In the two subsequent months, their distribution expanded west to San Pablo Bay, northwards up the SDWSC and east up the lower San Joaquin River; they left the last of these in December.

Age-0 striped bass were most common in FMWT sampling in Suisun Bay, but also found from San Pablo Bay through the lower Sacramento River during all years presented. During 2005 and 2006, they were also distributed in Cache Slough, the lower San Joaquin River, and the south Delta. They may have been present in the CS/SDWSC, but that region was not sampled in 2005 and 2006. In 2010, they were distributed in SDWSC and south Delta and in 2011 they were caught in Cache Slough, SDWSC, and lower San Joaquin River.

In 2005, age-0 striped bass were slightly more common from San Pablo Bay through Suisun Bay in salinities greater than 6 ppt (Figure 19). They were also found at salinities below 1 ppt within the Delta and Cache Slough. In 2006, bass were most common in the low salinity habitat (1-6 ppt) in Suisun Bay and the Confluence (Figure 19). They were also common in higher salinities (>6 ppt) in San Pablo Bay, Carquinez Strait, and Suisun Bay. In 2010, age-0 striped bass were most common in salinities above 6 ppt (Figure 19). They were also found below 1 ppt in the Delta and the CS/SDWSC region. In 2011, striped bass were most common in low salinity habitat, but were also captured in the other salinity ranges, including the CS/SDWSC region (Figure 19). Age-0 striped bass were most common in salinities above 6 ppt during low outflow years. During high outflow years bass were most common in the low salinity habitat.

Age-0 striped bass year-end mean lengths have fluctuated but generally increased throughout the study period and most substantially during the 2000s when abundance was very low (Figure 11). The 2011 mean December striped bass fork length was lower than the 2006 and 2010 means, but higher than that of 2005.

Apparent growth rates of age-0 striped bass have fluctuated though time (Figure 20). The 2011 apparent growth rate was 0.27 mm/day and slightly above the mean growth rate and similar rates for 2006 (0.31mm/day) and 2010 (0.28mm/day). The 2005 growth rate was 0.18mm/day, the lowest of the decade (Figure 20).

Conclusion

All pelagic fish abundance indices reported increased in 2011, but remained low compared to historical abundance indices. These increases were most likely caused by factors associated with the increased outflow in 2011. To further examine how pelagic fishes, especially delta smelt, use their habitat, 20mm, STN, and FMWT expanded sampling into the Cache Slough and SDWSC region beginning in 2008 (20mm), 2009 (FMWT; STN temporarily) and 2011 (STN continuous). These areas provided habitat and substantial catches for several pelagic species. Specifically, delta smelt and wakasagi catches in the CS/SDWSC region were relatively high during the 2011 STN survey, accounting for almost 40% of the total delta smelt catch and 15 of the 23 wakasagi collected. American and threadfin shad were also abundant in the region, with 21% and 96%, of their total respective STN catches occurring in this region. The 2011 FMWT survey collected relatively fewer delta smelt in the CS/SDWSC region, only 9% of the total catch; however, these non-index stations continued to produce relatively high catches of American shad

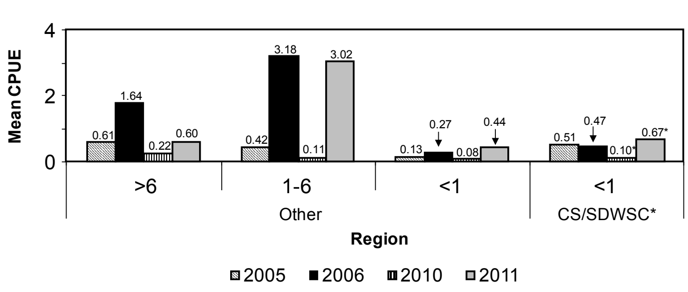

Figure 19 Fall Midwater Trawl age-0 striped bass mean CPUE by salinity group for FLaSH years 2005-2006 and 2010-2011

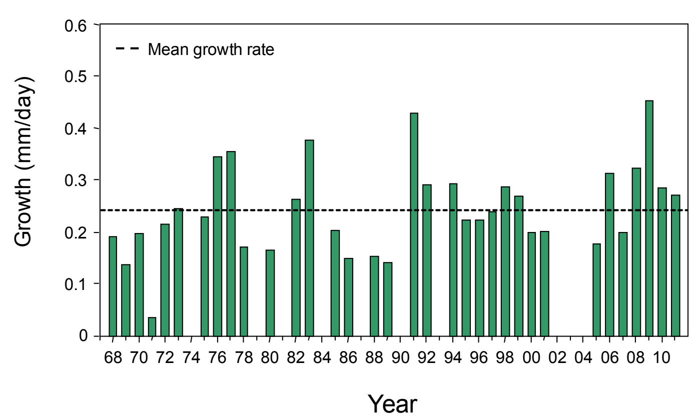

Figure 20 Fall Midwater Trawl age-0 striped bass apparent growth rates from September through December. Dotted line represents the mean apparent growth rate for all years.

(30 to 50+ per tow on the high end) and threadfin shad (100 to 900+ on the high end). Additionally, wakasagi were regularly caught in the SDWSC and Cache Slough area (1-6 per month). Therefore, these stations appear to provide year-round habitat for pelagic fish species.

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Notes

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Jason DuBois, California Department of Fish and Game, email October 3, 2008.

For more information about the studies or data used in this report:

- For the Summer Townet Survey, please contact Katherine Osborn (kosborn@dfg.ca.gov)

- For the Fall Midwater Trawl Survey, please contact Dave Contreras (dcontreras@dfg.ca.gov).

- For the 20mm Survey, please contact Julio Adib-Samii (jadibsamii@dfg.ca.gov).

Delta Smelt Regional Feeding Patterns in Fall 2011

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Introduction

The delta smelt (*Hypomesus transpacificus*) is a small pelagic fish endemic to the upper San Francisco Estuary (Moyle 2002). Once a common fish in the estuary, the delta smelt has suffered a long-term decline in abundance which led to its listing as threatened and recent up-listing to endangered under Federal (Federal Register 1993) and California (Fish and Game Commission 2009) Endangered Species acts, respectively. For the management of this species the Interagency Ecological Program (IEP) has conducted considerable monitoring and research into delta smelt life history in recent years (Baxter et al. 2010). One component of current IEP research is the investigation of limited food for this fish. Delta smelt is a zooplanktivore (Lott 1998, Nobriga 2002, Feyrer et al. 2003, and Hobbs et al. 2006) and is dependant on small invertebrates for food which have suffered changes in abundance and species composition in the estuary over time (Baxter et al. 2010). Delta smelt is one of several pelagic fishes in the upper San Francisco Estuary believed to be susceptible to food limitation during summer and fall resulting in decreased condition and survivorship of larval and juvenile fish (Bennett and Moyle 1996). Understanding what prey organisms were utilized for food in the context of available prey, or lack of, and the associated condition of fish, will clarify the existence and timing of food limitation in the delta smelt population.

We conducted a diet study to determine the types and number of prey consumed by delta smelt collected in the low salinity zone (1-6 ppt salinity; LSZ) and Cache Slough-Sacramento River Deep Water Ship Channel (CS/SDWSC) and to relate use of prey in these regions to measures of stomach fullness. The goal of this study was to examine the diet composition and stomach fullness of age-0 delta smelt during the late summer and fall (August through December) of the wet year that occurred in 2011. The diet study is one part of the larger Fall Low Salinity Habitat (FLaSH) sampling and analyses designed to determine whether delta smelt in the LSZ were larger, fatter, grew faster, or eventually had higher fecundity and better egg quality as compared to fish found in CS/SDWSC. Future work will include examination of delta smelt from the LSZ when it's positioned in the western Delta versus Suisun Bay, as it was in 2011.

The questions being investigated were:

1. What are the feeding patterns of delta smelt in the low salinity zone vs. Cache Slough-Sacramento Deep Water Ship Channel?
2. Is there evidence of reduced feeding success at different months or regions in the estuary?

Methods

Delta smelt were collected in the upper San Francisco Estuary by IEP long-term monitoring surveys conducted by the Department of Fish and Game (DFG) in August by Summer Townet Survey (TNS) and in September-December by Fall Midwater Trawl (FMWT). Sampling by both projects occurred during daylight between sunrise and early afternoon. For a description of the 2011 sampling effort and delta smelt catch see Contreras et al. in this newsletter. A Clarke-Bumpus (CB) mesozooplankton net, that targets copepods and cladocerans, was towed once at each TNS station. The FMWT conducted a mesozooplankton and mysid net tow immediately following the fish sample tow at a subset of stations. Following identification and fork length (FL) measurements in the field, fish were wrapped in foil and placed in a Dewar of liquid nitrogen. Fish were transferred to Dr. Swee Teh, UC Davis (Davis, CA) whose laboratory recorded frozen fish lengths and weights and removed various organs for later examination; the entire digestive tract was removed and preserved in a 20 ml vial of 95% ethanol (ETOH) for identification of stomach contents. Vials of digestive tracts were transferred to DFG (Stockton, CA) for stomach content analysis.

To identify consumed prey, stomachs were removed from the digestive tract and teased open in a Petri dish with a probe and scalpel and their contents transferred to a droplet of water. All stomach contents were identified to the lowest possible taxon and counted using a dissecting scope. Some stomach items were only noted as present when quantification was not possible such as with debris or unidentified animal or plant material. Body lengths were recorded to the nearest 0.1 millimeters (mm) for large or uncommon items including mysids, amphipods, cumaceans, and shrimp.

The wet weight of prey in stomachs was determined by length-weight equations for larger zooplankton (Table 1) in addition to multiplying the count of each prey type using a wet weight estimate in grams (g) (Table 2). Wet weights of the various prey types (and their associated age classes) were grouped into higher level categories for reporting purposes and the categories summed for each fish to calculate a total stomach content mass. The prey category "other" included infrequently encountered items in stomachs including copepod nauplii, cumaceans, ostracods, terrestrial invertebrates, shrimp, and annelid worms. To examine the amount of food present in stomachs as a percent of body weight as maximum daily ration, stomach content wet weight (g) was divided by body weight (g) and multiplied by 100 for each fish. Only 171 of 180 fish with stomach contents contributed to stomach weight as a percent of body weight because 9 fish from the LSZ lacked body weight data. Wet weight (g) estimates and length-weight equations of larger zooplankton (Tables 1 and 2) were generated from gut contents of fish from other diet studies (DFG unpublished), and when not available, were back calculated from literature values of carbon weight summarized by Kimmerer (2006). Monthly diet composition was reported as percent of prey by number (%N) and weight (%W). Use of both measures is important because percent-number tends to overemphasize the contribution of lots of small organisms and percent-weight tends to overemphasize the contribution of a few large and heavy organisms. Unidentified animal and plant material and debris were not included in determination of %N or %W, as enumeration of these items was not possible.

Table 1 Length-weight relationships of prey types used to calculate percent wet weight of prey and gut fullness. Prey type body length is in millimeters (mm) and wet weight in micrograms (µg) from CDFG unpublished work.

	Prey type	*L-W relationship*	*Source*
Mysids			
	Hyperacanthomysis longirostris	$W = 126.7 \times L^{1.699}$	CDFG unpublished
	Unid Mysids	$W = 126.7 \times L^{1.699}$	Used *H. longirostris*
Amphipods			
	Gammarus spp.	$W = 205.7 \times L^{1.895}$	CDFG unpublished
	Corophium spp.	$W = 148.1 \times L^{1.633}$	CDFG unpublished
Shrimp			
	Palaemon macrodactylus	$W = 5.0 \times L^{3.154}$	CDFG unpublished

Stomach fullness was estimated similar to Knight and Margraf (1982) using the maximum observed stomach content mass within each 1 mm FL interval to generate a power function: $V = a \times L^b$, where V = stomach capacity (g), L = fork length (mm), and a and b are parameters, to estimate the maximum possible stomach content mass at length. The power function included only maximum stomach mass values equal to or greater than the previous maximum mass value per length interval. The use of the power function allows for comparison of fullness among fish of varying lengths and stomach volumes. A fullness index was determined for each fish with the formula: $\log_{10}$ fullness = $\log_{10}$ ((observed stomach content mass / maximum estimated stomach content mass) x 100). Only those fish with stomach contents present were used in this analysis. Statistical summaries and box plots were generated with SYSTAT 10.

To examine use of invertebrates by delta smelt in relation to available prey in the environment, the proportional abundance (0-1) of a prey type in the environment relative to all other organisms collected by the mesozooplankton net was plotted against the proportional abundance (0-1) of that same prey type in the stomach of delta smelt. Plots were also generated of actual density (# m^{-3}) of that prey type relative to the proportional abundance in stomachs. Each data point (n = 17) in the plots represents a sample of 1 to 37 fish collected at a station with a corresponding mesozooplankton sample by the TNS and FMWT studies.

Results

Delta smelt (34-70 mm FL) in the fall of 2011 had a high feeding incidence (99%), with only 2 of 182 stomachs found empty (Figure 1). A diverse mix of zooplankton types and sizes (Figure 2) including copepods, cladocerans, mysids, and amphipods were found in stomachs of delta smelt collected August-December 2011.

Calanoid copepods were the primary food item in both the LSZ and CS/SDWSC (Figures 3-6), yet the types and amounts found in stomachs varied between regions and among months, in part due to their availability (see Hennessy in this newsletter). Major food items by percent number in stomachs from the LSZ included calanoid co-

Table 2 Table of prey type wet weight values in micrograms (µg) used to calculate percent weight of prey and gut fullness. Weight values of prey were generated during this study and from estimates in the literature. Conversion of carbon (µg) and dry weight (µg) literature values to wet weight (µg) was done using ratios reported by Beers (1966) for copepods: dry weight = carbon weight / 0.42 and wet weight = dry weight / 0.13.

	Prey type	*Wet weight (µg)*	*Source*
Copepods			
	UnID copepod	29.2	DFG unpublished; Mean of UnID calanoid and cyclopoid
	Copepod nauplii	2.4	DFG unpublished
	Cyclopoid copepodid	13.7	Kimmerer (2006)
	Acanthocyclops vernalis	38.2	DFG unpublished
	Oithona davisae	4.2	Kimmerer (2006)
	Limnoithona tetraspina juvenile	0.5	Kimmerer (2006)
	Limnoithona tetraspina	5.6	DFG unpublished
	UnID cyclopoid (Other cyclopoid)	44.4	DFG unpublished
	UnID cyclopoid	21.7	DFG unpublished
	Calanoid copepodid	13.8	DFG unpublished
	Diaptomus spp. copepodid	11.4	Kimmerer (2006)
	Diaptomus spp.	73.3	Kimmerer (2006)
	Pseudodiaptomus spp. nauplii	1.8	Kimmerer (2006)
	Pseudodiaptomus spp. copepodid	13.7	Kimmerer (2006)
	Pseudodiaptomus forbesi	54.9	Kimmerer (2006)
	Pseudodiaptomus spp.	19.4	DFG unpublished
	Eurytemora affinis copepodid	10.1	Kimmerer (2006)
	Eurytemora affinis	40.3	Kimmerer (2006)
	Sinocalanus doerrii nauplii	2.7	DFG unpublished
	Sinocalanus doerrii copepodid	23.6	DFG unpublished
	Sinocalanus doerrii	70.7	DFG unpublished
	Acartiella sinensis copepodid	27.7	DFG unpublished
	Acartiella sinensis	75.3	DFG unpublished
	Tortanus spp. copepodid	30.1	DFG unpublished
	Tortanus spp.	219.6	DFG unpublished
	UnID calanoid	36.6	Kimmerer (2006)
	Harpacticoid copepods	22.7	DFG unpublished
Cladocerans			
	Bosmina	6.9	DFG unpublished
	Daphnia	50.4	DFG unpublished
	Diaphanosoma	28.3	DFG unpublished
	Ceriodaphnia	32.3	DFG unpublished
	Other cladocera	30.1	DFG unpublished
	UnID cladocera	22.5	DFG unpublished
Cumaceans		330.7	DFG unpublished
Rotifers		3.6	DFG unpublished
Ostracods		48.1	DFG unpublished
Terrestrial invertebrates		236.6	DFG unpublished
Clams		33.4	DFG unpublished
Other zooplankton		93.9	DFG unpublished
UnID animal material		NA	not quantifiable
UnID plant material		NA	not quantifiable
Debris (sand/silt/mud)		NA	not quantifiable

pepods *Pseudodiaptomus forbesi* and *Acartiella sinensis* and also cyclopoids *Limnoithona* spp. and other cyclopoid copepods (Figure 3). Zooplankton eaten less frequently in the LSZ included harpacticoid copepods and relatively larger amphipods, mysids, and cladocerans (Figure 4). Stomachs collected upstream in the CS/SDWSC were dominated numerically by *P. forbesi* with relatively low consumption of *Sinocalanus doerrii* and other calanoid copepods along with *Limnoithona* spp. (Figure 3) and even less use of other organisms (Figure 4). Monthly abundance of calanoid copepods in both regions decreased through the fall (Hennessy in this newsletter) and fish shifted to a more diverse range of prey (Figure 4). Major food items by percent weight in the LSZ were copepods *P. forbesi* and *A. sinensis*, along with other cyclopoid copepods, with little contribution by small *Limnoithona* spp. (Figure 5). A large percentage of total stomach mass was also made up of amphipods and mysids in the LSZ and mysids in the CS/SDWSC (Figure 6), notably in the late fall when density of copepods was low (Hennessy in this newsletter).

The maximum total wet weight (g) of stomach contents observed had a logarithmic increase with fork lengths (mm) as was expected with the increase in stomach size associated with larger fish, yet the amount of food present in stomachs was variable at length (Figure 7). Stomach content weight as a percent of body weight ranged from 0.003% to 2.42% and when plotted by hour via a box plot revealed a diurnal feeding pattern (Figure

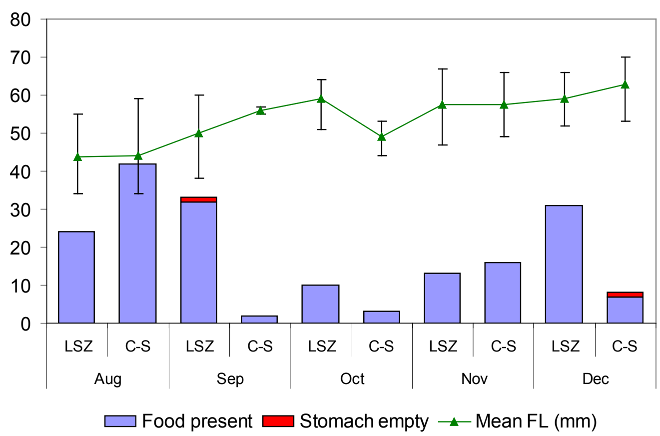

Figure 1 Number of delta smelt stomachs examined found with and without contents present and the mean (min-max) fork length (mm) of these fish collected in the low salinity zone (LSZ) and Cache Slough-Sacramento Deep Water Ship Channel (CS/SDWSC) August-December 2011

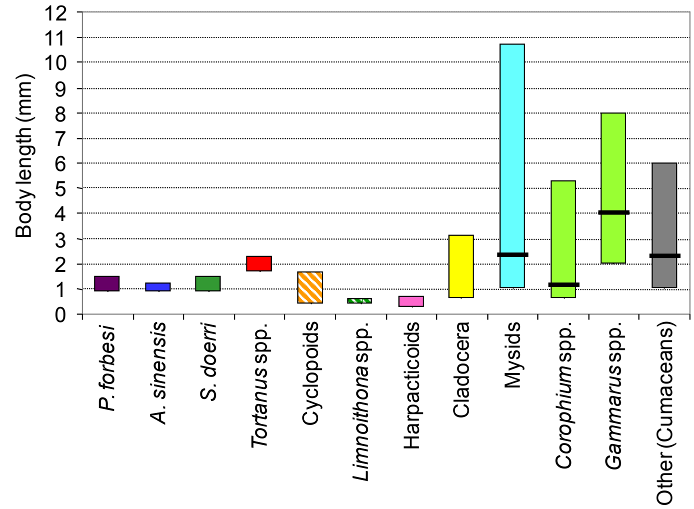

Figure 2 Body lengths (mm) of prey types found in stomachs of delta smelt collected August-December 2011. A few representative adult copepods and cladocerans were haphazardly selected for measurement from stomachs. Lengths of larger zooplankton (mysids, amphipods, and cumaceans) were regularly recorded and black lines in bars note mean body lengths (mm) of intact specimens found in stomachs.

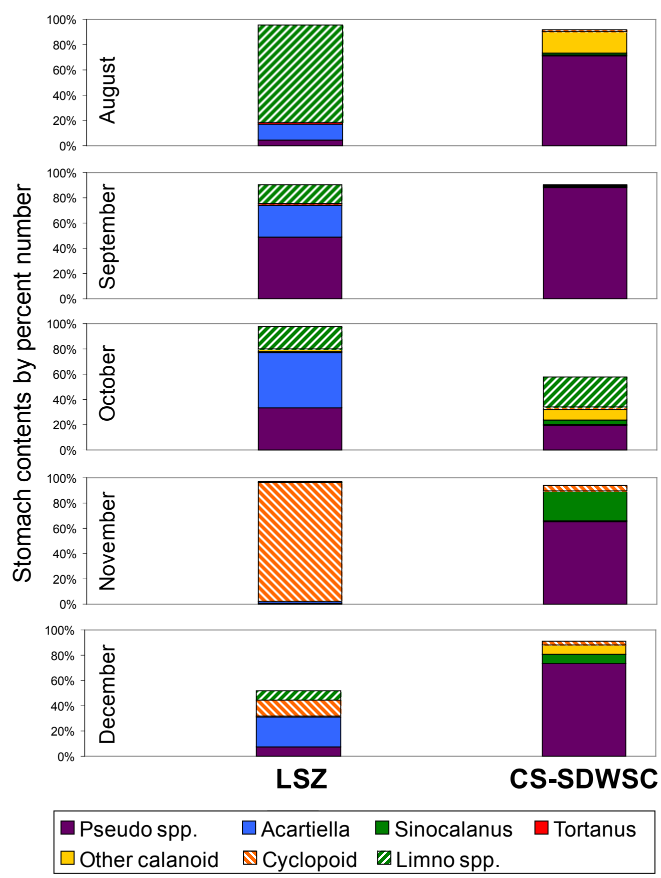

Figure 3 Diet by percent number (calanoid and cyclopoid copepods only) of delta smelt collected in the low salinity zone (LSZ) and Cache Slough-Sacramento Deep Water Ship Channel (CS/SDWSC) August-December 2011

8). The mass of food in stomachs was low in morning hours for fish from LSZ and CS/SDWSC and increased in the afternoon hours in the LSZ and less so in the CS/SDWSC (Figure 8). The mean $\log_{10}$ stomach fullness index, which incorporated the observed from maximum food present in stomachs at length, was higher overall in the LSZ (mean = 1.320) than CS/SDWSC (mean = 1.162). The fullness index on an hourly scale mimicked the diurnal feeding pattern with increased fullness of stomachs progressed from morning to afternoon (Figure 9). The same fullness indices on a monthly scale revealed a wide variation in fullness within months and were more variable among months, with LSZ values higher than those in CS/SDWSC (Figure 10).

Plots of prey type proportional abundance in the environment and in stomachs revealed extremely high use of adult *P. forbesi* and *A. sinensis* as food at relatively low to medium proportions of environmentally available adult *P. forbesi* (Figure 11). Conversely, *P. forbesi* copepodites (Figure 11) and adult *S. doerrii* and cyclopoid copepods other than *Limnoithona* spp. (Figure 12) were eaten infrequently and only contributed to moderate levels of stomach contents when at very high densities in the environment.

Summary

Delta smelt used a wide range of zooplankton for food in the fall of 2011. The type and amount of prey consumed varied between LSZ and CS/SDWSC and was due in large part to the available prey field as reported by Hennessy (in this newsletter) and also due to delta smelt not using some prey types even when available at high densities (*S. doerrii* and small copepods). The major food group copepods (notably *P. forbesi*) had considerably higher densities upstream in CS/SDWSC than downstream in the LSZ, yet the variety of copepod types available and used for food was more varied in the LSZ. The use of larger zooplank-

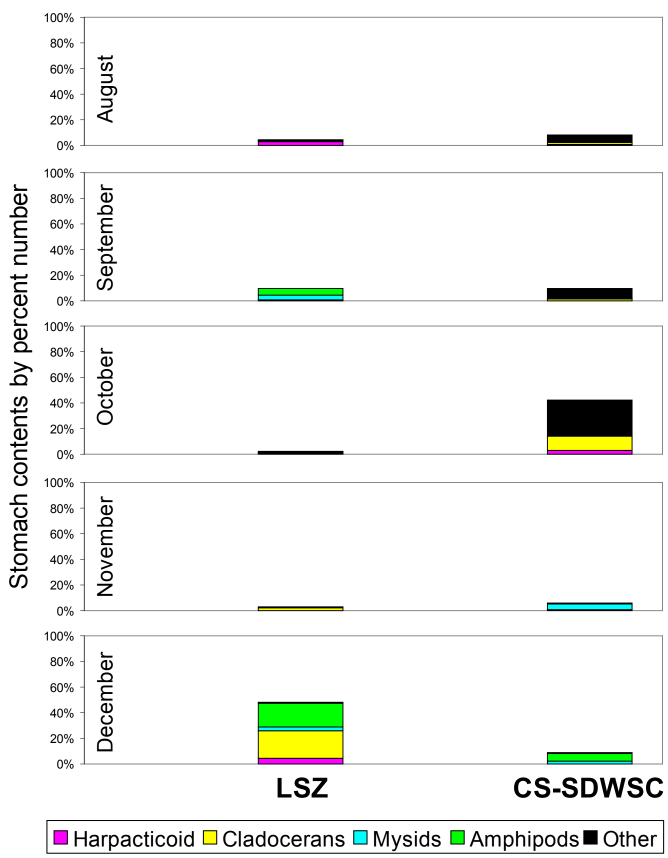

Figure 4 Diet by percent number (harpacticoid copepods, cladocerans, mysids, amphipods, and miscellaneous other prey types) of delta smelt collected in the low salinity zone (LSZ) and Cache Slough-Sacramento Deep Water Ship Channel (CS/SDWSC) August-December 2011

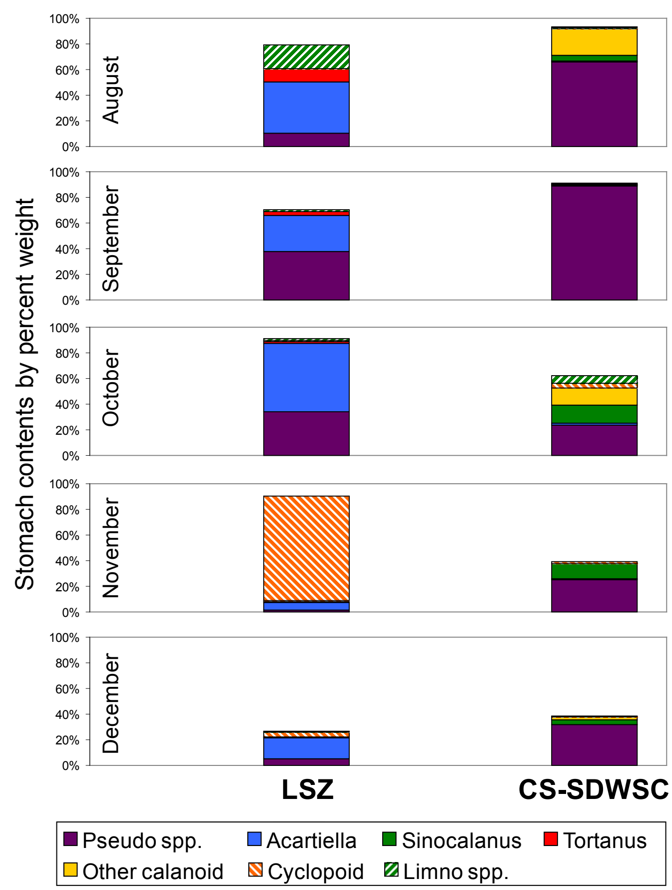

Figure 5 Diet by percent wet weight (calanoid and cyclopoid copepods only) of delta smelt collected in the low salinity zone (LSZ) and Cache Slough-Sacramento Deep Water Ship Channel (CS/SDWSC) August-December 2011

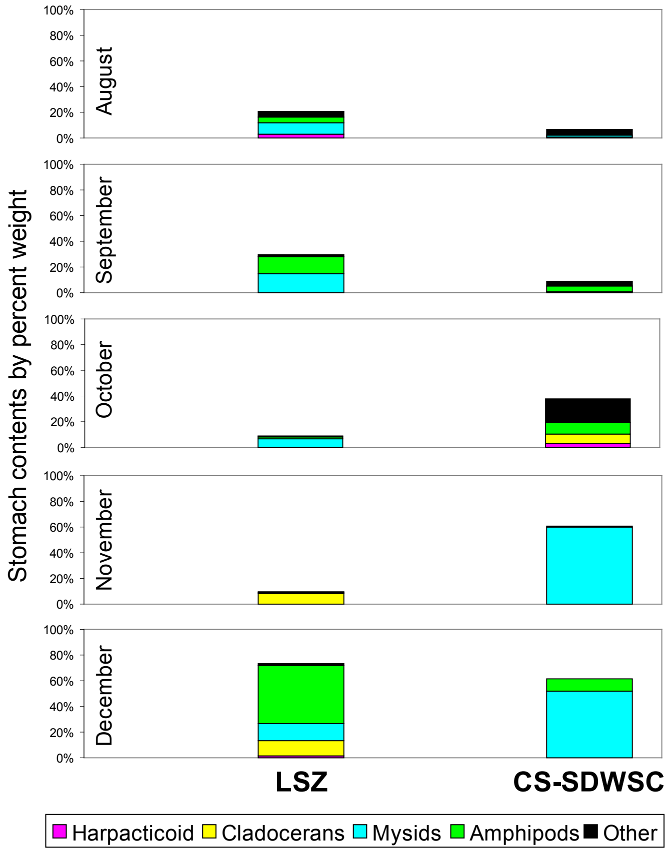

Figure 6 Diet by percent wet weight (harpacticoid copepods, cladocerans, mysids, amphipods, and miscellaneous other prey types) of delta smelt collected in the low salinity zone (LSZ) and Cache Slough-Sacramento Deep Water Ship Channel (CS-SDWSC) August-December 2011

ton such as mysids and amphipods contributed in large part to stomach fullness, notably late in the fall when copepods densities were in decline (Hennessy in this newsletter). Stomach fullness was higher in the LSZ which can be attributed to access to a wider variety and size range of invertebrates that delta smelt can use as food. Delta smelt fed throughout daylight hours, as reported by Hobbs et al. (2006). DFG sampling generally extended from early morning into early afternoon, which might result in missing some detections of maximum fullness that could be occurring late in the day. Access to larger zooplankton and a more varied prey field in the LSZ could contribute to delta smelt's ability to reach satiation at a faster rate and thus earlier in the day than in CS/SDWSC.

Additional diet work is currently under way and results are pending.

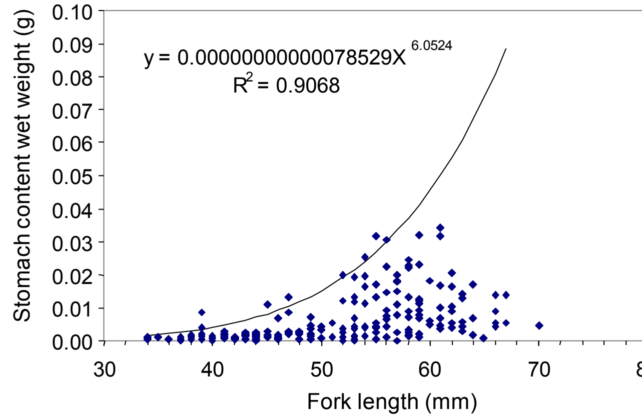

Figure 7 Wet weight (g) of delta smelt stomach contents and the relationship of the maximum observed gut content mass (g) values per 1 mm fork length (mm) intervals

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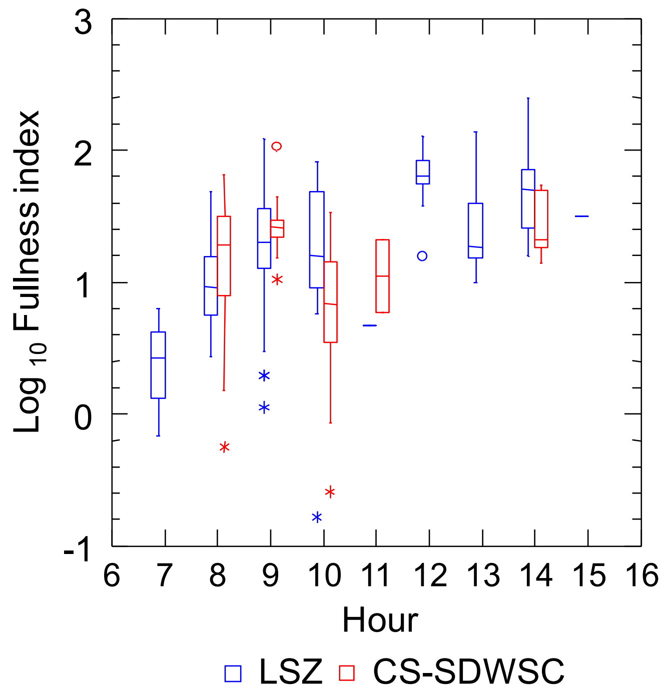

Figure 9 Box plot of log_{10} fullness index values by the hour. Delta smelt were collected in the low salinity zone (LSZ) and Cache Slough-Sacramento Deep Water Ship Channel (CS/SDWSC) August-December 2011.

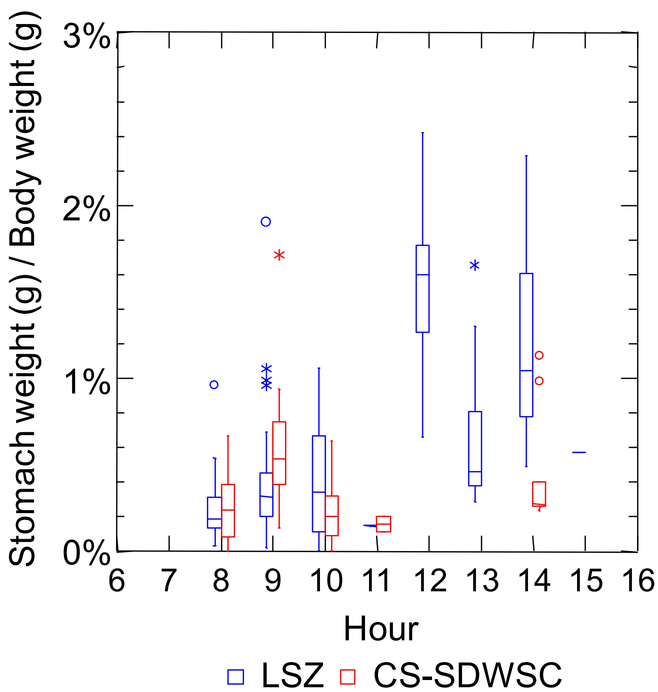

Figure 8 Box plot of stomach content wet weight (g) as a percent of body weight (g) by the hour. Delta smelt were collected in the low salinity zone (LSZ) and Cache Slough-Sacramento Deep Water Ship Channel (CS/SDWSC) August-December 2011.

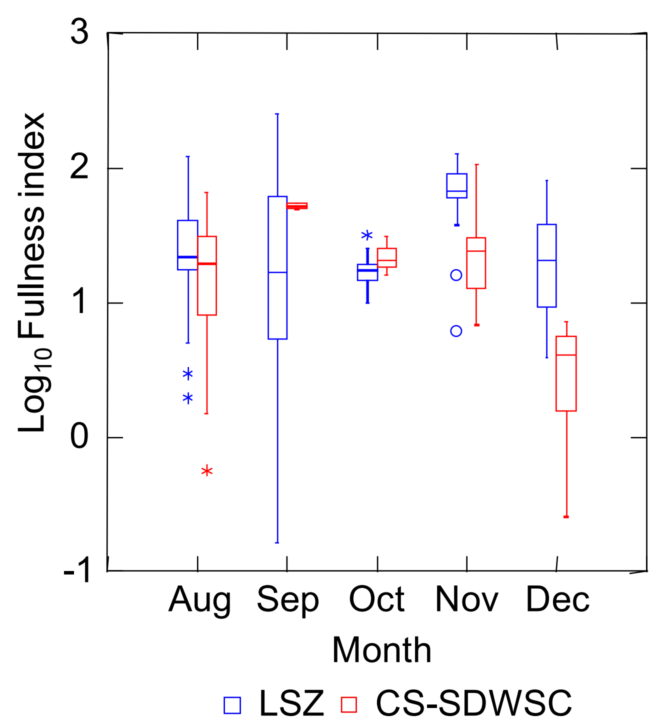

Figure 10 Box plot of log_{10} fullness index values by the month. Delta smelt were collected in the low salinity zone (LSZ) and Cache Slough-Sacramento Deep Water Ship Channel (CS/SDWSC) August-December 2011.

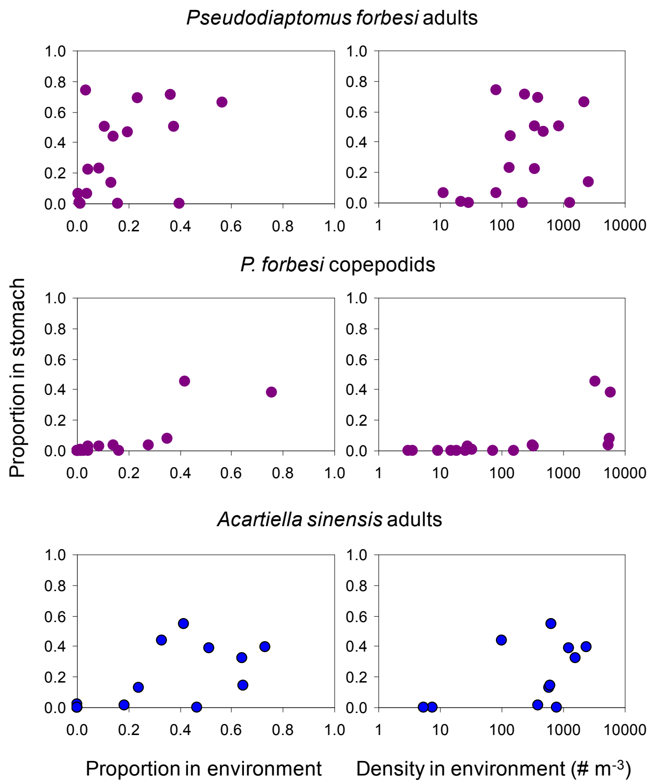

Figure 11 Proportion of calanoid copepod prey types found in stomachs of delta smelt relative to the environmental proportion and density (# m^{-3}) of the same prey type

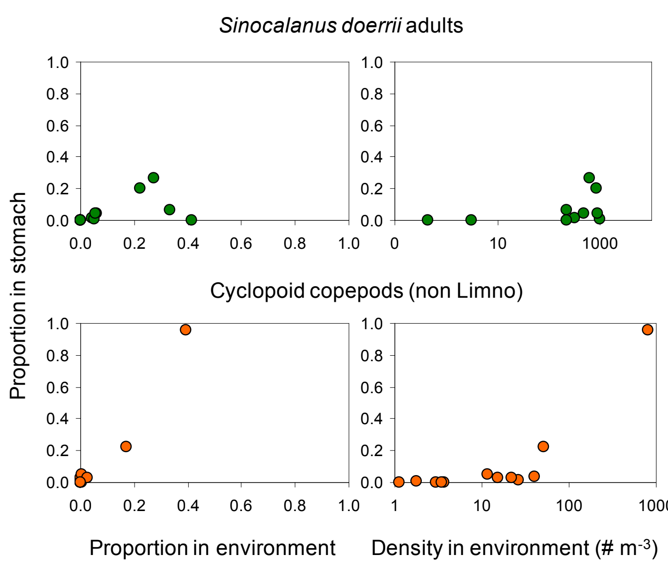

Figure 12 Proportion of calanoid and cyclopoid copepods prey types found in stomachs of delta smelt relative to the environmental proportion and density (# m^{-3}) of the same prey type

Contributed Papers

Assessing phytoplankton communities in the Sacramento and San Joaquin Rivers using microscopic and indirect analytical approaches

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Abstract

Long-term monitoring data of phytoplankton community species composition exist for the San Francisco Estuary-Delta (SFE). These data are based on conventional microscopy techniques. In recent years, these efforts have been augmented with new technologies (e.g., spectrofluorometry and flow cytometry) to indirectly monitor phytoplankton communities over broader temporal and spatial scales. River surveys in the Sacramento and San Joaquin rivers were carried out in spring 2010 to characterize phytoplankton community structure and environmental parameters upstream and downstream of the Sacramento Regional and Stockton Waste Water Treatment Plants. Phytoplankton community composition was assessed using four methods; conventional light microscopy, measurements of size-fractionated chlorophyll-*a* concentrations, flow cytometry, and spectrofluorometry (bbe FluoroProbe). From these observations we tested the hypotheses that 1) phytoplankton communities will be less abundant and dominated by flagellates in the Sacramento River, the San Joaquin River will have more algal biomass and be dominated by diatoms, and 2) using a combination of measuring size fractionated chlorophyll-*a*, flow cytometry and spectrofluorometry is sufficient to characterize phytoplankton communities at a functional group level.

Introduction

Riverine phytoplankton are critical players in freshwater and estuarine ecology. Variation in light availability

(Cole and Cloern 1984, Reynolds 1984, Leland et al. 2001), nutrient abundance and ratios (Conley and Malone 1992, Glibert et al. 2011, Wilkerson et al. 2006, Dugdale et al. 2007, Van Nieuwenhuyse 2007), and river flow (Mallin et al. 1993, Alpine and Cloern 1992, Jassby et al. 1996, Sommer et al. 2004) all help determine the distribution, abundance, composition, and ecology of riverine phytoplankton. Phytoplankton communities are often complex and composed of different functional groups that have high diversity and rapid seasonal shifts in their composition (Pinckney et al. 1998). Phytoplankton community structure changes may be a signal of environmental change (Lehman 2000a, 2000b, Sommer and Lengfellner 2008).

Changes in San Francisco Estuary-Delta (SFE) phytoplankton have been documented during monitoring programs carried out by CA Department of Water Resources and USGS over the last 30 years. Phytoplankton biomass (measured as chlorophyll-*a*) has decreased over the last 40 years in the SFE but has increased in the Delta over the past decade (Lehman 2000a, Jassby et al. 2002, Jassby 2008). There have been shifts observed in phytoplankton community composition from diatoms to increasing dominance of smaller flagellates and cyanobacteria that will have negative consequences for higher trophic levels (Lehman 2000a, 2004, Brown 2010, Glibert 2010, Glibert et al. 2011).

Phytoplankton community structure may strongly influence foodweb structure and trophic efficiency (Cloern and Dufford 2005, Mallin and Paerl 1994, Jassby et al. 2003, Brown 2009). The type of phytoplankton is important because different sized cells and species are preyed upon by different zooplankton, influencing trophic structures (Nobriga 1998, Kimmerer 2004, Sommer et al. 2007). A threshold limit of 10 µg/L chlorophyll-*a* was used to define a bloom by Cloern (1991) and has been shown experimentally and used by Mueller-Solger et al. (2002) to set the limit below which zooplankton are food-limited. Allochthonous organic matter supply, including phytoplankton, from the Sacramento and San Joaquin rivers is a potentially important food source for the northern SFE (Mueller-Solger et al. 2002, Jassby et al. 2002, Sobczak et al. 2002, 2005). Diatoms and cryptophytes are generally considered good food for estuarine and freshwater consumers, while green algae and especially cyanobacteria are nutritionally inferior (Brett and Mueller-Navarra 1997, Lehman et al. 2005, Lehman 2007, Cloern and Dufford 2005).

Assessing phytoplankton communities is traditionally achieved by microscopy. In order to determine the impact of water project operations on the estuary, the Department of Water Resources Environmental Monitoring Program conducts monthly phytoplankton monitoring at 15 sites throughout the SFE-Delta, microscopy based counts are available from 1975 to the present (http://www.water.ca.gov/bdma/meta/phytoplankton.cfm). This approach is expensive and time consuming and for these reasons is undesirable for monitoring programs that gain relevance with prolonged effort and where, historically, sustained funding is limited. Measuring chlorophyll-*a*, present in all phytoplankton, is one way to estimate the bulk biomass of phytoplankton, but the concentration of chlorophyll-*a* gives information about quantity and not quality of the phytoplankton present.

Several less time consuming indirect approaches, including flow cytometry or spectrofluorometry, are now available for assessing the phytoplankton community. Flow cytometry allows fast counting and optical analysis of individual particles in a water sample; for this study the flow cytometer was used to estimate abundance and size spectra of the phytoplankton communities. Using the flow cytometer we assume that each fluorescent particle counted represents a phytoplankter, as the flow cytometer detects the chlorophyll fluorescence of each cell. The bbe FluoroProbe is a submersible spectrofluorometer that measures the chlorophyll fluorescence of algae to assess biomass and then uses the different excitation wavelengths of accessory pigments to separate the community into four taxonomic groups: green, brown, blue-green, and cryptophytes. The four taxonomic groups are distinguished by programming the FluoroProbe to recognize "fluorescent fingerprints" of the accessory pigments present in each group. While each approach gives complementary information about the phytoplankton community, the indirect methods don't provide overlapping information, and thus are not suitable for direct comparison.

The scientific objective of this project was to make simultaneous measurements at discrete station locations using flow cytometry and size fractionated chlorophyll-*a* as well as continuous sampling measurements by the bbe FluoroProbe at the same time and location during the spring in the Sacramento and San Joaquin rivers. Our goal was to then compare the indirect approaches with direct microscopy-based phytoplankton counts from samples collected at the same time. Our hypotheses are that 1) phytoplankton communities will be less abundant and dominated by flagellates in the Sacramento River, the San Joaquin River will have more algal biomass and be dominated by diatoms, and 2) using a combination of measuring size fractionated chlorophyll-*a*, flow cytometry and spectrofluorometry is sufficient to characterize phytoplankton communities at a functional group level.

Methods

Surveys of the Sacramento and San Joaquin rivers were carried out aboard the *R/V Questuary* over two days, the 26th to the 28th of April 2010. Thirteen stations were sampled in the Sacramento River and 14 stations were sampled in the San Joaquin River (Figure 1), with all water collection occurring on outgoing tides. Water samples from stations above and including the Stockton Waste Water Treatment Plant (SWWTP) in the San Joaquin River (C10, C7, C6, SWWTP) were collected from shore as the vessel could not travel under the Navy Drive Bridge in Stockton, CA. These surface samples were collected using a clean bucket and stored in the dark in 20-L low density polycarbonate "cubitainers" until they were brought to the vessel for analysis (within six hours). All other water samples were collected from the surface (<1m) at mid channel stations using 3-L Niskin bottles mounted on a SBE-33 rosette. Temperature and conductivity measurements were made using a Seabird SBE-19 CTD also mounted to the rosette. The rosette was equipped with a LiCor 4Π photosynthetically active radiation (PAR) sensor. Light attenuation, k (/m), was calculated by linear regression of log transformed PAR versus depth. Secchi depth was measured at each location to estimate light penetration depth. A YSI 6600 V2 water quality monitoring sonde was used for measurements of pH. No measurements of temperature or conductivity were made for samples collected from shore. From the discrete surface water collections analyses of nitrate (NO_3), nitrite (NO_2), phosphate (PO_4), silicate ($Si(OH)_4$), ammonium (NH_4), size-fractionated chlorophyll-*a*, phytoplankton enumeration, and flow cytometry were made.

Water samples for nutrient analyses were prefiltered through Whatman 25 mm GF/F filters to remove sediment particles which are known to interfere with colorimetric determination of nutrients (Hager and Schemel, 1996; Wilkerson et al. 2006). NO_3, NO_2, PO_4, and $Si(OH)_4$ concentrations were analyzed on 20 ml water samples using a Bran and Luebbe Technicon-II Auto Analyzer employing the protocol of Whitledge et al. (1981). NH_4 concentrations were measured on separate 25 ml water samples using a spectrophotometer and 10 cm pathlength cuvette cell according to Soloranzo (1969).

Size fractionated chlorophyll-*a* was collected onto Whatman GF/F filters (nominal pore size 0.7 µM, referred to here as "total" chlorophyll) and Nuclepore polycarbonate filters (5.0 µM pore sized) under a gentle vacuum and analyzed by *in vitro* fluorometry using the extraction protocol of Arar and Collins (1992). Chlorophyll in <5 µM cells was calculated as the difference between chlorophyll caught on the GF/F and the >5 µM filters. Chlorophyll-*a* was extracted in 90% vol:vol acetone at 4º C for 24 hours. Analysis was performed on a Turner Designs Model 10 fluorometer, calibrated with commercially available chlorophyll-*a*; pigment concentrations were corrected for phaeophytin using the protocol of Holm-Hansen et al. (1965).

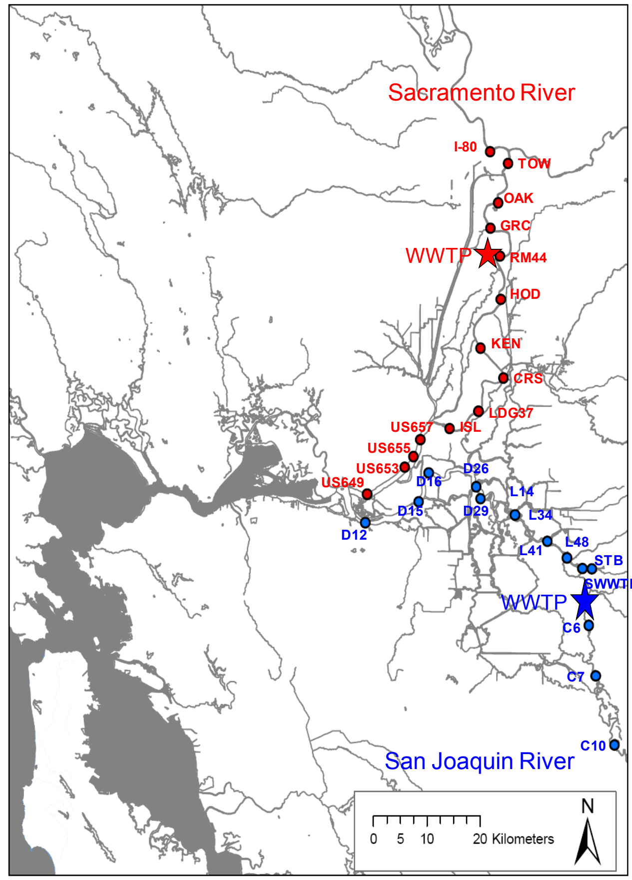

Figure 1 Study site showing locations of 27 fixed geographic stations sampled in the Sacramento (red) and San Joaquin (blue) rivers. Stars show approximate location of the Sacramento Regional Waster Water Treatment Plant (red) and the Stockton Waste Water Treatment Plant (blue).

The number and size distribution of red fluorescent particles (assumed to be chlorophyll-*a* containing cells) were obtained using a CytoSense flow cytometer and 20 ml water samples (Dubelaar et al. 1998). Approximately 1 ml of the 20 ml sample is used by the flow cytometer for analysis. To minimize fluorescent particle degradation, the flow cytometer was installed on the *R/V Questuary* so that samples could be analyzed immediately upon collection. The flow cytometer produced profiles of forward scatter and side scatter as well as fluorescence for each particle in the water sample. From forward and side scatter characterization, the size distribution of particles was estimated.

Phytoplankton enumeration was made by microscopic identification. Water samples (250 ml) were taken at each station and preserved with Lugol's solution, and then analyzed using the Utermohl inverted microscope technique (Lund et al. 1958) with a Nikon Diaphot Phase Contrast microscope. Samples were kept in the dark at room temperature until counted. Aliquots of 27 ml were settled for 24 hours and counted to a minimum of 400 cells per sample using random fields of view at 400x magnification. Phytoplankton were identified to the lowest possible taxonomic group and then assigned using the following functional group categories: centric diatoms, pennate diatoms, cryptomonads, flagellates (including dinoflagellates), blue-green algae, chlorophytes, and "other" unidentified material.

Phytoplankton community structure was also assessed continuously using a bbe FluoroProbe (http://www.bbe-moldaenke.de/chlorophyll/fluoroprobe/) that was plumbed into the baywater flow-through system onboard the *R/V Questuary*. The inlet was located approximately 1m below the water surface. The FluoroProbe provided an *in vivo/ in situ* horizontal map of algal groups by measuring chlorophyll and accessory pigments and recognizing "fluorescent fingerprints" of algae in four different taxonomic groups: 1) green 2) brown 3) blue-green and 4) cryptophytes. The green group represents cells with chlorophyll-*a* and chlorophyll-*b* in Chlorophyta. The brown group represents cells with fucoxanthin (diatoms and chrysophytes) or with peridinin in dinoflagellates. The blue-green group represents cells with phycocyanin in blue-green algae and the cryptophytes are recognized by phycoerythrin in Cryptophyta. The fluorescent groups represented in FluoroProbe results have the potential to overlap with the functional groups represented in microscopic counts. FluoroProbe results were compared to discrete (station) results by averaging its continuous output over the five minute period as the vessel passed over the station.

Results

Mean (±SD) and ranges of values for several environmental parameters measured at stations in the Sacramento and San Joaquin rivers are provided in Table 1 to highlight where differences and similarities were seen between the two rivers. River flow in April was greater in the Sacramento River compared to the San Joaquin River. Secchi depth and light attenuation coefficients in the Sacramento River showed relatively little variation across all stations and the Sacramento River had less light availability than the San Joaquin River. The San Joaquin River was more variable across stations with respect to Secchi depth and light attenuation coefficient, with peak water clarity of 1.4 m at station L14 (data not shown). pH was similar between the two rivers with little variation between stations. Mean temperature was significantly different between the two rivers (t = test, $p = 0.003$), with cooler conditions in the Sacramento River. The peak temperature in the Sacramento River was at ISL (17.2 ºC) and the peak temperature in the San Joaquin River was at L41 (17.6 ºC) (data not shown). Conductivity in the Sacramento River increased moving downstream with a range of 145-242 µs/cm and peaked at station US649 (Figure 1). The San Joaquin River had significantly higher conductivity than in the Sacramento River (t = test, $p = 0.000$), (270-367 µs/cm) with a peak at station L14 (data not shown) (Table 1).

Ammonium concentrations in the Sacramento River were less than 1 µM at stations above the Sacramento Regional Wastewater Treatment Plant (SRWWTP), but increased by more than 30-fold between stations GRC and HOD where the WWTP discharge enters the river (Figure 2A). Ammonium declined downstream of HOD but remained consistently high (>5 µM). Nitrate was relatively constant in the upper Sacramento River to ISL, with a mean ± SD of 8.63 ± 0.66 µM, but increased by 2-fold between ISL and US649 (Figure 2A). Nitrite concentrations were low (0.13 to 0.75 µM) and phosphate ranged from 0.85 to 1.85 µM (Figure 2A). Silicate concentrations ranged from 166 to 312 µM (data not shown). The San Joaquin River was characterized by relatively high NO_3 (>20 µM) throughout the river transect (Figure 2B), and exhibited a peak of more than 60 µM downstream of the SWWTP's outfall. Ammonium concentrations in the San

Joaquin River (<4 µM) were low compared to concentrations observed in the Sacramento River and substantially lower than the NO_3 concentrations (Figure 2B). Nitrite concentrations were low (0.28 to 0.63 µM) and phosphate ranged from 1.45 to 3.08 µM (Figure 2B). Silicate concentrations ranged from 120 to 207 µM (data not shown).

Chlorophyll-*a* concentrations in the Sacramento River at the three stations above the SRWWTP were 1.6-times higher than the average of the five stations below the treatment plant (Figure 3A). However, the peak chlorophyll-*a* concentration in the Sacramento River (6.4 µg/L) occurred downstream, (US649) near the confluence of the Sacramento and San Joaquin rivers (Figures 1 and 3A). Chlorophyll-*a* concentrations were higher and more variable in the San Joaquin River compared to the Sacramento River (Figures 3A and B). The upper San Joaquin River stations (C10 to STB) had the highest chlorophyll-*a* (averaging 8.5 µg/L) with a peak at station C7. Chlorophyll-*a* at stations L48 to D12 averaged 5.1 µg/L (Figure 3B). Averaged over each of the river surveys, the percentage of chlorophyll-*a* in cells >5 µM in size was 78% in the San Joaquin River and 66% in the Sacramento River (Figures 3A and B). At the peak chlorophyll-*a* station in the San Joaquin River (C7) 95% of the chlorophyll-*a* was in cells >5 µM; the peak chlorophyll-*a* in the Sacramento River (US649) was roughly evenly split (55%) between cells >5 µM and <5 µM in size (Figure 3A and B).

The abundance of fluorescent particles and the contribution of larger particles (5 to 50 µM) were higher in the San Joaquin River than in the Sacramento River (Figures 3C and D). Sixty four percent of fluorescent particles in the San Joaquin River were 5-50 µM while 44% of fluorescent particles were in this larger range in the Sacramento River (Figures 3C and D). The peak fluorescent particle abundance in the Sacramento River was observed at I-80 ($1.9x10^6$/L). Fluorescent particle counts then decreased downstream but recovered to near upstream values by station US649 (Figure 3C). The three stations upstream of the SWWTP in the San Joaquin River (C10, C7, C6) and the station immediately downstream (STB) had the highest overall fluorescent particle counts with the peak ($3.7x10^6$/L) located at station C7. Stations downstream of STB, as well as the station immediately adjacent to the SWWTP had lower and similar fluorescent particle counts (Figure 3D).

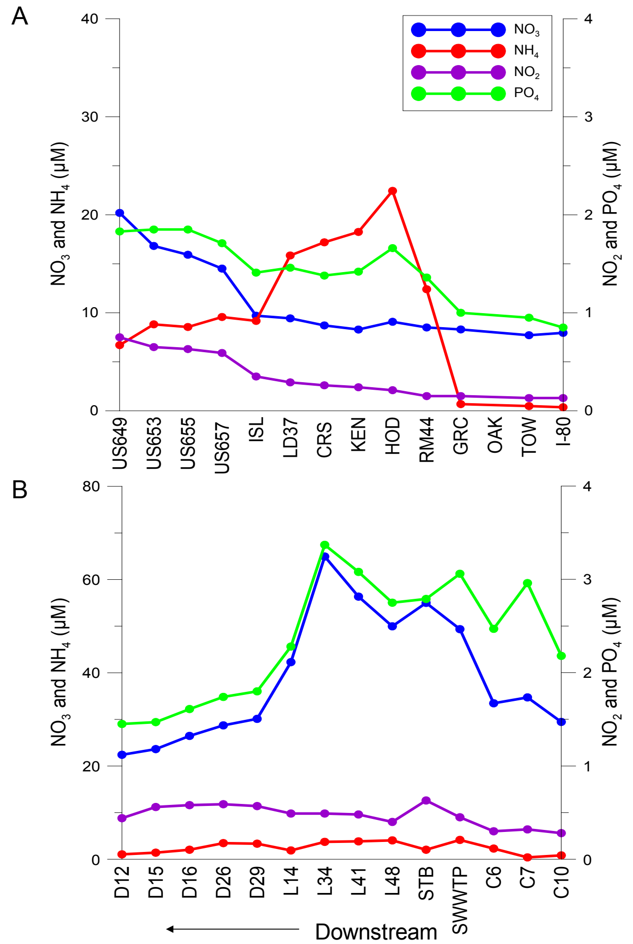

Figure 2 Inorganic nutrient concentrations along river transects in the Sacramento (A) and San Joaquin (B) rivers. Station locations are plotted from downstream (right) to upstream (left) along the x- axis and are not plotted as river distance. SRM44 is the approximate location of the Sacramento Regional Waste Water Treatment Plant(A); SWWTP is the location of the Stockton Waster Water Treatment Plant (B).

Table 1 Environmental parameters measured during transects in the Sacramento and San Joaquin rivers during spring 2010, the values shown represent the average (±SD) and range of all stations in each river. Flow data were retrieved from the Department of water resources website at http://www.water.ca.gov/dayflow/

	Sacramento River (n=13)	*San Joaquin River (n=14)*
Flow (cm/s)	575 @Freeport (4/26/10)	158 @Vernalis (4/28/10)
Secchi Depth (m)	0.55±0.05 (0.50-0.60)	0.94±0.36 (0.50-1.40)
K (/m)	2.42±0.57 (1.69-3.27)	1.84±0.68 (1.22-3.02)
Temperature (ºC)	16.72±0.30 (16.10-17.20)	17.15±0.33 (16.70-17.60)
EC (µs/cm)	176.31±36.0 (145.0-242.0)	300.6±29.43 (270.0-367.0)
pH	7.56±0.09 (7.46-7.71)	7.69±0.18 (7.37-7.91)

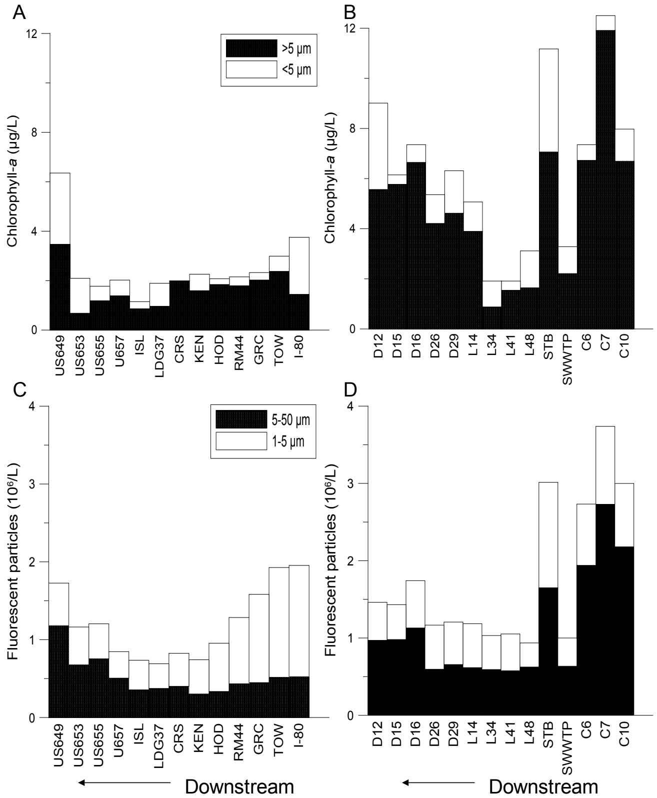

Figure 3 Size fractionated chlorophyll-a in the Sacramento (A) and San Joaquin (B) rivers. The number of fluorescent particles measured by flow cytometry in the Sacramento (C) and San Joaquin (D) rivers.

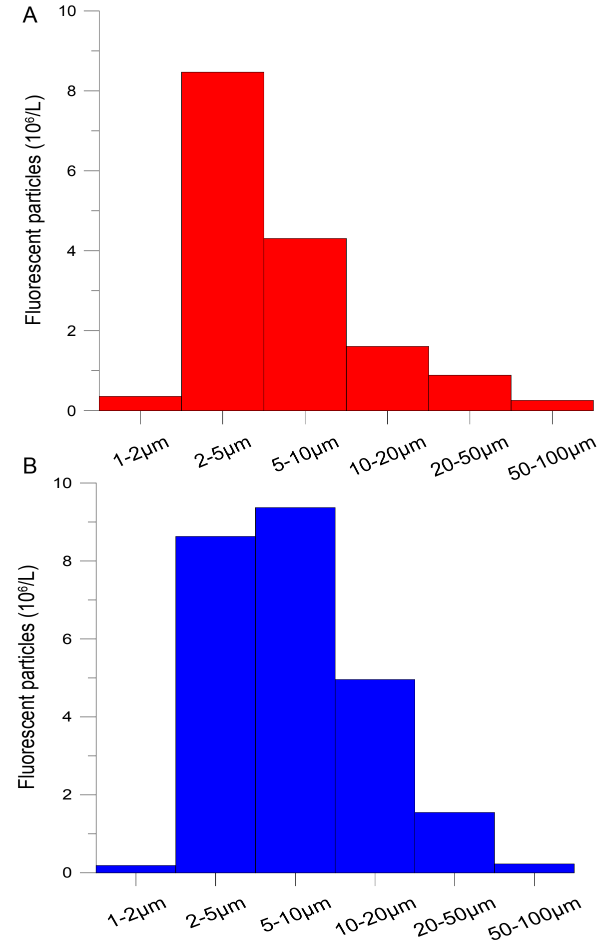

Figure 4 The number of fluorescent particles measured by flow cytometry and separated into size classes for the Sacramento (A) and San Joaquin (B) Rivers

Further breakdown of the fluorescent particle size classes described by the flow cytometer also reveals that the majority of fluorescent particles in the Sacramento River were smaller compared to the majority of fluorescent particles in the San Joaquin River (Figure 4). The Sacramento River had >50% of its fluorescent particles in the 2-5 µM size range (Figure 4A); the San Joaquin River had a more diverse distribution in the 2-5 µM, 5-10 µM, and 10-20 µM size classes, but had the majority of fluorescent particles in the 5-10 µM size range (Figure 4B).

Based on microscopic counts averaged over all stations within each river, the phytoplankton community in the Sacramento River was composed of 38% flagellates, 32% chlorophytes, 12% centric diatoms, 12% pennate diatoms, 6% cryptophytes and <0.5% blue-green algae (Figure 5A and Table 3). The genus of the most common algal species in the Sacramento River was a flagellate that could not be identified from the preserved samples. The most commonly seen identifiable species in the Sacramento River were the pennate diatom *Navicula* and the cryptophyte *Cryptomonas*. Phytoplankton abundance was higher in the San Joaquin River compared to the Sacramento River and was dominated by centric diatoms, including *Cyclotella sp.* and *Melosira sp.* (Figure 5B, Table 2). Averaged over all stations, the San Joaquin River contained 43% centric diatoms, 26% flagellates, 20% chlorophytes, 6% cryptophytes, 4% pennate diatoms and 1% blue-green algae (Figure 5B and Table 3). The most frequently seen genera of chlorophytes in the San Joaquin Rivers were *Tetraedron* and *Chlorella* (Table 2).

The Fluoroprobe measurements of chlorophyll-*a* and accessory pigment fluorescence determined that the phytoplankton community in the Sacramento River was made up of; 35% “brown” algae, 59% “green” algae, 1% “blue-green” algae, and 5% “cryptophytes” (Figure 6A and Table 3). The peak pigment concentration in the Sacramento River was located at station US649 (3.0 µg/L). The average total pigment concentration for the Sacra-

Table 2 Five most frequently observed identifiable phytoplankton genera in the Sacramento and San Joaquin rivers ranked by abundance. These genera represent only those that could be identified by inverted microscopy.

	Sacramento River		*San Joaquin River*
1	*Navicula* (pennate diatom)	1	*Cyclotella* (centric diatom)
2	*Crytomonas* (cryptophyte)	2	*Melosira* (centric diatom)
3	*Pyramimonas* (chlorophyte)	3	*Cryptomonas* (cryptophyte)
4	*Tetraedron* (chlorophyte)	4	*Tetraedron* (chlorophyte)
5	*Frustulia* (pennate diatom)	5	*Chlorella* (chlorophyte)

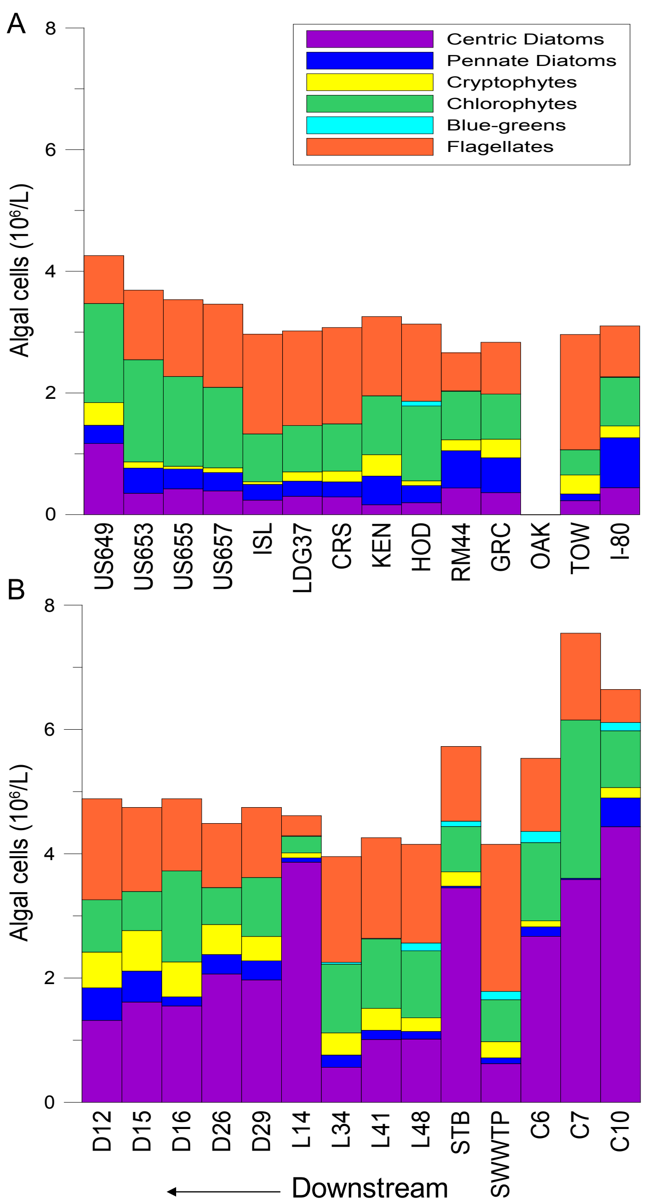

Figure 5 Phytoplankton abundance and community composition along the Sacramento (A) and San Joaquin (B) rivers determined by microscope counts

mento River was 1.6 µg/L, 2.6 times lower than in the San Joaquin River (average = 4.1 µg/L). In the San Joaquin River the phytoplankton community was determined to be 58% "brown" algae, 33% "green" algae, 1% "blue-green" algae, and 8% "cryptophytes" (Figure 6B and Table 3).

Discussion

The contrast in the physical and chemical environments of the Sacramento and San Joaquin rivers provided a natural system for testing how direct (microscopy) and indirect (chlorophyll-*a*, flow cytometry, and FluoroProbe) methods for characterizing phytoplankton communities would show differences in community structure during the spring bloom period. Our hypotheses were that 1) phytoplankton communities will be less abundant and dominated by flagellates in the Sacramento River, the San Joaquin River will have more algal biomass and be dominated by diatoms, and 2) using a combination of measuring size fractionated chlorophyll-*a*, flow cytometry, and spectrofluorometry is sufficient to characterize phytoplankton communities at a functional group level. Using these indirect measures would provide data almost in real time and minimize the need for expensive and time consuming direct taxonomic microscope enumeration. It is important to recognize that these methods cannot be directly compared to one another as they provide data that complement one another but are not appropriate for absolute comparison. In our analysis, we highlight the differences between phytoplankton communities of the Sacramento and San Joaquin Rivers and see whether the different approaches used generally describe a similar pattern of phytoplankton community composition, and if not, identify limitations. Overall, the patterns that emerged using the indirect and direct approaches showed consistent spatial trends in these variable river environments. For example, flow cytometry, the FluoroProbe, and size fractionated chlorophyll-*a* showed more phytoplankton and larger cells in the San Joaquin River compared to the Sacramento River.

The U-shaped distribution seen in the indirect approaches from upstream to downstream stations in the Sacramento River was previously described for chlorophyll-*a* along a spring 2009 transect in the Sacramento River by Parker et al. (2012). Accompanying the decrease in chlorophyll-*a* they observed a 50% decrease in primary production at the stations adjacent to the SRWWTP compared to upstream stations. The depressed primary

Table 3 Comparison of microscopy versus FluoroProbe determinations of phytoplankton community structure in the Sacramento and San Joaquin rivers, during spring 2010

		% Contribution in Sacramento River		*% Contribution in San Joaquin River*	
Microscope (Functional Groups)	FluoroProbe (Fluorescent Groups)	Microscopy	FluoroProbe	Microscopy	FluoroProbe
Centric Diatoms		12		43	
Pennate Diatoms	Browns	12	35	4	58
Flagellates (dinoflagellates)		38		26	
Cryptophytes	Cryptophytes	6	5	6	8
Greens (flagellates)	Greens	32	59	20	33
Cyanobacteria	Blue-Green	0	1	1	1

production and phytoplankton biomass was hypothesized to result from the input of wastewater effluent-NH_4. According to Dugdale et al. (2007), elevated NH_4 concentrations inhibit diatom growth. Our results are consistent with these hypotheses as phytoplankton in the Sacramento River were dominated by flagellates over diatoms (while the San Joaquin River was dominated by diatoms).

Overall, the trends that emerged using the indirect approaches were consistent between the two river environments, with higher overall phytoplankton biomass in the San Joaquin River and a majority of larger cells (flow cytometry), dominated by "browns" (FluoroProbe). In contrast, the Sacramento River phytoplankton biomass was lower, the majority of cells were smaller (flow cytometry), and the phytoplankton community was dominated by "greens" (FluoroProbe). These indirect approaches compared well with the patterns seen in direct microscope counts and size fractionated chlorophyll-*a* (Figures 3, 5 and 6). Supporting the FluoroProbe results, the San Joaquin River was dominated by centric diatoms (*Cyclotella* and *Melosira*) that have brown fucoxanthin pigment while the Sacramento River had a high proportion of flagellates, which could have been small flagellate chlorophytes.

Each of the direct and indirect methods used in this study has advantages and limitations both inherent in the technique and subject to the experience of the user. While microscopy is labor intensive and requires experienced taxonomic knowledge it is the only method that provides identification to genus and cell abundance that can be compared directly with the long-term Department of Water Resources record. Chlorophyll-*a*, a proxy of biomass, can be compared to long term records for chlorophyll but is relatively crude in that it provides no information on community composition. However chlorophyll-*a* mea-

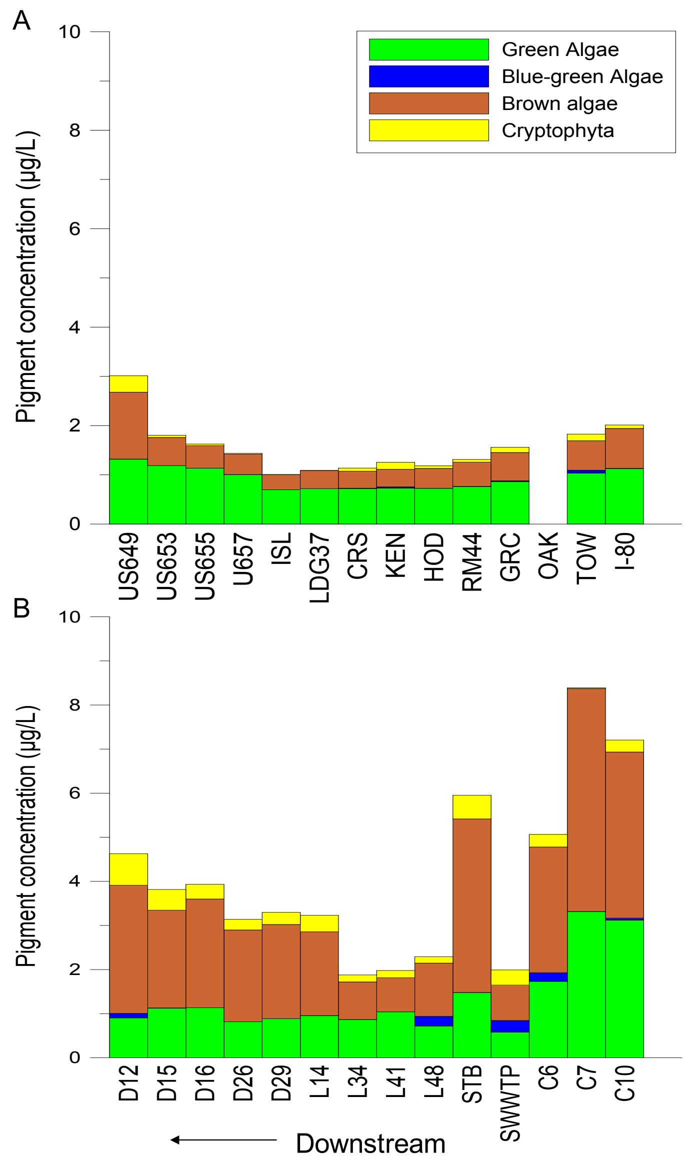

Figure 6 Phytoplankton community composition as measured by the bbe FluoroProbe Sacramento (A) and San Joaquin (B) rivers

surements can be made with very little training or experience, are relatively inexpensive, and data are available almost immediately. Flow cytometry used in the context of this study gives size distribution of particles and phytoplankton enumeration. Size distributions provide an indication of the type of phytoplankton making up the community and may also be compared with size-fractionated chlorophyll-*a*. The flow cytometer can effectively count phytoplankton by combining the advantages of microscopy for its identification power and the use of the flow cytometer for its speed (http://www.cytobuoy.com/).

The flow cytometer has the ability to detect the fluorescence emitted by some accessory pigments in algal cells at two different wavelengths other than chlorophyll-*a*: 536-601 nm for phycoerythrin and 601-668 nm for phycocyanin (Takabayashi et al. 2006). The flow cytometer was not quantitatively used for this purpose in this study, but preliminary analysis of the phycoerythrin and phycocyanin in our samples fit well with our finding that there was a relatively small contribution of cyanobacteria (phycocyanin) and cryptophytes (phycoerythrin and phycocyanin) in both river transects, which was also shown by microscope counts and FluoroProbe results.

Aside from direct microscope counts, the FluoroProbe provides the most comprehensive information about phytoplankton community composition. Although the FluoroProbe distinguishes and quantifies four taxonomic groups based on accessory pigments, it is difficult to compare the FluoroProbe data with microscopy counts of preserved samples in a mixed community because flagellate cells may have pigments in the "green" fluorescence range or the "brown" fluorescence range and many unidentified flagellates could belong to either group (Table 3). The "brown" group was assumed to be mostly diatoms since they are more common than dinoflagellates in the Sacramento-San Joaquin Delta (Greenberg 1964, Leland et al. 2001, Brown 2010, Lehman 2000a, Cloern and Dufford 2005), but brown algae included in the FluoroProbe settings could also represent chrysophytes and dinoflagellates. There is no way to distinguish which phytoplankton genera make up the total pigment concentration from the "brown" group but assumptions can be made based on the overlap with microscopy counts (Table 3). The dominance of diatoms (or the "brown" group) in the San Joaquin River as compared to the dominance of flagellates (possibly chlorophytes) in the Sacramento River was shown by both methods. It has also been shown that the algal culture species used to calibrate the FluoroProbe will affect the accuracy of the measurements (Lawrenz and Richardson 2011). For the bbe FluoroProbe used in this study (Mueller-Solger, personal communication, see "Notes") calibration results showed that browns and cryptophytes may be underestimated while greens overestimated. This study showed the FluoroProbe underestimated chlorophyll-*a* measurements (Figure 7), this could result in an underestimate of the "brown" group and cryptophytes as reported by the FluoroProbe (Table 3).

This study showed consistent trends with previous studies on the phytoplankton abundance and composition of the Sacramento and San Joaquin rivers. Working with a long term data set collected by the Department of Water Resources' Environmental Monitoring Program, Brown (2009) reported a significant difference in the phytoplankton communities of the 1990s and 2000s compared to the 1970s due to a severe decrease in centric diatoms and increase in flagellate taxa. Demonstrating that historically diatoms dominated and that there has been a shift to flagellates in the Sacramento River, Greenberg (1964) noted the dominant phytoplankton in the Sacramento River were diatoms, specifically *Synedra*, *Melosira*, and

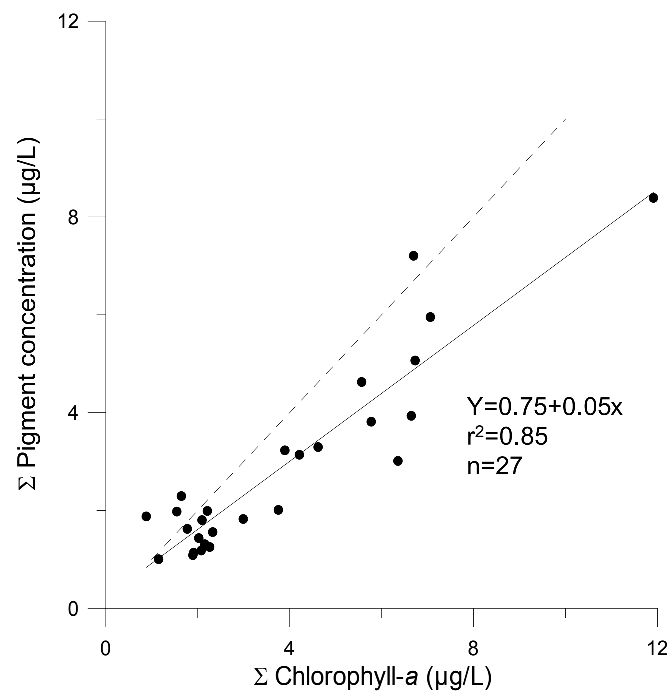

Figure 7 Total pigment concentration measured by the bbe FluoroProbe vs. Chlorophyll-*a*. The dashed line represents 1:1; solid line is the model II least squares regression.

Cyclotella. While *Synedra* was sometimes present in our Sacramento River samples, *Melosira* and *Cyclotella* were not, but they were two of the dominant genera of the San Joaquin River. Based on the dominance of flagellates found in the Sacramento River during this study, and these previous studies, it would appear there has been a shift from a diatom to a flagellate dominated community. While assessing chlorophyll-*a* concentrations and phytoplankton community composition in the SFE-Delta, Gehrts et al. (2004) noted that the peak chlorophyll-*a* concentrations in the Sacramento River were dominated by the diatom *Achnanthes gibberula*. The genus *Achnanthes* was seen in a few of our Sacramento River samples but was far outnumbered by flagellates. Gehrts et al. (2004) also showed peak chlorophyll-*a* concentrations in the spring at stations in the San Joaquin River (including C10) that were higher than the peak in the Sacramento River, and were also dominated by centric diatoms, as was also shown in this study. Lehman (1998, 2000a, 2000b) described the phytoplankton community of the SFE-Delta to have shifted from diatoms to flagellates, due to changes with climate variations caused by interdecadal climate regime shifts between 1975 and 1993. Kimmerer (2005), using long-term silicate measurements in the SFE-Delta, linked a decrease in silicate uptake to the decline in diatom biomass caused by elevated benthic grazing. Size selectivity of benthic grazers has also been cited as a reason for the shift from larger diatoms to smaller flagellates (Werner and Hollibaugh 1993, Greene et al. 2011). Other explanations for the decrease in phytoplankton biomass and shift from diatoms to flagellates may be due to diminished access by diatoms to the nitrate pool by increased levels of ammonium (Dugdale et al. 2007), changes in phosphorus delivery to the estuary (Van Nieuwenhuse 2007), and changes in N:P ratios (Glibert 2010, Glibert et al. 2011).

Finer scale spatial patterns within each river were also consistent for the three indirect methods. For the Sacramento River, chlorophyll-*a*, flow cytometry, and FluoroProbe showed higher levels of phytoplankton upstream of the SRWWTP (I-80 to GRC), a mid-river region of relatively low phytoplankton measures (RM44 to ISL), and a return to upstream levels at downstream stations (US657-US649). The microscope counts for the Sacramento River show a similar trend except that phytoplankton abundances at the upstream stations were similar to those at mid-river. Microscope counts did show the increase in phytoplankton measures at downstream stations (US657 to US649) apparent in the data from the indirect approaches. This difference in the upstream pattern could be due to the high amount of detritus seen in the upper Sacramento River stations (I-80 to GRC). Microscope counts were limited to cells >2 μM in size. High levels of detritus may have obstructed the microscopic count of smaller sized cells for these stations. The Secchi depth was also low at these stations (average of 0.5 m) which indicates high levels of detritus (data not shown). The flow cytometer filters out non-fluorescent particles and, like the FluoroProbe, can include smaller particles. The Sacramento River's lower overall abundance compared with the San Joaquin River was apparent in both the direct and indirect approaches.

For the San Joaquin River, direct and indirect measures showed similar trends with the highest phytoplankton biomass occurring upstream of the SWWTP (C10 to C6), a dip at the station nearest the SWWTP, a return to upstream levels at station STB, a sharp decrease at stations L48 to L34, and then a gradual increase downstream (L14 to D12). Disregarding station STB's increase abundance, which we expected due to high residence times at this station, the San Joaquin River also displayed a U-shaped distribution of phytoplankton biomass moving downstream. Overall, the San Joaquin River had higher phytoplankton biomass and a greater proportion of cells in the larger size class compared to the Sacramento River. These results fit well with direct counts that showed a high level of centric diatoms in the San Joaquin River, which generally fit into the larger size range. The majority of centric diatoms seen in the San Joaquin River also compare well with FluoroProbe results that indicated a dominance of "brown" algae (58%) in the San Joaquin River (Table 3).

A necessary assumption when using fluorometry to measure chlorophyll-*a* is that fluorescence intensity per unit of chlorophyll-*a* is constant (Lawrenz and Richardson 2011). However it has been recognized that this relationship is not constant and varies between species (Strickland 1968, Holm-Hansen et al. 1965). The trends in *in vivo* chlorophyll-*a*, determined by the FluoroProbe in this study, were consistent with chlorophyll-*a* trends measured in extracted samples (Figure 7). However, regression analysis of FluoroProbe chlorophyll-*a* and extracted chlorophyll-*a* collected at all locations in both rivers indicate that the FluoroProbe underestimates chlorophyll-*a* by approximately one quarter (i.e. 75% of extracted chlorophyll-*a* is reported by the FluoroProbe) (Figure 7).

Similar underestimations of chlorophyll-*a* by the FluoroProbe (~60%) were seen in three rivers of the Czech Republic (Gregor and Marsalek 2004). It was speculated to be the result of "fluorescence quenching" in subsurface waters due to high irradiance. Alternatively, low chlorophyll-*a* estimates may be a function of a high number of suspended particles that scatter excitation light from the FluoroProbe receptors. The high sediment conditions of the SFE-Delta likely exacerbate this potential problem, as well as fluorescent responses from phytoplankton cells.

Gregor et al. (2005) reported that FluoroProbe readings compared well with microscope counts in a number of reservoirs and concluded that when detailed community composition determinations are not necessary, the FluoroProbe was a good screening tool for phytoplankton quantification. Discrepancies only occurred when samples had low concentrations of chlorophyll and when the same phytoplankton community was being compared at different stages of growth or depths in the water column. Twiss (2011) noted that while the FluoroProbe does account for "yellow substances" or chromorphic dissolved organic matter (CDOM), different FluoroProbe instruments are not equally accurate when measuring within a specific fluorescence range, so careful calibration should be made.

The spatial trends seen across the river transects were consistent between chlorophyll and flow cytometry results, however, it is difficult to compare these measures directly because the measurement units are different between methods. It was assumed in both approaches that the biomass measured (either as chlorophyll-*a* or fluorescent particle counts) was attributed to phytoplankton. While the trends were the same, the absolute numbers and relative fractions were inconsistent between the percent contribution of cells in the >5 μM range reported by chlorophyll-*a* versus the flow cytometry. Chlorophyll-*a* results indicate a 78% and 66% contribution of the larger size class in the San Joaquin and Sacramento rivers, respectively. The flow cytometer displayed 64% of fluorescent particles in the 5-50 μM range for the San Joaquin River and 44% for the Sacramento River. This discrepancy may be explained by the majority of fluorescent particles in the Sacramento River belonging to the 2-5 μM size range, which is on the border of the chlorophyll-*a* size group cutoff (Figure 4). Interestingly, the flow cytometer underestimated total cell counts compared to microscopy direct counts, this could be due to the flow cytometer missing a certain size class or counting error on the microscope due to the high amount of detritus in river samples, such that detritus may have been counted as small flagellates since most flagellates were coated in debris. Another possible reason for this inconsistency is the difference in the volume of sample analyzed by the flow cytometer vs. the volume of the sample settled for analysis by direct microscope counts. Twenty ml samples were collected for analysis by the flow cytometer but only ~1 ml of each sample is examined for the output, in contrast 250 ml samples were collected for microscope counts and 27 ml aliquots were settled for identification.

Given the documented changes in the phytoplankton community of the SFE and phytoplankton's importance in the trophic dynamics of the estuary (Glibert et al. 2011, Brown 2010, Cloern and Dufford 2005, Jassby et al. 2003), characterization of the phytoplankton community is essential. Taken together, these indirect approaches may provide a valuable alternative to the high cost, labor intensive direct microscopy approach for characterizing the phytoplankton community in the freshwater portion of the SFE system. These approaches offer high throughput and low cost alternatives, allowing determination of phytoplankton community structure on broad temporal and spatial scales.

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Notes

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