Interagency Ecological Program for the San Francisco Estuary

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Of Interest to Managers

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This issue of the Interagency Ecological Program (IEP) newsletter includes five status and trends articles. Three articles utilize Bay Study data to report on Bay Study fishes, shrimp, and crabs from 2012 to 2016. The additional articles include one describing zooplankton trends through 2016, and the other describing pelagic fish trends in 2017 from long term monitoring projects.

The first three articles use the Bay Study data to report on the status and trends of Bay Study fishes, shrimp, and crabs from 2012 to 2016. In the first article, **Kathryn Hieb**, **Jeremiah Bautista**, and **Jennifer Giannetta** (CDFW) discuss the distribution and abundance of both marine pelagic and upper estuary demersal fishes caught by the Bay Study during this period. Possible relationships between these trends and physical characteristics such as sea surface temperature, Delta outflow, or climate events are also mentioned. The second article **Kathryn Hieb** (CDFW) discusses the annual abundance and distribution of commonly collected Caridean shrimp by the Bay Study otter trawl focusing on 2012 to 2016. The pattern for juvenile, adult, ovigerous, and total (all sizes and sexes) is described for each shrimp species. For the third article, **Kathryn Hieb** (CDFW) presents relative abundance indices and distribution patterns on common crabs found in the San Francisco Estuary. An important commercial species, Dungeness crab, had the highest index in 2013 and varied in distribution between years based on water temperature or life stage. The other common *Cancer* crab species, *C. antennarius*, *C. gracilis*, and *C. productus*, fluctuated in abundance during the reported years with *C. productus* being the least common, and *C. antennarius* increasing from 2012 to 2015.

In the fourth article, **April Hennessy** (CDFW) reports on the distribution and relative abundance of zooplankton in 2016 in comparison to long term trends observed since 1974. Several zooplankton groups increased in 2016 compared to 2015. Calanoid copepods increased in winter 2016 compared to previous winters, including *Eurytemora affinis*, which had a winter abundance that exceeded all other seasons for the first time. The introduced cyclopoid copepod *Limnoithona* spp. had a record high fall abundance and *L. tetraspina* remains the most abundant copepod in the upper estuary. Mysids also increased in 2016 and the native mysid *Neomysis kadiakensis* showed record high fall abundance while the introduced mysid *Hyperacanthomysis longirostris* continues to be the most abundant. Both mysids and calanoid copepods are important food sources for native fish.

In the last article, **James White**, **Felipe La Luz**, and **Christina Burdi** (CDFW) report on the pelagic fish trends during the 2017 water year from four IEP long term monitoring surveys. Catch patterns and abundance indices are presented for American Shad, Threadfin Shad, Delta Smelt, Longfin Smelt, Splittail, Wakasagi, and age-0 Striped Bass. Abundance indices increased for American Shad, Longfin Smelt, Splittail, and age-0 Striped Bass and decreased for Threadfin Shad compared to 2016, but remain low compared to historical values. Wakasagi, a species closely related to and capable of hybridizing with Delta Smelt, were detected as far downstream as Napa River and Suisun Bay, which is similar to previous wet years. Delta Smelt showed slight increases in the abundance indices for larvae and juveniles, but remain at historically low levels with the lowest index for sub-adults ever recorded.

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

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

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

Status and Trends

Bay Study Fishes Status and Trends Report for the San Francisco Estuary, 2012–2016

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Introduction

The 2012 to 2016 San Francisco Bay Study (Bay Study) Status and Trends fishes report includes demersal species from the entire estuary and pelagic species from the lower estuary. Results for the upper estuary pelagic species, including American Shad, Delta Smelt, Longfin Smelt, and Striped Bass, were reported in the "2015 Pelagic Fishes Upper Estuary Status and Trends Report" with the Summer Townet and Fall Midwater Trawl results, published in the Summer 2016 IEP Newsletter (Finstad and Baxter 2016). The most recent abundance indices, long-term abundance trends, and distributional information are presented here for common fishes and some less-common species of interest, such as the surfperches and several subtropical species collected in the reporting period. Presented first are the upper estuary demersal fishes, followed by the marine pelagic fishes, surfperches, marine demersal fishes, and the subtropical species. Within each section, species are presented phylogenetically.

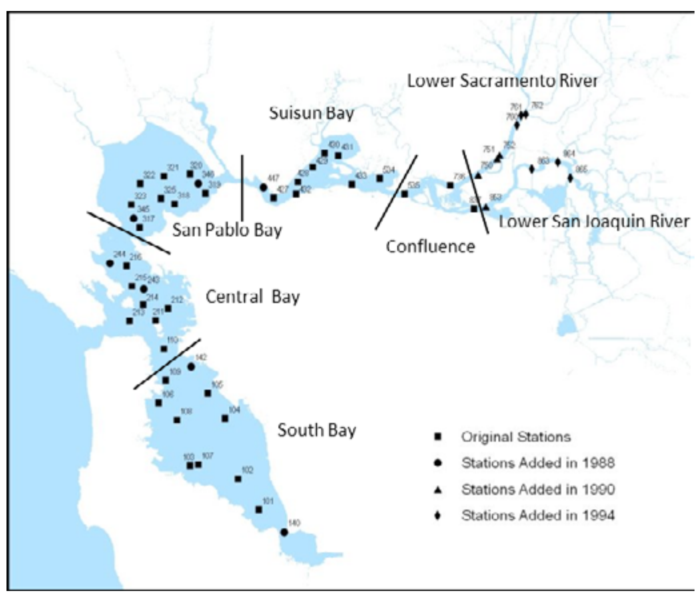
Methods

The Bay Study has sampled from South San Francisco Bay to the western delta monthly since 1980 with an otter trawl and midwater trawl deployed from a fisheries research vessel. There are some data gaps, most significantly: limited midwater trawl sampling in 1994, no winter sampling from 1989 to 1997, limited sampling at stations in and near the confluence of the Sacramento and San Joaquin rivers in 2007 and 2008 to reduce Delta Smelt take, and 7 missed surveys in 2016 (January, February, March, April, August, September, and October 2016 were not sampled). Because of these gaps we were not able to calculate pelagic fish indices for 1994 and indices for most species for 2016. Otherwise, abundance indices were routinely calculated for 35+ fishes and several species of crabs and caridean shrimp. Only the fishes are included in this report; the crabs and shrimp are subjects of separate Status and Trends reports, published in this issue of the IEP Newsletter on pages 30 and 43, respectively.

The Bay Study currently samples 52 stations (Figure 1); of these, 35 were consistently sampled since 1980 ("core" stations) and used to calculate abundance indices. Stations added in 1988, 1991, and 1994 are used for distributional analyses and to track abundance of species common in the western delta. Stations are fairly evenly distributed between channels and shoals in most regions, although depths <3 meters are not sampled. Most stations have a soft substrate, such as mud, sand, or a mix of shells – we intentionally avoid rocky areas and eelgrass beds. Additional information about study methods, including index calculation, can be found in IEP Technical Report 63 (Baxter et al. 1999).

Bay Study midwater trawl data was used to describe abundance trends and distributional patterns of pelagic fishes and the otter trawl data was used for demersal fishes. Annual and monthly abundance indices were used for annual and seasonal abundance. Catch-per-unit-effort (CPUE), as catch per tow standardized 12 minutes tow time for the midwater trawl or 5 minutes tow time for the

Figure 1. Map of open water stations sampled by the San Francisco Bay Study with the midwater and otter trawls.



otter trawl, was used for distribution by station, region, and channel-shoal. In addition, annual CPUE (catch per tow) was used for Shokihaze Goby abundance trends, as it was common upstream of the "core" stations used for abundance indices. In 2016, sampling was limited to May to July, which was only a portion of the index period for most species, and November and December, months not used for most indices. Therefore, we calculated May to July CPUE (catch per tow) to compare 2016 abundance to 2012-2015 and previous years for many fish species.

We included an updated analysis of the upper estuary demersal fish community, first done for an IEP workshop presentation in 2008. For this, we first categorized fish common to the estuary upstream of Carquinez Strait as either demersal or pelagic and native or introduced. We next calculated CPUE (catch per hectare) by station for each major species including Striped Bass, Yellowfin Goby, Shokihaze Goby, and Starry Flounder, and groups such as introduced gobies, all natives, and other introduced species. We then averaged the station CPUE for all stations and all months sampled in the year for an annual species and group CPUE. These annual CPUEs were used to describe abundance trends of the upper estuary demersal fish community and relative abundance, as percent CPUE.

We also updated an analysis of Northern Anchovy catch by salinity zone, first conducted by Kimmerer (2006). Northern Anchovy June to October total catch (all sizes) was averaged and log-transformed for each of three salinity zones: high (>20 psu), medium (10 to 20 psu), and low (0.5 to 10 psu). The annual catch was plotted for each salinity zone to examine trends over time.

Several physical data sets were used to describe the oceanic and estuarine environmental conditions that were then related to abundance trends and distributional patterns. Daily outflow at Chipps Island (Dayflow, DWR, see "Notes") from October 2011 to September 2016 were plotted and the 1979 to 2016 daily values were averaged to monthly values and plotted. Monthly Pacific Decadal Oscillation (PDO) indices, from Nathan Mantua (University of Washington, see "Notes"), and North Pacific Gyre Oscillation (NPGO) indices, from Emanuele Di Lorenzo (Georgia Institute of Technology, see "Notes"), were plotted for 1950 to 2016. Monthly ocean upwelling anomalies (base period 1955-2016, 39°N), from the NMFS Pacific Fisheries Environmental Laboratory (see "Notes"), were plotted from 1979 to 2016. Daily sea surface temperatures (SSTs), from Southeast Farallon Island (SEFI, Point Blue Conservation Science and Scripps Institute of Oceanography, see "Notes"), were used to calculate monthly values and anomalies (base period 1955-2016). Monthly SST anomalies and monthly SSTs from 1979 to 2016 from SFEI were plotted. In addition, we plotted monthly SSTs from Buoy 142 (National Data Buoy Center, see "Notes") and SFEI for 2010 to 2016; Buoy 142 is 12.5 km (7.75 miles) from the Golden Gate in the Gulf of the Farallones, while SFEI is 40 km (25 miles) from the Gate. Finally, monthly near surface water temperature from Fort Point, at the south end of the Golden Gate Bridge (National Data Buoy Center, see "Notes"), and monthly near bottom water temperature from the Richmond-San Rafael, San Mateo, and Benicia bridges (USGS, see "Notes) were plotted for 2010 to 2016.

Results

Physical Setting

The period of 2012 to 2016 was one of extreme climate events in California, including: 1) An unprecedented "hot" drought from 2012 to 2015, with record low snowpack in 2015 (Griffin and Anchukaitis 2014, Belmecheri et al. 2016, Mote et al. 2016) and record high air temperatures (Swain 2015, Luo et al. 2017), 2) The development of a large region of warm ocean water in the North Pacific in 2013 that extended throughout the California Current System (CCS) in 2014 and 2015 (Bond et al. 2015), and 3) A strong El Niño event from 2015 to 2016 (Jacox et al. 2016). The 2013 to 2015 warm water event was originally called "The Blob" in the literature (Leising et al. 2015), but eventually was termed the North Pacific marine heatwave (Di Lorenzo and Mantua 2016). This marine heatwave combined with the 2015-16 El Niño resulted in the warmest 3-year period on record (1920-2016) in the CCS (Jacox et al. 2018).

In 2015, a combination of warm ocean temperatures and increased nutrients provided by seasonal upwelling created a toxic algal bloom with record-breaking concentrations of the neurotoxin domoic acid from Southern California to Washington (McCabe et al. 2016). The bloom impacted all levels of the food chain and closed several commercial and recreational fisheries in 2015 and 2016 along the west coast, including mussels, razor clams, rock crab, Dungeness crab, Northern Anchovy and Pacific Sardine. Domoic acid was also detected in whales, dolphins, porpoises, and seals, and led to a substantial increase in the number of stranded and dead sea lions. This was the largest toxic bloom reported on the west coast of North America and the largest geographic area of marine mammals detected with domoic acid globally (McCabe et al. 2016).

After relatively high Delta outflow in 2011, outflow decreased each year from 2012 to 2015, then increased slightly in 2016 (Figure 2, Table 1). 2011 was classified "Wet" per DWR's Sacramento Valley Hydrologic Classification Index, while 2012 to 2016 were classified as "Below Normal", "Dry", or "Critical" (Table 1). The January to June average daily outflow at Chipps Island decreased from 57,667 cfs in 2011 to approximately 7,700 cfs in 2014 and 2015, then increased to 24,869 cfs in 2016 (Table 1). Most of the past decade had low freshwater outflow (Figure 2); from 2007 to 2016, only 2011 was not classified as "Below Normal" to "Critical" (Table 1).

The outflow pattern differed each year in the timing, magnitude, and duration of peak outflow events (Figure 3). In 2012, there was a small peak in February, with several larger peaks from mid-March to early April. In 2013, outflow peaked in early December (2012) and early January, while in 2014, there were small outflow peaks in February, March and early April. In water year 2015, there was a peak in December (2014) and a smaller peak in early February. The higher outflow year of 2016 had peaks in January and from March to early April.

Figure 2. Mean monthly Delta outflow (cfs) at Chipps Island, 1979-2016.

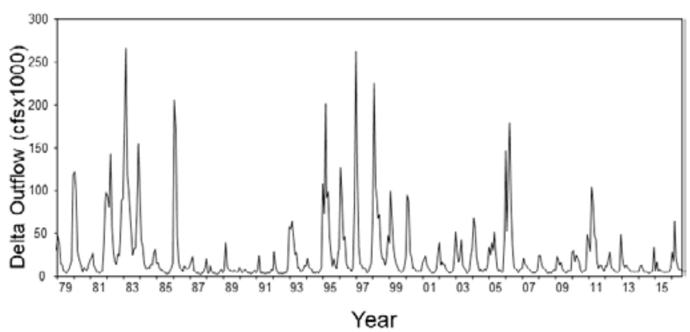
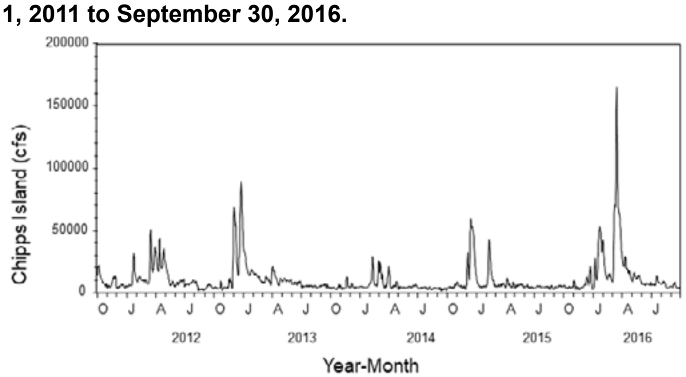


Figure 3. Daily Delta outflow (cfs) at Chipps Island, October 1, 2011 to September 30, 2016.



The San Francisco Estuary is situated between two major marine faunal regions, the cold-temperate fauna of the Pacific Northwest and the warm-subtropical fauna of southern and Baja California, and is a transitional area with elements of both faunal groups (Parrish et al.

Table 1. Mean monthly Delta outflow at Chipps Island (cfs), January-June and March-May and Water Year Types based on DWR's Sacramento Valley Index, 1980-2016.

Year	*January-June*	*March-May*	*Water Year Type*
1980	67,208	49,528	Above Normal
1981	15,228	15,758	Dry
1982	83,069	93,354	Wet
1983	136,638	161,127	Wet
1984	35,165	20,215	Wet
1985	10,062	8,182	Dry
1986	76,940	77,266	Wet
1987	10,839	11,324	Dry
1988	7,711	6,852	Critical
1989	12,355	19,331	Dry
1990	6,493	5,812	Critical
1991	7,913	10,714	Critical
1992	10,232	7,599	Critical
1993	45,573	44,484	Above Normal
1994	10,302	8,895	Critical
1995	102,768	129,843	Wet
1996	58,588	59,067	Wet
1997	74,964	20,112	Wet
1998	104,267	86,795	Wet
1999	46,237	42,277	Wet
2000	43,643	45,760	Above Normal
2001	14,607	15,118	Dry
2002	16,784	14,160	Dry
2003	28,773	26,590	Above Normal
2004	32,781	30,244	Below Normal
2005	34,331	39,820	Above Normal
2006	101,589	125,386	Wet
2007	12,002	11,563	Dry
2008	14,333	9,992	Critical
2009	14,162	15,951	Dry
2010	22,645	20,803	Below Normal
2011	57,667	78,746	Wet
2012	15,152	20,130	Below Normal
2013	12,697	10,853	Dry
2014	7,676	8,270	Critical
2015	7,776	6,290	Critical
2016	24,869	32,227	Below Normal

1981, Briggs and Bowen 2012). The northern Pacific Ocean entered a cold-water regime in 1999 (Peterson and Schwing 2003), which was hypothesized to benefit many cold-temperate species, including Dungeness crab, English Sole, and many of the rockfishes (Cloern et al. 2010, McClatchie et al. 2016). This most recent cold-water regime was preceded by a warm-water regime from 1977 to 1998, which resulted in increased abundance of warm-subtropical species in San Francisco Estuary, including California Halibut, White Croaker, Pacific Sardine, and California Tonguefish.

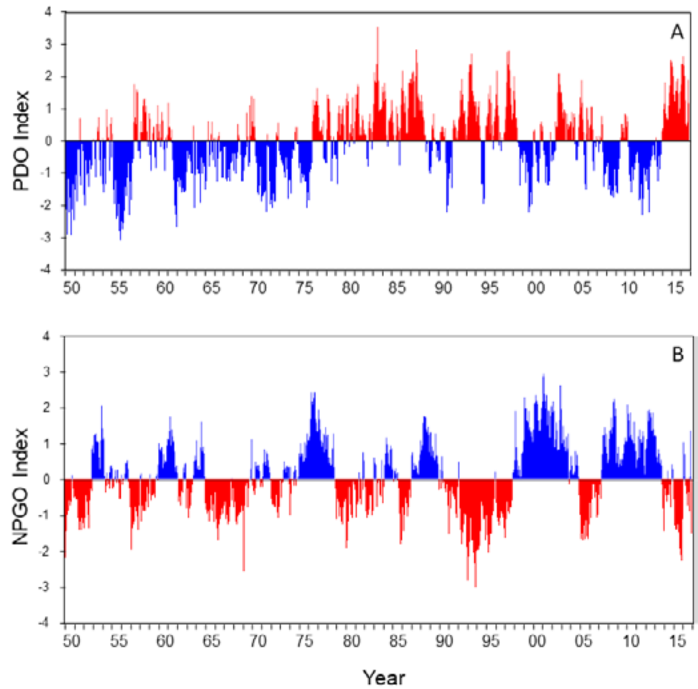
Northward movement of subtropical fishes and invertebrates during El Niño events is well documented (Lluch-Belda 2005). This may be movement of juveniles and adults with the warmer water or transport of planktonic eggs and larvae northward with currents (Lenarz et al. 1995). During El Niño events, internal Kelvin waves transport tropical water east to west along the equator and then north and south towards the poles when the waves reach South America (Fiedler and Mantua 2017). This poleward movement of warm water is believed to transport planktonic life stages from south to north within the CCS and could be especially important for subtropical species with a long pelagic larval duration (Higgins et al. 2017), including the California Tonguefish (*Symphurus atricaudus*), California Lizardfish (*Synodus lucioceps*), and Spotted Cusk-Eel (*Chilara taylori*).

The PDO and NPGO are 2 basin-scale ocean climate indices. The PDO drives upwelling north of 38°N while the NPGO drives upwelling south of 38°N, with San Francisco Estuary situated at approximately 38°N. A positive PDO index is associated with warmer ocean temperatures, a stronger Alaska Current, and a weaker California Current, while a positive NPGO index is associated with increased salinity, upwelling, nutrients, and primary production and a stronger California Current (Di Lorenzo et al. 2008, Di Lorenzo et al. 2009).

Major ecosystem regime shifts have occurred in the North Pacific when the PDO and NPGO show strong, simultaneous, and opposite sign reversals, such as in 1999 (Di Lorenzo et al. 2008). During cold-water regimes, the PDO indices were generally negative and the NPGO indices positive (Figure 4), with frequent La Niña events, while warm-water regimes generally had positive PDO indices and negative NPGO indices, with frequent and strong El Niño events.

Note that the positive PDO indices and negative NPGO indices in 2014 and 2015 were not entirely associated with an El Niño event. These indices reflected the well-documented North Pacific marine heatwave, which interacted with and was followed by an El Niño event that developed in 2015 and continued through early 2016 in the tropics. The development of the 2015-2016 El Niño event was affected by the North Pacific heatwave, while the El Niño event in turn fed back to the heatwave via teleconnections (Di Lorenzo and Mantua 2016). This resulted in a more extreme heatwave, which in combination with the 2015-2016 El Niño event, affected a similar area as the large 1997-1998 El Niño event, but lasted longer (McClatchie et al. 2016).

Figure 4. A) Monthly Pacific Decadal Oscillation (PDO) indices and B) Monthly North Pacific Gyre Oscillation (NPGO) indices, 1955-2016.



The coastal ocean along central California is marked by 3 seasons: the upwelling season, from spring to late summer; the oceanic season, from late summer to late fall; and the Davidson Current season, from late fall to spring. Many coastal fish and invertebrate species in the CCS reproduce in winter during the Davidson Current season, when pelagic eggs and larvae are likely to be transported to or retained in nearshore areas (Parrish et al. 1981). Juveniles of most species settle nearshore and enter estuaries to rear before the onset of upwelling, as pelagic life stages present during the upwelling season could be transported offshore, often far from their preferred nearshore nursery areas.

From 2012 through 2014, coastal upwelling anomalies were well above average for many months, especially summer 2012, early 2013, and summer 2014 (Figure 5A). Upwelling was weakest from late 2014 through spring 2016, corresponding with high SST anomalies (Figure 5B), but anomalies were still positive many months. Warm water from the North Pacific marine heatwave resulted in Gulf of the Farallones (GOF) SST anomalies of 2 to 3°C in fall and winter of 2014 and from July to October 2015 (Figure 5B), with SSTs near 17°C for several months (Figure 6). These were by far the highest water temperatures since 1999, when the northern Pacific Ocean shifted to a cold-water regime. SSTs near 17°C were also recorded during the large 1982-83 and 1997-98 El Niño events (Figure 6). SST anomalies were 1 to 1.5°C in fall and winter of 2015-16 (Figure 5B), when the El Niño event rather than the marine heatwave dominated. When upwelling returned in April 2016 (Figure 5A),

Figure 5. A) Monthly upwelling index anomalies (39°N), 1979-2016 and B) Monthly Sea Surface Temperature (°C) anomalies from Southeast Farallon Island, 1979-2016. Both figures used 3-month running means to slightly smooth the data.

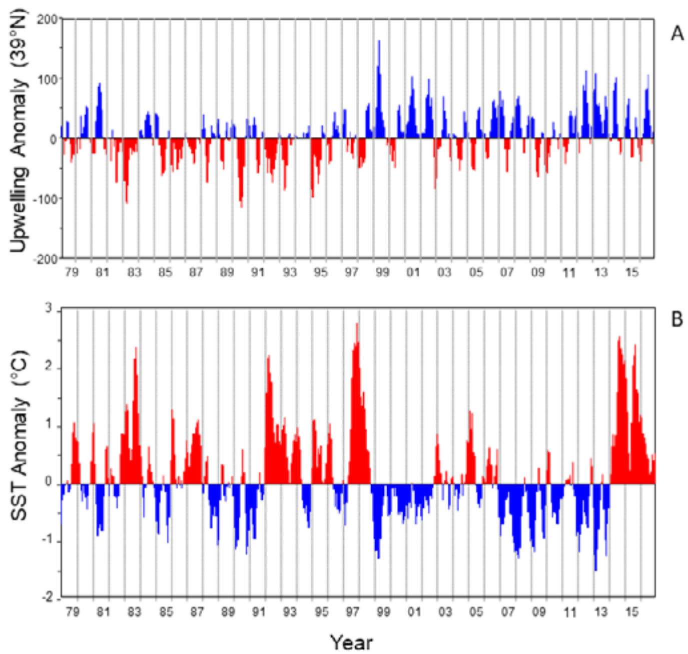
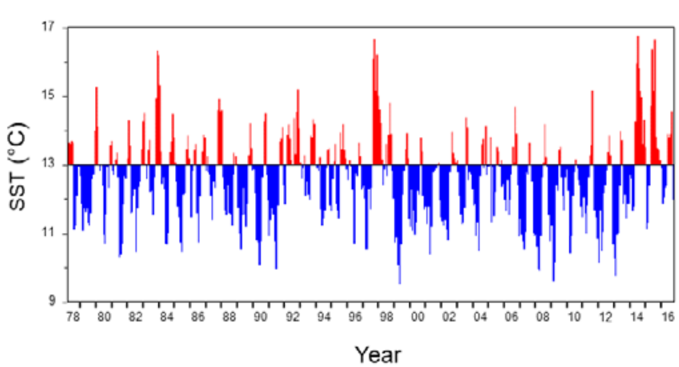


Figure 6. Monthly Sea Surface Temperature (°C) from Southeast Farallon Island, 1978-2016. Note that the X-axis crosses the Y-axis at 13°C.



the positive SST anomalies rapidly decreased (Figure 5B) and were near the long-term average for most of the remainder of 2016. Although the 2015-16 El Niño event was one of the largest on record at the tropics, upwelling favorable winds (local forcing) damped the temperature and nutrient anomalies attributed to the coastally trapped waves (remote forcing) earlier than expected, especially in central and southern California (Frischknecht et al. 2017).

Many marine fishes and invertebrates that rear in San Francisco Estuary reproduce in coastal waters in late fall and winter and water temperature is important for gonadal maturation, triggering spawning, and egg and larval growth and survival. In the GOF, SSTs were 0.5 to 1.5°C cooler than the long-term mean in late fall and winter of 2011-2012, 2012-2013, and 2013-2014 (Figure 5B), in contrast to the relatively warm SSTs in late fall and winter of 2014-15 and 2015-16.

Ocean productivity, as measured by seabird reproductive success at Southeast Farallon Island (SEFI), was mixed from 2012 to 2016. Surprisingly, Cassin's Auklet, which feed exclusively on euphausiids, had above average reproductive success all 5 years, including the warm water years of 2014, 2015, and 2016 (Warzybok et al. 2016). In previous large El Niño events, including 1983, 1992, and 1998, reproductive success was very poor for many seabirds at SEFI, including Cassin's Auklet. The Common Murre, with a chick diet primarily of smelts (Osmeridae), juvenile rockfishes, and Northern Anchovy, had slightly above average reproductive success in 2012 and 2013, followed by below average and declining reproductive success from 2014 to 2016 (Warzybok et al. 2016). Rhinoceros Auklet, with a chick diet primarily of juvenile rockfishes and Northern Anchovy, had slightly below average reproductive success in 2012 and above average reproductive success from 2013 to 2016 (Warzybok et al. 2016).

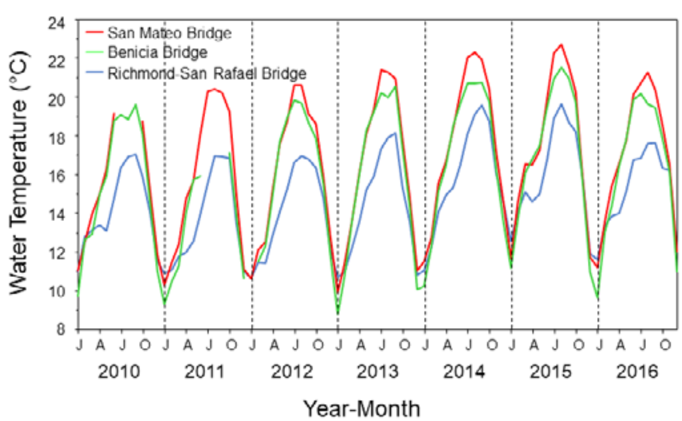
Northern Anchovy was an important component of Common Murre and Rhinoceros Auklets chick diets from 2002 to 2008, but were almost absent from chick diets from 2009 to 2014 (Warzybok et al. 2016). In 2015 and 2016, anchovies were again an important part of Common Murre and Rhinoceros Auklets chick diets (Warzybok et al. 2016), which was a significant change in prey items.

Water temperatures in the estuary had the expected seasonal trends, with the coldest temperatures in winter and early spring and the warmest temperatures in summer and early fall (Figure 7). Winter minimum temperatures were similar for all regions, with Suisun Bay (Benicia Bridge station) slightly colder than Central and South bays (Richmond-San Rafael Bridge and San Mateo Bridge stations, respectively). Summer temperatures were consistently highest in South Bay, followed by Suisun and Central bays.

In contrast to the estuary temperatures, the coldest ocean SSTs were in spring and summer, concurrent with upwelling, and the warmest temperatures in fall, after upwelling ended (Figure 8A). The SSTs from Buoy 142, which is 12.5 km from the Golden Gate, were often slightly warmer than the SSTs from SEFI. However, during the warmest period from 2014 to 2015, they were very similar. Central Bay, the region closest to the coast, consistently had warmer water temperatures than the ocean from spring through late fall, ranging from 2 to 3°C warmer at Fort Point (Figure 8B) to 4 to 5°C warmer in upper Central Bay at the Richmond-San Rafael Bridge (Figure 8B). As Central Bay temperatures decreased in the late fall and winter, ocean temperatures became slightly warmer than bay temperatures.

The marine heatwave resulted in warmer San Francisco Estuary temperatures from South to Suisun bays from 2014 to 2016, with temperatures exceeding 22°C in South Bay, near 20°C in upper Central Bay (Richmond-San Rafael Bridge), and near 22°C at the Benicia Bridge in late summer and fall (Figure 7). Peak water temperatures were usually 20 to 21°C in South Bay, 17 to 18°C in upper Central Bay, and 19 to 20°C in Suisun Bay (Figure 7). Ontogenetic movements of fishes, shrimp, and crabs to cooler, deeper, and higher salinity waters with growth is well documented in estuaries (Deegan 1993, Beck et al. 2001). Consequently, the 2 to 3°C increase in Central Bay water temperature in 2014 and 2015 may have changed the migration patterns as well as the distribution and abundance of several marine species that are common in Central Bay in late summer and fall. The most likely scenario was an earlier migration to the coast as bay temperatures approached or exceeded thermal preferences.

Figure 7. Monthly near bottom water temperature (°C) at the San Mateo, Benicia, and Richmond-San Rafael bridges, 2010-2016.



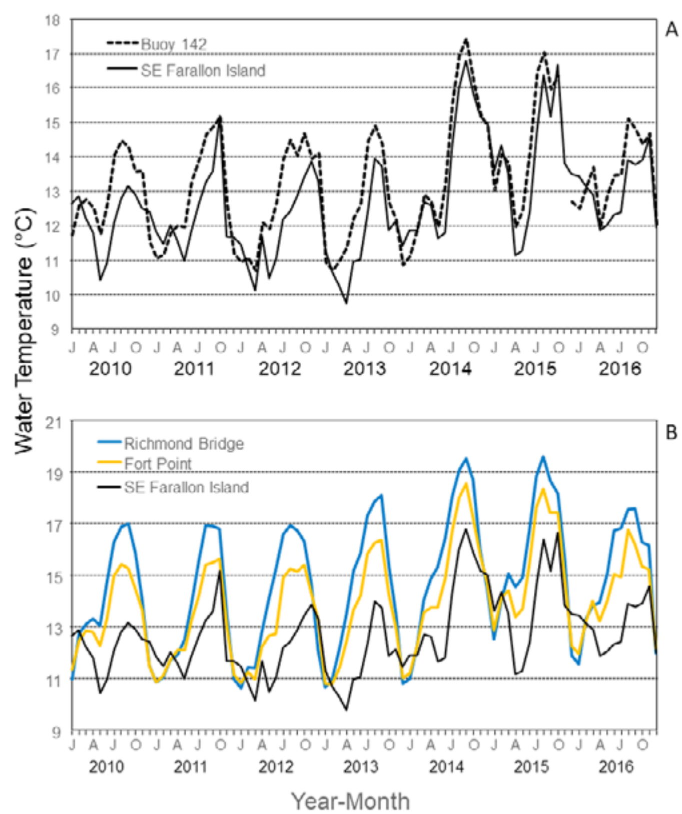
Upper Estuary Demersal Fishes

Shokihaze goby

The Shokihaze Goby (*Tridentiger barbatus*) is native to China, Japan, Korea, and Taiwan, and was first collected in the San Francisco Estuary by the Bay Study in 1997 (Greiner 2002). It is a short-lived species; age-1 fish spawn in brackish water during spring and early summer and many die in late summer and fall, possibly due to the parental investment of nest guarding (Slater 2005). Since the Shokihaze Goby is common upstream of the Bay Study's original sampling area, abundance is calculated as the January to December mean CPUE (catch per tow) for all 52 stations sampled by the otter trawl, including the lower Sacramento and San Joaquin river stations added in 1991 and 1994.

Shokihaze Goby was the 2nd most common goby collected by the otter trawl from 2012 to 2016 and the

Figure 8. A) Monthly SST (°C) from Buoy 142 and Southeast Farallon Island, 2010-2016 and B) Monthly near bottom water temperature (°C) at the Richmond-San Rafael Bridge, Fort Point SST, and Southeast Farallon Island SST, 2010-2016.



most common of the introduced gobies (Table 2). The mean annual Shokihaze Goby CPUE was near the study-period average in 2012 and 2013, but record high in 2014 and 2015 (Figure 9). We did not calculate a January to December 2016 mean CPUE, but based on the May to July mean CPUE, Shokihaze Goby abundance was also high in 2016 (Table 3). Over 80% of the Shokihaze Gobies collected in 2012 and 2014 were age-0, while 50 to 60% were age-0 in 2013 and 2015. Strong recruitment in 2012 and 2014 lead to increased age-1+ catches in 2013 and 2015, respectively (Figure 9).

Table 2. Annual catch of the top 40 demersal species in the Bay Study otter trawl, 2012-2015. N=Native, I=Introduced.

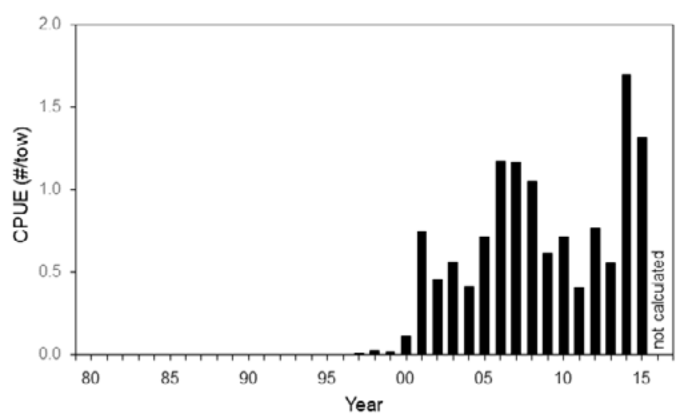
Rank	*Species*	*N or I*	*2012*	*2013*	*2014*	*2015*	*2016*	*Total*
1	Speckled Sanddab	N	5601	11217	7778	2767	2164	29527
2	Bay Goby	N	14939	5411	3162	189	221	23922
3	California Tonguefish	N	17	1350	853	12608	2938	17766
4	English Sole	N	1848	4998	1823	1994	630	11293
5	Plainfin Midshipman	N	926	3977	2591	1319	257	9070
6	Pacific Staghorn Sculpin	N	1474	2177	1044	78	24	4797
7	Striped Bass	I	1374	1376	799	453	506	4508
8	Shiner Perch	N	928	1643	755	442	30	3798
9	Shokihaze Goby	I	480	342	1019	815	279	2935
10	Cheekspot Goby	N	1257	598	231	72	125	2283
11	Brown Rockfish	N	72	791	554	453	257	2127
12	White Croaker	N	404	290	360	230	34	1318
13	Chameleon Goby	I	53	591	207	165	30	1046
14	California Lizardfish	N	18	631	183	83	55	970
15	Longfin Smelt	N	390	331	72	44	24	861
16	California Halibut	N	26	41	59	345	387	858
17	Yellowfin Goby	I	113	225	107	54	100	599
18	Starry Flounder	N	140	90	14	53	47	344
19	Sand Sole	N	15	63	82	121	60	341
20	Shimofuri Goby	I	60	60	49	109	59	337
21	Bay Pipefish	N	95	67	52	64	23	301
22	Showy Snailfish	N	39	147	78	2		266
23	Brown Smoothhound	N	40	58	63	55	19	235
24	Pacific Sanddab	N	6	51	8	124		189
25	White Catfish	I	63	61	24	5	10	163
26	Barred Surfperch	N	20	73	16	17	1	127
27	Walleye Surfperch	N	29	44	25	8		106
28	Tule Perch	N	38	44	15	7	1	105
29	Diamond Turbot	N	19	26	18	21	19	103
30	Bonyhead Sculpin	N	33	24	25	13	4	99
31	Bat Ray	N	23	36	15	14	7	95
32	Saddleback Gunnel	N	29	61	4			94
33	Channel Catfish	I	28	16	22	9	11	86
34	Lingcod	N	15	53	5	2	1	76
35	Leopard Shark	N	7	9	20	21	7	64
36	River Lamprey	N	31	8	6	4	10	59
37	Night Smelt	N	24	30				54
38	Bigscale Logperch	I	19	10	4	2	17	52
39	Splittail	N	26	9	8	2	3	48
40	Big Skate	N	8	27	10	2		47

Shokihaze Goby CPUE was highest from August to December, with some annual variation in the seasonal peak. For example, age-0 CPUE peaked in November and December of 2012 but from August to October of 2015. This pattern was largely driven by the seasonal abundance of age-0 fish, which were usually first collected in July or August, when fish were 20 to 24 mm TL. CPUE of age-1+ Shokihaze Goby peaked from June to August, concurrent with reproduction. There was little annual variation in the seasonal abundance of age-1+fish.

Shokihaze Goby were widely distributed in San Francisco Estuary from 2012 to 2016, collected in all regions each year, except for Central Bay. Within these years, the main distributional change was their expansion in South Bay. First collected in South Bay in 2002, Shokihaze Goby catches remained low there until November and December 2014, when almost 200 age-0 fish were collected at station #101, between the Dumbarton and San Mateo bridges. This same year class was detected at station #101 in early 2015, with 41 and 81 gobies collected in January and February 2015, respectively. These high catches contributed to the record high Shokihaze Goby annual CPUEs in 2014 and 2015.

Other than the increased South Bay catches in 2014 and 2015, Shokihaze Goby distribution varied little between the years reported. In 2012, it was most commonly collected at the confluence of the Sacramento

Figure 9. Annual catch-per-unit-effort (CPUE; catch per tow) of Shokihaze Goby (all sizes), Bay Study otter trawl, January-December, 1980-2015.



and San Joaquin rivers and the lower Sacramento River; this was mainly age-0 fish collected from near Chipps Island to lower Sherman Island in the Sacramento River. In 2013, it was most commonly collected in Suisun Bay and the confluence; catches were dominated by age-0 fish from Carquinez Strait and lower Sherman Island. In 2014 and 2015, Shokihaze Goby was most common in South and Suisun bays and the confluence, with the upper estuary distribution very similar to 2013. However, Shokihaze Goby appeared to move slightly upstream in the Sacramento River in 2014 and 2015, with fish collected near Rio Vista. Distribution in 2016 was very similar to 2013, but with higher catches in San Pablo Bay, especially the shoal station near China Camp (#323).

Adult Shokihaze Goby were typically collected further downstream than juveniles. Age-1+ fish were widely distributed in winter, but most common in Carquinez Strait and the confluence area. Their distribution slowly contracted through spring, as adults in the lower rivers migrated downstream, likely in response to decreasing salinity. Age-0 fish were usually first collected from Carquinez Strait to the lower Sacramento River in August, with a slow movement upstream through fall.

Overall, Shokihaze Goby was more common at channels than shoals. From 2012 to 2016, the mean channel CPUE was 1.9 fish per tow and the shoal CPUE 0.3 fish per tow. There was some seasonal variation to this pattern, with the highest age-0 shoal CPUE in late summer. By late fall, most age-0 fish had moved to the channels and were uncommon at the shoals.

Yellowfin Goby

The Yellowfin Goby (*Acanthogobius flavimanus*) is an introduced fish from Asia with a partially catadromous life history. Adults migrate to brackish water to spawn from December through July and juvenile fish migrate upstream to lower salinity and fresh water habitats to rear through summer and fall (Wang 1986). Lifespan is to 3 years, although some age-1 adults die after spawning due to the parental investment of nest guarding (Magnhagen 1993, Lissaker et al. 2006).

Yellowfin Goby was the 5th most abundant goby collected from 2012 to 2016 (Table 2) and ranked 3rd of the introduced gobies. The abundance of age-0 Yellowfin Goby was very low from 2012 to 2015, with a slight increase in 2014 (Figure 10). The 2015 and 2012 indices were the 4th and 5th lowest of the 36-year study period. We did not calculate a 2016 age-0 abundance index due to the reduced sampling, but based on the May to July mean CPUE, age-0 Yellowfin Goby abundance increased slightly in 2016 (Table 3). The decline in Yellowfin Goby abundance, especially after 2000, may be due to inter-specific competition with other introduced gobies, specifically *Tridentiger spp*. Most notably, the Shokihaze

Table 3. May to July mean CPUE (catch per tow) for selected Bay Study fishes, 1997-2016. ND=No Data, MWT tow time not recorded.

Year	Shokihaze Goby	Yellowfin Goby	Starry Flounder	Starry Flounder	Pacific Herring	Northern Anchovy	Jack smelt	Shiner Perch	Brown Rockfish	White Croaker	White Croaker	Pacific Staghorn Sculpin	Bay Goby	Speckled Sanddab	CA Halibut	CA Halibut	English Sole	California Tonguefish
	All ages	Age-0	Age-0	Age-1	Age-0	All Sizes	Age-0	Age-0	Age-0	Age-0	Age-1+	Age-0	All Sizes	All Sizes	Juvenile	Age-2+	Age-0	All sizes
1997	0.00	1.12	0.94	0.09	ND	ND	ND	0.59	0.00	0.13	0.56	2.26	2.06	9.07	0.00	0.05	4.53	0.10
1998	0.00	1.69	0.51	0.22	5.01	238.52	0.32	0.11	0.00	1.61	0.58	0.69	0.62	0.46	0.02	0.03	2.79	2.96
1999	0.06	2.31	0.79	0.16	3.45	425.63	0.03	0.29	0.00	0.03	0.34	6.64	1.53	5.53	0.19	0.22	11.19	0.38
2000	0.03	7.07	0.03	0.03	25.07	384.12	0.16	0.15	0.00	1.88	0.33	2.03	2.30	10.44	0.00	0.19	14.82	0.00
2001	0.30	0.22	0.03	0.03	29.51	123.94	2.10	1.25	0.11	2.38	0.41	8.28	2.69	5.57	0.00	0.10	24.81	0.04
2002	0.12	0.34	0.19	0.00	48.96	166.36	1.45	2.51	0.67	0.76	0.52	8.53	5.32	13.59	0.00	0.08	13.21	0.10
2003	0.15	0.90	0.85	0.03	18.67	311.86	0.40	1.21	0.03	0.49	0.24	5.52	1.21	6.11	0.00	0.02	15.07	0.00
2004	0.21	0.63	0.83	0.03	8.31	129.89	0.87	3.00	0.02	0.10	0.25	3.16	1.08	6.11	0.00	0.04	15.69	0.03
2005	0.31	0.78	0.45	0.04	3.23	159.89	0.55	0.75	0.00	0.17	0.15	1.43	0.41	0.48	0.06	0.02	3.80	2.02
2006	0.44	0.11	0.70	0.03	5.47	229.70	0.46	0.68	0.00	0.00	0.12	1.56	0.12	1.25	0.04	0.26	1.55	0.00
2007	0.62	0.15	1.12	0.04	16.26	353.30	1.47	0.44	0.00	0.05	0.25	3.63	0.42	1.70	0.00	0.25	14.22	0.81
2008	0.52	0.16	0.32	0.13	90.34	314.29	2.16	0.44	0.01	0.01	0.15	7.99	1.27	0.70	0.00	0.08	35.74	0.02
2009	0.49	0.14	0.13	0.05	27.69	162.85	3.05	0.18	0.14	0.43	0.08	5.69	1.75	2.41	0.00	0.07	23.18	0.00
2010	0.29	0.66	0.55	0.04	41.35	171.52	1.28	0.20	0.78	0.87	0.21	6.37	3.08	18.18	0.01	0.07	15.73	0.59
2011	0.03	0.06	0.16	0.08	59.22	83.08	1.78	0.03	0.02	0.07	0.42	4.98	5.27	5.09	0.00	0.05	11.06	0.01
2012	0.07	0.03	0.08	0.02	9.86	156.61	1.59	0.57	0.01	0.19	0.28	4.90	11.70	11.80	0.00	0.04	3.59	0.04
2013	0.29	0.09	0.01	0.04	18.37	210.92	3.29	1.82	3.31	0.13	0.53	9.10	3.78	30.40	0.00	0.06	17.77	4.99
2014	0.40	0.09	0.01	0.00	8.50	619.56	1.43	4.40	1.15	0.34	1.07	5.74	2.49	21.46	0.00	0.06	6.20	3.82
2015	0.51	0.04	0.08	0.01	0.65	249.40	0.04	0.17	2.38	0.20	0.44	0.31	0.07	5.26	0.46	0.15	13.20	45.69
2016	0.47	0.27	0.12	0.01	1.08	399.09	1.56	0.06	1.25	0.07	0.08	0.16	0.18	8.50	0.92	0.75	4.33	18.27

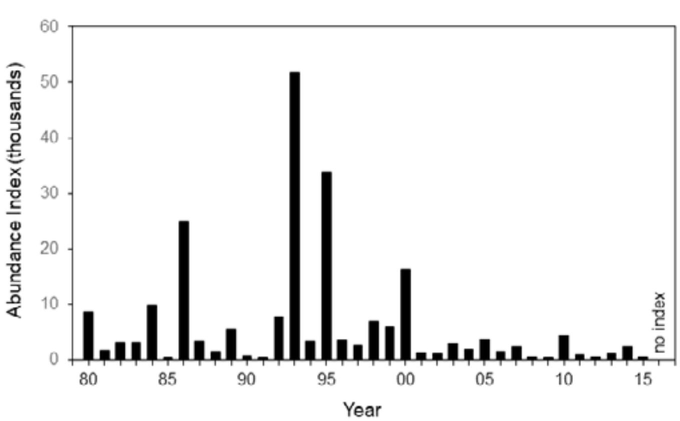
Note: ND= No data, MWT tow duration not recorded until 1998. Indices Adjusted to account for a missing survey

Goby was first collected in 1997 and its abundance increased substantially in 2001 (Figure 9).

Age-0 Yellowfin Goby were most abundant from June to August, with a second peak often in December. There was some annual variation in this pattern; for example, in 2013, age-0 fish abundance was highest in November and December, while in 2014, it was highest in September. There was more seasonal variation in abundance in the low abundance years. Age-0 Yellowfin Goby were first collected by the otter trawl in May, June, or July. Years with the lowest abundance, such as 2015, most often had later first collections. Age-1+ Yellowfin Gobies were collected year-round, but were most abundant from January to April, concurrent with spawning. From 2012 to 2015, there was very little variation in this seasonal pattern, with peak abundance in either January or February.

In the 1980s and 1990s, age-0 Yellowfin Goby were usually collected in all regions and often from all stations, but very low abundance from 2012 to 2016 resulted in non-detection in several regions and many stations. It was not collected at the confluence of the Sacramento and San Joaquin rivers in 2012, the lower Sacramento River in 2014, or the lower San Joaquin River in 2016. From 2012 to 2015, age-0 Yellowfin Goby were initially collected in Suisun Bay, expanded upstream to the lower rivers through summer and fall, and started its downstream reproductive migration in December, when CPUE was often highest in Central Bay. In 2016, age-0 fish were initially most common in San Pablo Bay rather than Suisun Bay; this was likely due to higher freshwater outflow in spring 2016. There was also a smaller Yellowfin Goby population in South Bay, primarily below the San Mateo Bridge. We did not collect Yellowfin Goby in South Bay all months, probably because age-0 fish migrated to South Bay sloughs and tributaries to rear, areas that we do not sample.

Figure 10. Annual abundance of age-0 Yellowfin Goby, Bay Study otter trawl, May-October, 1980-2015.



Age-1+ Yellowfin Goby were not as widely distributed as age-0 fish, as they were less common in the lower rivers. Its distribution was broadest in January, with fish typically collected from South Bay through the confluence. CPUE was highest in San Pablo and Suisun bays through April, concurrent with their spawning migration. Age-1+ Yellowfin Goby were also more common in the channels in January, and appeared to move to the shoals over the next 2 to 3 months. By April, age-1+ CPUE was highest at the shoal stations for all years except 2012. This channel to shoal movement was likely part of their spawning migration, as they used the channels to move to downstream shoals for reproduction. Male Yellowfin Goby construct a Y-shaped burrow, where the females deposit their eggs (Dotsu and Mito 1955). Such a burrow would be much easier to construct in the soft sediment of the shoals rather than the hard-packed sediment of the channels.

Starry Flounder

The Starry Flounder (*Platichthys stellatus*) is an estuary-dependent species that spawns in the ocean and river mouths, but rears in brackish and fresh water areas of estuaries (Wang 1986, Baxter et al.1999). Settlement occurs between 8-15 mm TL (Orcutt 1950) and the small juveniles immigrate into San Francisco Estuary in late spring. Starry Flounder rear in estuaries for up to 4 years, moving to higher salinity and cooler waters with age (Orcutt 1950). From 2012 to 2016, it ranked 18th in the otter trawl and was the 5th most common flatfish (Table 2).

Age-0 Starry Flounder abundance indices from 2012 to 2015 were low and continued the trend of low abundance since 2008 (Figure 11A). The 2013 and 2014 indices were the 3rd and 7th lowest in the 37-year study period. In 2013, only 2 age-0 Starry Flounder were collected; this was the lowest total catch since 1992, when none were collected. Although the 2012 and 2015 indices were higher than the 2013 and 2014 indices, they were still well below the study-period mean. Based on the May to July mean age-0 CPUE, age-0 Starry Flounder abundance continued to be low in 2016, although it was the highest annual CPUE since 2011 (Table 3). We will know more about the size of the 2016 year class in 2017, when we collect the age-1 fish.

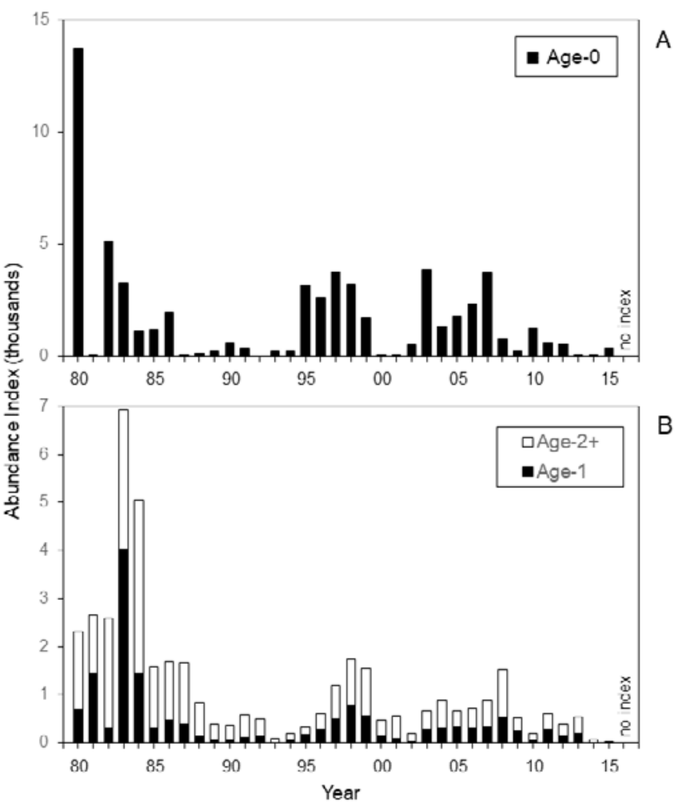
Age-0 Starry Flounder usually recruit to the gear in May or June, with later collections in years with low abundance. They were collected from June through

December in 2012 and May through December in 2015. However, in 2013 they were collected only in June and July and in 2014, only in June, August, September, and December (no July survey).

During the low freshwater flow years of 2012 to 2016, age-0 Starry Flounder were collected from Suisun Bay to the lower Sacramento and San Joaquin rivers, with a few in San Pablo Bay. The highest regional CPUE was in Suisun Bay from 2012 to 2015, and at the confluence in 2016, which had limited sampling. In all years age-0 Starry Flounder strongly preferred the shoals, with either all collected at shoal stations (2013 and 2014) or the mean shoal CPUE 3 to 6 times the channel CPUE other years.

As expected, the age-1 Starry Flounder indices were low from 2012 to 2015 (Figure 11B), with the 2014 and 2015 indices near record low. These were the extremely poor 2013 and 2014 year classes; only one age-1 fish was collected in 2014 and 3 in 2015. Based on the mean May to July CPUE, age-1 Starry Flounder abundance was also very low in 2016 (Table 3). Age-1 abundance was usually highest in winter and early spring, but catches were too low and sporadic to determine seasonal trends from 2012 to 2016.

Figure 11. Annual abundance of Starry Flounder, 1980-2015: A) age-0, Bay Study otter trawl, May-October, and B) age-1 and age-2+, Bay Study otter trawl, February-October.



Age-1 Starry Flounder were collected primarily from Suisun Bay through the lower rivers, with a few fish in Central and San Pablo bays. The broadest distribution was in winter and spring, with fish moving downstream to Suisun and San Pablo bays through summer. Age-1 Starry Flounder were occasionally collected in the confluence and lower rivers in summer and fall. Age-1 fish were more common at the shoals than channels, but the preference was not as strong as for age-0 fish. For example, in 2012, the mean shoal CPUE was 1.3 times the channel CPUE and in 2013 it was 3 times. Most of the channel collections were from the lower Sacramento River in winter and early spring.

In summary, age-0 and age-1 Starry Flounder abundance was very low from 2012 to 2015, with evidence of poor recruitment in 2016. Based on the relationship between Starry Flounder abundance and outflow (CDFG 2010, Kimmerer 2002), low abundance in low outflow years was expected. Although outflow increased slightly in 2016, we had limited sampling and therefore no abundance index; we will have better abundance data for the 2016 year class in 2017, when we collect the age-1 fish.

Upper Estuary Demersal Fish Community

The upper estuary demersal fish community did not experience the abundance decline in the early 2000s reported for the pelagic fish community (Sommer et al. 2007). Since the late 1990s, total abundance of upper estuary demersal fish has been relatively stable (Figure 12A), with a slight declining trend since 2011. In the earlier years of the Bay Study, the upper estuary demersal fish community was dominated by young Striped Bass. As Striped Bass abundance declined through the 1980s and 1990s, introduced gobies became more common. Initially, Yellowfin Goby dominated, but by the early 2000s, Shokihaze Goby was well established and more common than Yellowfin Goby (Figure 12B); it was often the most common demersal species collected in the upper estuary. The annual CPUE of native species, primarily Pacific Staghorn Sculpin and Starry Flounder, was stable from 2009 to 2015.

Marine Pelagic Fishes

Pacific Herring

The Pacific Herring (*Clupea pallasii*) is an estuary-dependent species that spawns and rears in San Francisco

Bay. From 2012 to 2016, it was the 2nd most common pelagic fish collected by the midwater trawl (Table 4). Spawning occurs in late winter and early spring, when the adhesive eggs are deposited on substrates such as aquatic vegetation, rocks, pier pilings, and other man-made structures. After hatching and larval development, young Pacific Herring remain in shallow waters and begin to school. Juveniles are found in shallow subtidal areas and sloughs until late spring, when they migrate to deeper waters within the estuary. By fall, age-0 Pacific Herring emigrate from the estuary to spend 2 to 3 years rearing in the ocean before reaching maturity and returning to spawn.

Three of the four age-0 Pacific Herring indices from 2012 to 2015 were relatively low, with the 2015 index the lowest for the study period (Figure 13). The 2012 and 2014 indices were similar and below the study-period mean, while the 2013 index was slightly above the mean. Based on the May to July CPUE, abundance increased in 2016 from 2015, but remained low relative to other recent years (Table 3). Age-0 fish first recruited to the gear in March of 2012, 2013, and 2014 and April 2015; peak abundance was from April to June. Emigration began in summer, and by July or August, most had left the estuary.

Age-0 Pacific Herring were collected from South Bay to upper Suisun Bay in 2012 and 2013, to the Sacramento River near Decker Island in 2014, and to the Sacramento River near Sherman Lake in 2015. Fish were most common at the South Bay shoal station near Candlestick Point (#106), the channel station near Hunter's Point (#109), all the Central Bay stations except for the Southampton Shoal station (#243), and the 3 most downstream San Pablo Bay stations. Over all months, annual CPUE was highest in Central Bay followed by South Bay in 2012 and 2014 and highest in Central Bay followed by San Pablo Bay in 2013 and 2015. There was a downstream shift in distribution from South and

Figure 12. A) Annual CPUE of upper estuary demersal fishes, 1980-2015 and B) Percent CPUE for selected upper estuary demersal fishes for 1995-2000, 2001-2007, and 2008-2015.

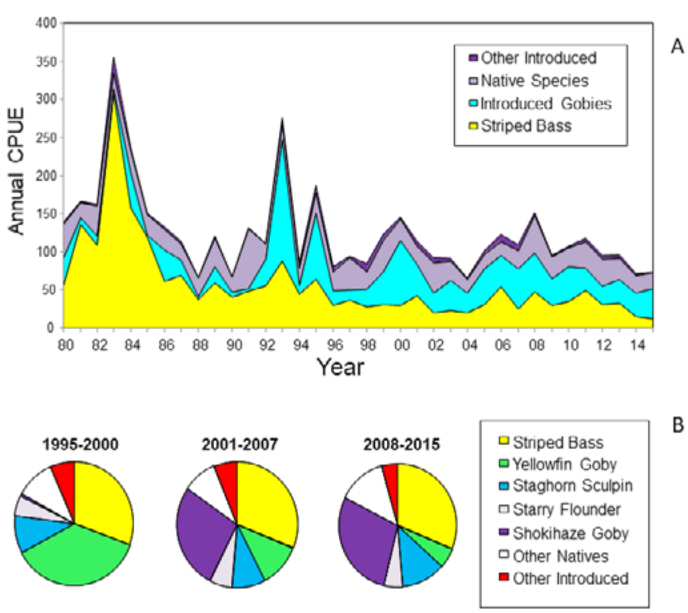


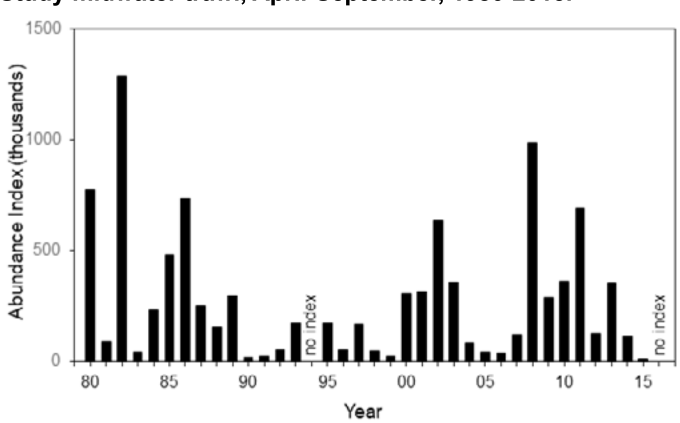
Table 4. Annual catch of the top 30 pelagic species in the Bay Study midwater trawl, 2012-2015. N=Native, I=Introduced.

Rank	Species	N or I	2012	2013	2014	2015	2016	Total
1	Northern Anchovy	N	59680	68186	63707	90788	112857	395218
2	Pacific Herring	N	2575	6675	2649	414	211	12524
3	Jacksmelt	N	1533	1244	1573	503	396	5249
4	American Shad	I	1148	741	601	673	1220	4383
5	Threadfin Shad	I	582	452	435	820	886	3175
6	Striped Bass	I	302	282	137	386	243	1350
7	Topsmelt	N	172	373	103	85	121	854
8	Pacific Pompano	N	141	420	208	42		811
9	Longfin Smelt	N	208	207	67	57	15	554
10	Threespine Stickleback	N	411	2	8	3	6	430
11	Chinook Salmon	N	73	130	70	61	62	396
12	Shiner Perch	N	80	93	201	20		394
13	Night Smelt	N	120	238	1	1		360
14	Walleye Surfperch	N	114	72	51	28	6	271
15	Delta Smelt	N	81	65	42	53	7	248
16	Bat Ray	N	32	63	14	25	17	151
17	White Croaker	N	19	18	20	7	18	82
18	Whitebait Smelt	N	30	38	4	3		75
19	Splittail	N	28	14	2	5	7	56
20	Pacific Sardine	N	3	1	1	10	21	36
21	Barred Surfperch	N	3	4	1	1		9
22	Lingcod	N	4	4	1			9
23	Tule Perch	N		2	2	4		8
24	Pacific Lamprey	N	7					7
25	White Seaperch	N		2	4	1		7
26	Steelhead	N	1		4			5
27	Bay Pipefish	N	1	1	2			4
28	Mississippi Silverside	I		3			1	4
29	California Grunion	N				1	2	3
30	Common Carp	I	3					3

San Pablo bays to Central Bay each year, with South, San Pablo, and Suisun bay CPUEs highest in spring and rapidly decreasing after May. Although age-0 Pacific Herring were overall more common at channel than shoal stations, there was a shift from shoals to channels with age. In South and San Pablo bays, it was common for shoal CPUE to be higher than channel CPUE in spring. Usually by June or July, concurrent with movement to Central Bay, South and San Pablo bay channel CPUE increased. In Central Bay, channel CPUE was higher than shoal CPUE most months.

The CDFW Herring Project has recorded landings, estimated spawning biomass, and calculated age structure and condition indices for the Pacific Herring fishery in San Francisco Bay since 1972. The commercial Pacific Herring fishery runs from December through March, targeting adult fish entering the estuary to spawn. Spawning biomass was above average from the 2011-12 to 2013-14 fishing seasons, ranging from 60.6 to 79.5 thousand tons (CDFW 2016). However, it decreased substantially in the 2014-15 and 2015-16 fishing seasons to 16.7 and 14.9 and thousand tons, respectively. Landings ranged from 1,634 to 3,198 tons for the 2011-12 to 2013-14 seasons, but were only 46 tons in 2014-2015 and 493 tons in 2015-16, with only 2 vessels participating in 2014-15 and 11 vessels participating in 2015-16. The landings of 46 tons in the 2014-15 season were the lowest for the fishery since 1972, other than zero landings in 2009-10, when the fishery was closed due to a record low spawning biomass the previous year. Low participation in the fishery in recent years reflected market demand, fuel prices, and reduced spawning biomass. Pacific Herring condition indices were near the long-term mean for both sexes from the 2011-12 to 2015-16 seasons and well above the low condition indices reported from 2003-04 to 2008-09 (CDFW 2016).

Figure 13. Annual abundance of age-0 Pacific Herring, Bay Study midwater trawl, April-September, 1980-2015.



Pacific Herring populations have generally declined throughout the California Current, although the San Francisco Estuary population has been cyclical with some stability (Thompson et al. 2017). Poor ocean and estuarine conditions in 2015 and 2016 negatively impacted Pacific Herring in the San Francisco Estuary, which is near the southern end of their range and the southernmost spawning population. Persistent record-high SSTs due to the marine heatwave and the 2015-16 El Niño and somewhat lower ocean productivity, coupled with drought conditions in the estuary, contributed to reduced biomass, spawning, and egg and larval survival in 2015 and 2016 (CDFW 2016).

Northern Anchovy

The Northern Anchovy (*Engraulis mordax*) is a small pelagic fish that is the most common fish in the lower estuary and by far the most common fish collected by the midwater trawl (Table 4). Also very common in the coastal ocean, it is an important prey species for many fishes and seabirds (Bergen and Jacobson 2001). Vrooman et al. (1981) separated the northern anchovy population into northern, central, and southern subpopulations. The San Francisco Estuary is situated between the northern and central subpopulations, and our catches reflect changes in the size and coastal movements of both subpopulations. Although the central subpopulation, centered in the Southern California Bight and Monterey, is the largest and historically the most heavily fished, there are currently no stock assessments, so we cannot readily determine subpopulation movements or size from fisheries data.

The 2012 to 2015 Northern Anchovy abundance indices (all sizes) were below the study-period mean and continued the trend of below average abundance since 2007 (Figure 14). The 2012 and 2013 indices were almost identical, as were the slightly higher 2014 and 2015 indices (Figure 14). The May to July 2016 mean CPUE was somewhat higher than the mean 2012-2015 CPUE (Table 3), but not necessarily indicative of an abundance increase, as only 3 months of data were available for a species that is common in the estuary for at least 7 months. Northern Anchovy age-0 catches were low from 2008 to 2016 in a NMFS trawl survey of Central California juvenile rockfishes and forage fishes (McClatchie 2016, Sakuma 2017). In contrast, Northern Anchovy comprised a significant portion of chick diet for 2 seabirds at Southeast Farallon Island in 2015 and 2016, after a near absence from 2009 to 2014 (Warzybok et al. 2016).

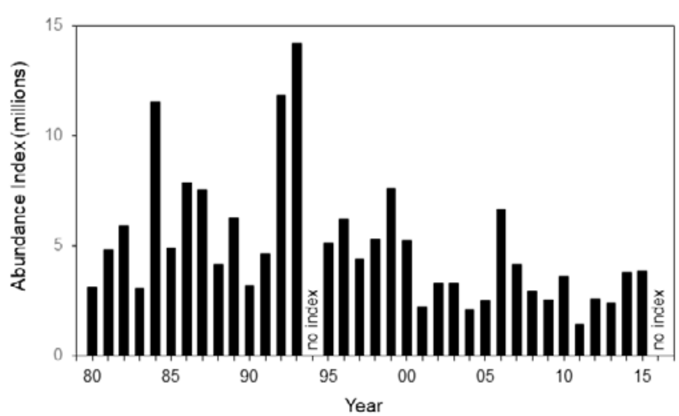
Spawning biomass for the southern subpopulation, as estimated from CalCOFI egg and larval survey data, was near or at record low levels from 2009 to 2016 (Thayer et al. 2017). From a recent high of nearly 2 million tons in 2005, biomass averaged 20,000 to 25,000 tons in recent years. This 99% decrease in spawning biomass was termed a collapse by MacCall et al. (2016) and occurred with very little fishing pressure. Ironically, large Northern Anchovy schools were reported nearshore in Monterey Bay in 2013-2015, leading to questions about the spatial coverage and accuracy of the CalCOFI egg and larval surveys (Davison et al. 2017). Aerial surveys confirmed that anchovies were concentrated within 4 km of shore, but during a period of overall low biomass (Davison et al. 2017, Thayer et al. 2017). This nearshore shift during periods of low biomass may be why our San Francisco Estuary Northern Anchovy indices were not lower during the population collapse. Our 2012 to 2015 indices were about 20% of our highest index from 1993 (Figure 14).

Northern Anchovies were collected every month sampled from 2012 to 2016. Abundance generally peaked in summer, declined rapidly in fall, and was lowest in winter, from November to February or March. There were occasionally 2 abundance peaks; in 2012, abundance peaked in March and July-August and in 2015, abundance peaked in April and July-August. We did not sample enough surveys in 2016 to determine if Northern Anchovy abundance was high outside of May to July.

Northern Anchovies were collected from South Bay near the Dumbarton Bridge to near Pittsburg in all years, with the highest catches at stations near the Bay Bridge, Treasure Island, and all the channel stations from Alcatraz to the Richmond-San Rafael Bridge. Annual CPUE was consistently highest in Central Bay, followed by South, San Pablo, and Suisun bays. The highest annual Central Bay CPUE was 466 fish per tow in 2015 and the lowest was 225 fish per tow in 2013. Overall, anchovies preferred channels to the shoals, with channel CPUE often 2 to 3 times shoal CPUE. The major exception was in South Bay in summer and early fall, when channel and shoal CPUE were often nearly equal or shoal CPUE was greater than the channel CPUE.

Kimmerer (2006) suggested that the overbite clam (*Potamocorbula amurensis*), introduced prior to 1987, caused a shift in Northern Anchovy distribution within San Francisco Estuary after 1987. In response to reduced food resources, anchovies have not utilized the lower salinity regions of the estuary, with a few exceptions, as they had prior to 1987. Over the study period, summer and fall Northern Anchovy catch exhibited downward trends in all zones, but most notably in the low salinity zone during the 1988-1992 drought and after the late 1990s (Figure 15). A decrease in overall anchovy abundance may also have contributed to this apparent shift away from the lower salinity regions, as abundance indices were relatively low from 2001 to 2005 and 2007 to 2015 (Figure 14). Note that in 2015, the low salinity zone average catch was the highest since 1998, although the abundance index remained low.

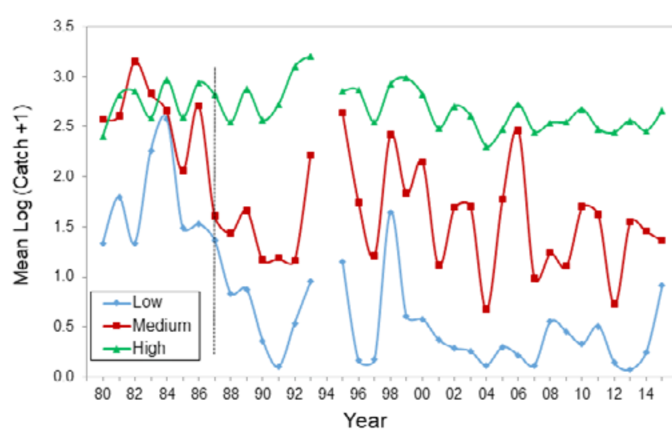
Figure 14. Annual abundance of Northern Anchovy (all sizes), Bay Study midwater trawl, April-October, 1980-2015.



Jacksmelt

The Jacksmelt (*Atherinopsis californiensis*) seasonally migrates from nearshore coastal waters to bays and estuaries to spawn and rear. From 2012 to 2016, it was the 3rd most common pelagic fish collected by the midwater trawl (Table 4). Most reproduction within the San Francisco Estuary occurs from September to April based on the presence of ripening and ripe females in San Pablo Bay (Ganssle 1966). Juvenile Jacksmelt rear

Figure 15. Mean annual catch by salinity zone of Northern Anchovy (all sizes), Bay Study midwater trawl, June to October, 1980-2015.



in shallow (<2 m) areas of South, Central, and San Pablo bays in late spring and summer. After growing to about 50 mm fork length (FL), they begin to migrate to deeper water, where they become vulnerable to the midwater trawl.

The 2012 to 2014 age-0 Jacksmelt abundance indices were relatively high, with the 2014 and 2012 indices the 2nd and 3rd highest for the study period (Figure 16). However, abundance declined substantially in 2015, when the age-0 index was well below the study-period mean and the lowest in 9 years. Age-0 fish were collected most months of the year, but were most common from July or August through November.

Age-0 Jacksmelt were collected from South Bay near the San Mateo Bridge to upper San Pablo Bay every year, with highest catches at 2 shoal stations in South Bay on the west side (#103 and #106), the channel station near Hunter's Point (#109), and the shoal stations near the Alameda rock wall (#142) and Paradise Cay (#244) in Central Bay. Overall, CPUE was highest in South or Central Bay, followed by San Pablo Bay. There was a movement from shoals to channels over time, as expected for a species that spawns and rears in shallow water. By November or December, it was usually most common at the Central Bay channel. The major exception was in 2015, when age-0 Jacksmelt channel and shoal catches were sporadic, with no apparent pattern. It is not uncommon for previously reported distributional patterns to fall apart when abundance is low, such as in 2015.

Surfperches

Most surfperches are transient species, migrating into bays and estuaries to give birth to live, fully formed young in late spring and summer, and returning to the coastal ocean in fall and winter. All the surfperches common to San Francisco Estuary underwent abundance declines in the 1980s per Bay Study trawl and sport fish survey data (DeLeón 1998). Consequently, in 2002, CDFG changed the sport fish regulations for San Francisco and San Pablo bays, adopting a closed season for all surfperches, except Shiner Perch (*Cymatogaster aggregata*), from April 1 to July 31, and a 5-fish combination daily bag limit for all species except Shiner Perch, which was given a 20-fish daily bag limit throughout the year.

Shiner Perch

Shiner Perch (*Cymatogaster aggregata*) was the most common of the surfperches collected and ranked 8th of all fishes collected by the otter trawl (Table 2). The 2012 to 2015 age-0 Shiner Perch abundance indices were mixed, with the 2012 and 2015 indices very low and the 2013 and 2014 indices near the study-period mean (Figure 17). The 2012 index was the 3rd lowest and the 2015 index the 2nd lowest during the study period. Age-0 indices have been low since 2005, except for 2013 and 2014. Based on the May to July mean age-0 CPUE, age-0 Shiner Perch abundance was very low in 2016 (Table 3) and similar to the May to July CPUE for the lowest index on record.

Age-0 Shiner Perch were first collected in April, May, or June and usually collected every month through December. The earliest first collections were in years with the highest abundance (2013 and 2014); in the low abundance year of 2015, no age-0 fish were collected after September. Abundance peaked in July of all years, although July 2014 was not sampled.

Age-0 Shiner Perch were most common in Central Bay, specifically the shoal stations near the Alameda rock wall (#142) and Berkeley Pier (#212). From 2012 to 2015, CPUE was highest in Central Bay, followed by South Bay and San Pablo Bay, with annual Central Bay

Figure 16. Annual abundance of age-0 Jacksmelt, Bay Study midwater trawl, July-October, 1980-2015.

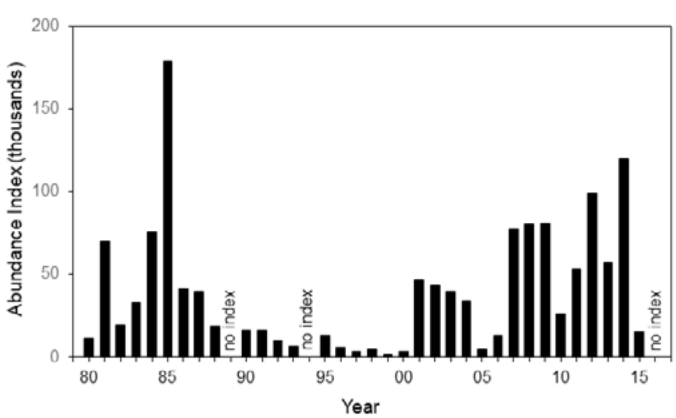
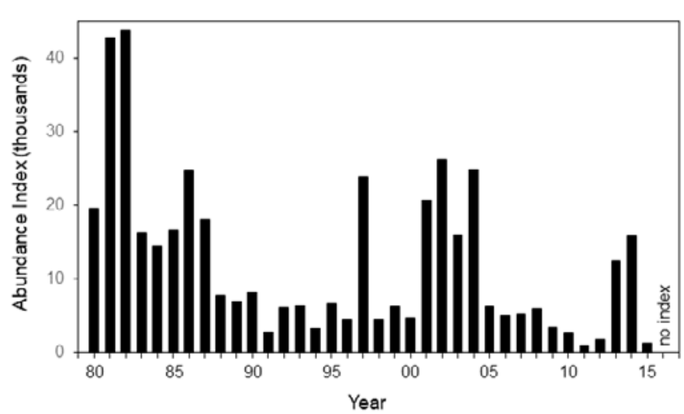


Figure 17. Annual abundance of age-0 Shiner Perch, Bay Study otter trawl, May-October, 1980-2015.



CPUE 5 to 11 times higher than South Bay CPUE. Age-0 Shiner Perch were far more common at shoal than channel stations in all embayments, months, and years until late fall and winter, when fish moved from the Central Bay shoals to the channel. By December, channel CPUE was usually higher than shoal CPUE.

Walleye Surfperch

The Walleye Surfperch (*Hyperprosopon argenteum*) was the 2nd most common surfperch collected in the midwater trawl and ranked 14th of all fishes collected by this net from 2012 to 2016 (Table 4). Age-0 Walleye Surfperch abundance indices were highly variable from 2012 to 2015, with the 4th highest index for the study period in 2012 and the 2nd lowest in 2015 (Table 5). We collected 74 age-0 fish in 2012, but only 2 in 2015 and none in 2016. Age-0 fish seasonal abundance was highest in June of 2012, 2013 and 2014, but in April of 2015, the lowest abundance year. The majority (81%, n=107) of all age-0 Walleye Surfperch collected from 2012 to 2015 were from the shoal station near Berkeley Pier (#212) and all but 3 of the remaining 25 fish were from shoal stations ranging from South Bay to lower San Pablo Bay.

The 2012 to 2015 age-1+ Walleye Surfperch indices did not vary as much as the age-0 indices (Table 5), as all were near or slightly above the 36-year study-period mean. Age-1+ fish were collected most months, but were most common from April through July, just before and after parturition. Age-1+ fish were more widely distributed than age-0 fish, with 42% (n=56) collected from the Berkeley shoal station, 59% (n=80) from other South, Central, and San Pablo bay shoal stations, and 2 fish from channel stations.

Other Surfperches

All the remaining surfperches reported are now relatively uncommon in our collections. The 2012 to 2015 Barred Surfperch (*Amphistichus argenteus*) abundance indices were all above the study-period mean and the 2013 index was the highest on record (Table 5). Except for 2013, we collected less than 20 Barred Surfperch per year. With such low catches, a seasonal abundance pattern was difficult to discern. For example, abundance was highest from January to March and in September and November of 2013. This lack of a seasonal pattern is not unexpected for an uncommon resident species.

All the Barred Surfperch collected from 2012 to 2016 were from shoal stations, with 91% (n=115) from South Bay and the remainder from Central and San Pablo bays. Historically, the majority of Barred Surfperch were collected from South Bay shoal stations along the eastern shore, but from 2012 to 2015, a large portion (n=71) were collected from the shoal station near Coyote Point (#106) on the western shore. Barred Surfperch is commonly associated with eelgrass beds in San Francisco Bay (Merkel & Associates 2005), a habitat not sampled by our trawls. It is also more common in Southern than Northern California (Karpov et al. 1995); South Bay, which is the

Table 5. Annual abundance surfperch indices from the Bay Study. The Walleye Surfperch, Pile Perch, and White Seaperch indices are from May to October and the Barred Perch, Black Perch, and Dwarf Perch indices are from February to October.

Year	*Walleye Surfperch*	*Walleye Surfperch*	*Barred Surfperch*	*Pile Perch*	*White Seaperch*	*Black Perch*	*Dwarf Perch*
	age-0	age-1+	all sizes	age-0	all sizes	all sizes	all sizes
1980	1277	642	415	857	588	0	439
1981	8089	1757	691	998	1248	129	543
1982	1640	992	223	471	349	54	259
1983	663	135	1030	778	271	88	460
1984	3846	922	502	110	873	216	50
1985	362	1031	81	301	138	66	0
1986	322	880	0	254	309	17	0
1987	1453	2624	159	0	265	0	0
1988	486	502	90	0	148	62	66
1989	2046	493	109	153	48	101	125
1990	516	341	105	0	95	48	26
1991	22	505	75	0	0	0	15
1992	443	297	27	0	0	100	0
1993	617	112	29	0	0	97	0
1994	no index	no index	53	0	0	125	0
1995	405	269	36	0	0	0	0
1996	684	380	39	0	0	225	0
1997	231	643	104	0	0	231	0
1998	537	911	32	75	0	65	0
1999	848	2985	30	0	0	36	0
2000	1229	114	29	31	0	119	0
2001	8121	1003	41	0	106	248	0
2002	12277	2079	76	42	260	95	0
2003	2439	567	302	0	371	63	111
2004	896	1438	76	0	487	253	94
2005	2916	655	34	0	47	93	32
2006	1568	26	46	0	0	62	34
2007	241	1205	123	0	0	36	42
2008	4128	529	105	0	61	69	0
2009	257	289	318	0	0	26	0
2010	1252	949	126	0	0	0	0
2011	1274	2346	572	0	0	36	0
2012	5667	1352	584	0	189	64	0
2013	1541	872	1400	0	37	0	0
2014	2457	804	546	0	47	115	217
2015	34	923	323	0	222	50	0
2016	no index	no index	no index	no index	no index	no index	no index
1980-2015 Mean	2022	902	237	113	171	83	70

warmest and highest salinity embayment of San Francisco Estuary, is more like a Southern California estuary than any other region of the estuary.

Only 1 age-0 Pile Perch (*Rhacochilus vacca*) was collected in 2012 and 2 in 2016, showing no sign of recovery in the estuary and continuing the trend of very low or 0 indices since 1987 (Table 5). All 3 age-0 fish were collected from Central Bay. We also collected 3 age-1+ Pile Perch in 2013, all from the Alameda rock wall station (#142).

The 2012 to 2015 White Seaperch (*Phanerodon furcatus*) indices were below or near the study-period mean (Table 5). The 2012 and 2015 indices were the highest since 2004, but are not indicative of a trend, as we collected only 4 fish in 2012 and 7 fish in 2015, for all months and both nets combined. All White Seaperch were collected from South and Central bays, with 73% (n=16) from shoal stations.

Black Perch (*Embiotoca jacksoni*) was the only surfperch common in the estuary that did not show a distinct decline during the late 1980s or early 1990s (Table 5). However, Black Perch catches have remained low relative to the most common surfperches throughout the study period. The 2012 to 2015 Black Perch indices (all ages) ranged from 0 in 2013 to slightly above the study-period mean in 2014, with no trend (Table 5). Note that in 2013 we collected 5 Black Perch, but none were from index stations or months. All but 1 Black Perch were collected from Central Bay, with 80% (n=20) from shoal stations, primarily the Alameda rock wall station (#142).

The 2012 to 2015 Dwarf Perch (*Micrometrus minimus*) indices were 0 in all years except for 2014 (Table 5), continuing the trend of very low or 0 indices since the early 1980s. However, we collected 3 to 6 Dwarf Perch per year from 2012 to 2015, with 9 from the non-index shoal station near Alameda (#142), 4 from the non-index Southampton shoal station (#243), and 2 from January 2013, a month not in the index period. Dwarf Perch is another species strongly associated with eelgrass beds in the San Francisco Bay, a habitat not sampled by our trawls.

Marine Demersal Fishes

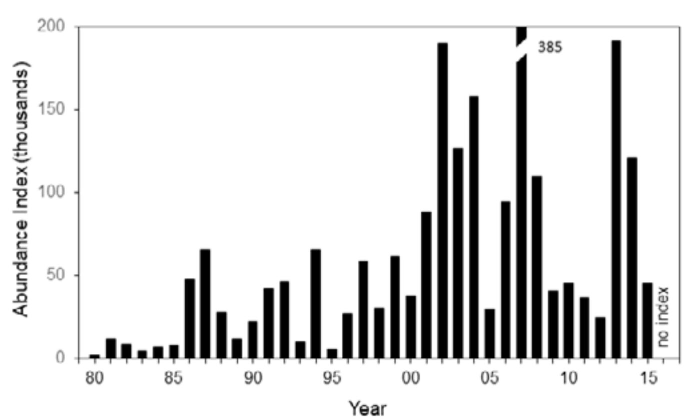
Plainfin Midshipman

The Plainfin Midshipman (*Porichthys notatus*) ranked 5th in demersal fish collected by the otter trawl from 2012 to 2016 (Table 2). Adult Plainfin Midshipman migrate from deeper water to the nearshore coast, bays, and estuaries in late spring and summer to spawn in very shallow subtidal and intertidal areas (Hubbs 1920). The eggs are deposited on the underside of rocks and the nest guarded by the male. The larvae remain in the nest for 2 to 3 weeks and emerge after their yolk is absorbed, at about 23-28 mm TL (Hubbs 1920). Many juveniles rear in the estuary through December, with some fish remaining until spring. It can reach a maximum size of 380 mm TL and inhabits depths from the intertidal to 328 meters (Miller and Lea 1972, Baxter et al. 1999).

The 2012 to 2015 age-0 Plainfin Midshipman abundance indices varied from the 2nd and 6th highest indices for the study period in 2013 and 2014 to below the study-period mean in 2012 and 2015 (Figure 18). The 9 lowest indices were from 1980 to 1995 and the 9 highest age-0 indices occurred since 2001. Warmer ocean temperatures and frequent El Niño events marked the earlier period, while colder ocean temperatures dominated the later period. We believe that Plainfin Midshipman somehow benefited from the colder ocean temperatures after the 1999 regime shift. One hypothesis is that adult Plainfin Midshipman migrated south along the coast with colder water and more fish were available to reproduce in San Francisco Estuary. Alternatively, more adults migrated into San Francisco Estuary to reproduce in years with colder SSTs, rather than reproduce along the coast. The highest age-1+ abundance indices were in 1999, 2002, and 2007, years with cold SSTs. However, as there is no demersal fishes sampling program outside of the estuary, we have no data to test the hypothesis of increased adult stock.

Age-0 Plainfin Midshipmen were first collected in May of all years except for 2012, when they were first collected in June, and were collected through December in all years. Peak abundance of age-0 fish was usually

Figure 18. Annual abundance of age-0 Plainfin Midshipman, Bay Study otter trawl, June-October, 1980-2015.



in September and October, with abundance decreasing rapidly through fall, when fish leave the estuary. It is interesting to note that age-0 abundance decreased after October of 2012 and 2013, years with cooler Central Bay temperatures, but after September of 2014 and 2015, years with the warmer Central Bay temperatures (Figure 7).

From 2012 to 2015, most age-0 Plainfin Midshipmen were collected from South to San Pablo bays, with a few in Suisun Bay and even the western Delta at the confluence. From 2012 to 2014, the highest annual catches were from Central Bay, including the shoal stations near Treasure Island, Southampton Shoal, and Paradise Cay (#211, 243, and 244) and the 2 channel stations near Angel Island (#214 and 215). In 2015, the highest age-0 catches were in San Pablo Bay, followed by South and Central bays. The first age-0 Plainfin Midshipman were usually collected in South Bay in May or June, Central Bay by June or July, San Pablo Bay by August, and Suisun Bay by September. CPUE was highest in South Bay in early summer and occasionally in San Pablo Bay in late summer, but consistently highest in Central Bay in fall and winter, as fish migrated downstream and out of the estuary. The highest monthly catches in Central Bay were 147 and 161 fish per tow in September and October 2013, respectively, and 140 fish per tow in September 2014. From 2012 to 2015, an average of 45 fish per tow were collected in Central Bay from August to October.

Concurrent with the movement of age-0 Plainfin Midshipman to Central Bay through fall, there was a movement from the shoals to the channels. In general, when age-0 Plainfin Midshipman were first collected in an embayment, they were most common at the shoals. Over 2 to 3 months they appeared to migrate to deeper water. This pattern is consistent with their reported spawning in shallow subtidal and intertidal areas (Hubbs 1920).

Age-1+ Plainfin Midshipmen were collected from January to September in 2012, 2013 and 2014 and through August in 2015. Age-1+ Plainfin Midshipmen consistently emigrated from the estuary by late summer or early fall, leaving the age-0 fish to rear. Distribution ranged from South Bay to San Pablo Bay, with highest CPUE in Central Bay each year.

Brown Rockfish

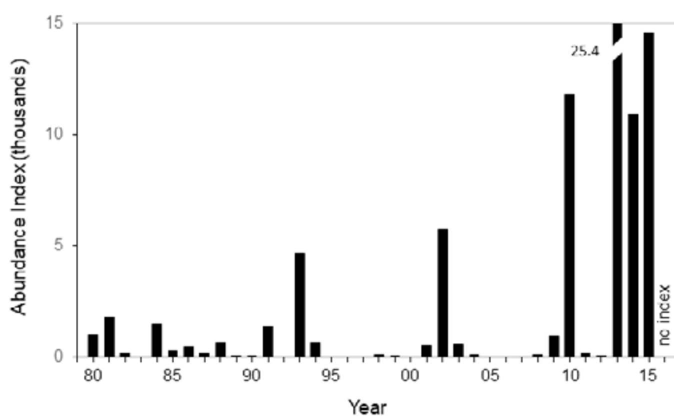
The Brown Rockfish (*Sebastes auriculatus*) is the most common rockfish that utilizes San Francisco Estuary as a nursery and ranked 11th in demersal fishes collected by the otter trawl from 2012 to 2016 (Table 2). It is a slow-growing, live-bearing fish, with some individuals reaching sexual maturity as early as 3 years. Larvae are born in coastal waters during winter and early spring. Juveniles immigrate to the estuary, where they remain for several years before moving to deeper waters, and eventually to coastal habitats (Kendall and Lenarz 1986). Brown Rockfish are often associated with structures such as pilings and rocks and are thus under sampled by trawl gear.

The 2012 to 2015 age-0 Brown Rockfish abundance indices were extremely variable, with the 3 of the 4 highest indices for the study period from 2013 to 2015 (Figure 19) and a near record-low index in 2012. From the May to July mean CPUE, it appears that 2016 also had good recruitment, comparable to 2014 (Table 3). We have hypothesized that Brown Rockfish, as a cold-temperate species, somehow benefited from colder SSTs since the late 1990s. Although the high abundance years of 2002, 2010, and 2013 had colder SSTs, the high abundance years of 2014 and 2015 had warmer SSTs (Figure 6). In addition, not all the years with colder SSTs had strong recruitment. Brown Rockfish larvae hatch in coastal waters in winter, and recruitment may be related to fine-scale ocean events, such as localized upwelling or downwelling and food production.

When abundant, age-0 Brown Rockfish were collected from April to December, with peak abundance from May through August. However, they were only collected in June of 2012, the year with extremely low abundance.

Age-0 Brown Rockfish were collected from South Bay to San Pablo bay in 2013 to 2015, but only 1 fish was collected in 2012, and was from San Pablo Bay. From 2013 to 2015, the highest catches were from the channel stations near Hunter's Point (#109) and Angel Island (#214) and the shoal stations near Candlestick Point in South Bay (#106) and Treasure Island in Central Bay (#211). The highest age-0 Brown Rockfish annual

Figure 19. Annual abundance of age-0 Brown Rockfish, Bay Study otter trawl, April-October, 1980-2015.



CPUE was 27.1 fish per tow at the Hunter's Point station in 2013. Overall, CPUE was highest in Central Bay, followed by South and San Pablo bays, with a seasonal movement to Central Bay in fall and winter.

With this movement of age-0 Brown Rockfish to Central Bay there was a migration from the shoals to the channels through spring and summer. For example, in 2015 Brown Rockfish were first collected at shoal stations in each embayment, then at channel stations. By July, Central Bay channel CPUE was higher than shoal CPUE, with a few fish still collected in South and San Pablo bays. The last fish were collected in South and San Pablo bays and Central Bay shoals in September. By October 2015, age-0 Brown Rockfish were only collected in Central Bay channel stations. This ontogenetic shift to channel stations is associated with habitat selection for deeper, cooler water as temperatures increase over the shoals and fish stage to emigrate from the estuary (Baxter et al. 1999, Kendall and Lenarz 1986).

Pacific Staghorn Sculpin

The Pacific Staghorn Sculpin (*Leptocottus armatus*) is a common native species that rears in marine, brackish, and occasionally freshwater intertidal and shallow subtidal areas. From 2012 to 2016, it ranked 6th of all demersal fishes collected by the otter trawl (Table 2). It is strongly associated with estuaries along its entire range (Emmett et al. 1991) and was classified as an *Estuary Resident* by Allen et al. (2006). In Central California, it spawns from October to March, rears from late winter through summer, and migrates to deeper water through summer and fall (Jones 1962, DeVlaming et al. 1984). Pacific Staghorn Sculpin grow rapidly, reaching 120 mm TL in one year. Adults move to deeper water after spawning, including offshore coastal waters (Tasto 1975).

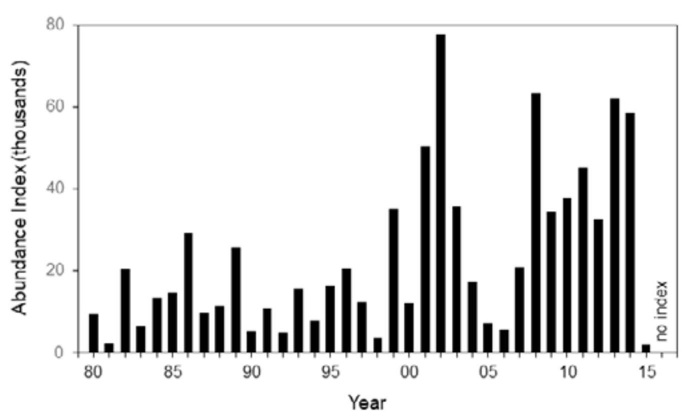
The 2012 to 2015 age-0 Pacific Staghorn Sculpin abundance indices were highly variable, with the 2013 and 2014 indices the 3rd and 4th highest and the 2015 index the lowest for the study period (Figure 20). Based on the May to July mean CPUE, abundance in 2016 was even lower than in 2015 (Table 3). Pacific Staghorn Sculpin is a cold-temperate species and the warm ocean temperatures from mid-2014 to early 2016 (Figures 5B and 6) may have resulted in migration of adults north along the coast in search of colder water, few adults entering the estuary to spawn, lower reproductive potential, or a combination of factors.

Although Pacific Staghorn Sculpin spawns in winter, we usually did not collect age-0 fish until March, as they grew large enough to be caught by our gear and moved from intertidal and shallow subtidal nursery areas. Peak abundance was from May or June through early fall, with some age-0 fish collected through December in all years except for 2015, which had the lowest annual abundance.

Age-0 Pacific Staghorn Sculpin were collected at almost every station from South Bay to the lower rivers in 2012, 2013 and 2014. Distribution was not as broad in 2015, a low abundance year, with fish collected primarily in Central Bay and scattered collections elsewhere. Several Central Bay stations consistently had the highest catches of age-0 Pacific Staghorn Sculpin, including the shoal stations near Treasure Island (#211) and at Southampton Shoal (#243) and especially the 2 channel stations near Angel Island (#214 and 215). In 2013, these 2 channel stations averaged 56.2 and 74.9 fish per tow, contributing to an annual Central Bay CPUE of almost 16 fish per tow.

The broadest distribution of age-0 Pacific Staghorn Sculpin was in April, May and June of 2012 to 2015, concurrent with the highest abundance. There was also a seasonal movement of age-0 Pacific Staghorn Sculpin from the upstream regions of Central Bay through spring and early summer. Concurrently, there was a movement from the shoals to the channels in all regions. However, there is evidence from the length-frequency data that some of the fish collected from the Central Bay channels in late spring and summer were a different cohort than the estuary-reared fish. We previously hypothesized that in years with strong summer upwelling, such as 2012, 2013, and 2014, Pacific Staghorn Sculpin move into Central Bay from the nearshore coast seeking warmer water (Fish et al. 2013).

Figure 20. Annual abundance of age-0 Pacific Staghorn Sculpin, Bay Study otter trawl, February-September, 1980-2015.



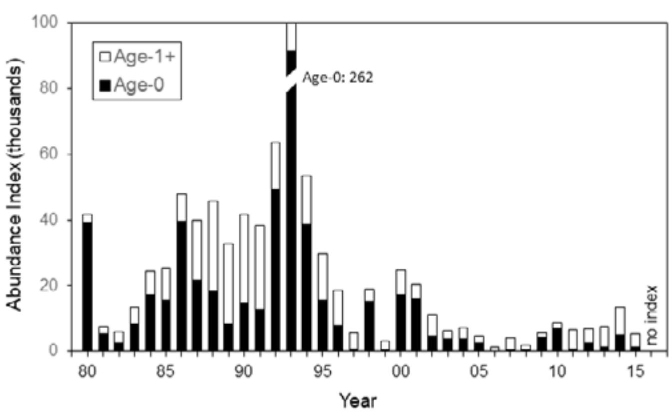
White Croaker

The White Croaker (*Genyonemus lineatus*) is a common coastal species that frequents bays and estuaries. From 2012-2016, it ranked 12th in demersal species collected by the otter trawl (Table 2). It is a member of the subtropical fish fauna and is more common south of Point Conception than to the north. It spawns from November through April in shallow, nearshore waters, and juveniles progressively move into deeper water as they grow (Love et al. 1984).

The 2012 to 2015 age-0 White Croaker indices were relatively low and below the study-period mean each year, as they have been since 2001 (Figure 21). The highest index of the 4 years reported here was in 2014 and the lowest indices in 2013 and 2015. Based on the May to July mean CPUE, age-0 White Croaker abundance was also very low in 2016 (Table 3). Age-0 fish were collected most months of the year, with peak abundance in summer (2013 and 2015), fall (2014) and winter (2012). This lack of a consistent seasonal trend was reflective of low abundance, not a significant variation in peak abundance.

Age-0 White Croaker were collected throughout South, Central, and San Pablo bays in 2012 to 2014, but had a narrower distribution in 2015, when they were restricted to several South and Central bay stations. In every year, the highest catches were at the channel station near Angel Island (#214); in 2015, nearly 80% of age-0 fish (n=52) were collected there. Although annual CPUE was far higher at channel stations than shoal stations, age-0 White Croaker were usually more common at shoal stations in spring and summer. There was a strong movement to channel stations in fall, consistent with the literature reporting that they move to deeper water with age. This seasonal movement to the channels was less apparent in 2015, the lowest abundance year.

Figure 21. Annual abundance of age-0 and age-1+ White Croaker, Bay Study otter trawl, February-October, 1980-2015.



The 2012 to 2015 White Croaker age-1+ indices were near or below the study-period mean all years, with the highest index in 2014 and the lowest in 2015 (Figure 21). Age-1+ indices have been consistently low since 1996 and were highest from 1987 to 1991, a period of warm ocean temperatures with an extended drought. The 2016 age-1+ White Croaker abundance was also very low based on the May to July mean CPUE (Table 3). As for age-0 fish, there was no consistent seasonal abundance trend for age-1+ fish, with abundance peaks in winter, summer and fall of the 4 years reported.

Almost all age-1+ White Croaker were collected from South Bay through lower San Pablo Bay from 2012 to 2015. In 2013, one fish was collected in Carquinez Strait. As for age-0 fish, age-1+ catches were consistently highest at the channel station near Angel Island (#214), ranging from 37% in 2013 (n=84) to 75% in 2015 (n=123) of the total catch. But unlike age-0 White Croaker, there did not appear to be a seasonal movement from the shoals to the channels. With a few exceptions, mean CPUE was substantially highest at Central Bay channel stations every month.

Bay Goby

The Bay Goby (*Lepidogobius lepidus*) is one of the most common gobies in the estuary; from 2012 to 2016, it was the 2nd most common demersal fish collected by the otter trawl and the most common goby (Table 2). It is a native resident species that rears in higher salinity areas and has a 2 to 3-year life span (based on length data), rarely reaching more than 120 mm TL here (CDFG 1987). However, in Morro Bay, it reportedly lives for 7 years (Grossman 1979). We are aging Bay Gobies from San Francisco Estuary using otoliths to resolve the age discrepancy. In San Francisco Estuary, reproduction can occur throughout the year, but peak larval abundance was in April and May (Wang 1986) and peak yolk-sac larval abundance usually June through August (CDFG unpublished data). Larvae are planktonic for 3 to 4 months (Grossman 1979) and descend to the bottom at about 25 mm TL (Wang 1986).

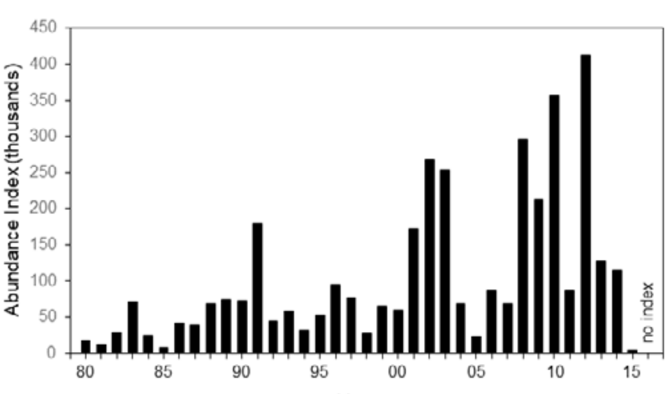
The Bay Goby annual abundance indices varied widely from 2012 to 2015, with the 2012 index the highest for the study period, the 2013 and 2014 indices near the study period mean, and the 2015 index the lowest for the study period (Figure 22). Based on the May to July mean CPUE, abundance was also very low in 2016 (Table 3). Bay Gobies were collected every month except for October and November 2015. Peak abundance was in spring and summer and the lowest abundance in late fall and winter. The exception was 2015, when abundance was very low all months except for July.

The size distribution of Bay Gobies was similar most years, with the smallest juveniles, 20-29 mm, collected from late fall through summer of the next year. In the extremely low abundance year of 2015, only 9 Bay Gobies 20-29 mm were collected the entire year, most in February. Catches of the largest fish dropped dramatically in October, coincident with decreasing temperatures. Grossman (1979) reported a substantial decrease in Bay Goby abundance from Morro Bay intertidal mudflats in winter, just before the highest gonadal index and with decreasing water temperatures. The very low catches of larger fish here during fall and winter could be a movement of adult fish to coastal waters or an estuarine habitat more suitable for reproduction that we do not sample.

Distribution ranged from South to Suisun bays every year, with 1 fish collected from the lower Sacramento River in 2012. The highest catches were from several South and Central Bay stations, including the channel and shoal stations between the Dumbarton and San Mateo bridges (#101 and 102), the channels station near the Bay Bridge (#110) and Angel Island (#214 and 215), and the shoal stations near Treasure Island and Paradise Cay (#211 and 244) and at Southampton Shoal (#243). In 2012, we collected an average of >100 fish per tow at 3 stations, with 174 fish per tow from the Angel Island channel station (#214). Most of these fish were age1+ and 79% (n=1,595) of the catch occurred in August and September.

Bay Goby distribution was broadest in spring and summer, coincident with the highest abundance. South Bay catches dropped rapidly through summer, with low catches after July. Suisun Bay catches also dropped rapidly through summer, with no fish collected upstream after June or July. As fish left South Bay and upstream, catches increased in Central Bay through summer, with the highest catches from July to September. After September, Central Bay catches decreased to their seasonal late fall and winter low. This migration of Bay Gobies to Central Bay from upstream and South Bay generally corresponded with a movement from the shoals to the channels. The trend was for the highest shoal catches in spring and highest channel catches in summer, although this was confounded if fish rapidly left an area, such as South Bay and Suisun Bay. In some years, it appeared that Bay Gobies simply disappeared from a region with no movement to the channels to migrate downstream.

Figure 22. Annual abundance of Bay Goby (all sizes), Bay Study otter trawl, February-October, 1980-2015.



The decline in Bay Goby abundance in 2015 and 2016 was similar to the decline reported for several other marine demersal species, including Plainfin Midshipman, Pacific Staghorn Sculpin, and Speckled Sanddab. We believe that warm ocean temperatures affected the distribution or recruitment of these species, although we do not know the specific mechanisms that resulted in the substantial Bay Goby decline. It is possible that maturing and adult Bay Gobies moved to the nearshore coastal waters when Central Bay water temperatures increased to over 18°C (Figure 7), resulting in poor juvenile recruitment. Throughout the study period, the highest Bay Goby indices were in years with cold ocean temperatures, including 2001 to 2003, 2008 to 2011, and 2012 (Figures 6 and 22). Conversely, the lowest abundance was during periods of warm ocean temperatures, including most of the 1980s and 1990s, 2005, 2015, and 2016 (Figures 6 and 22).

Speckled Sanddab

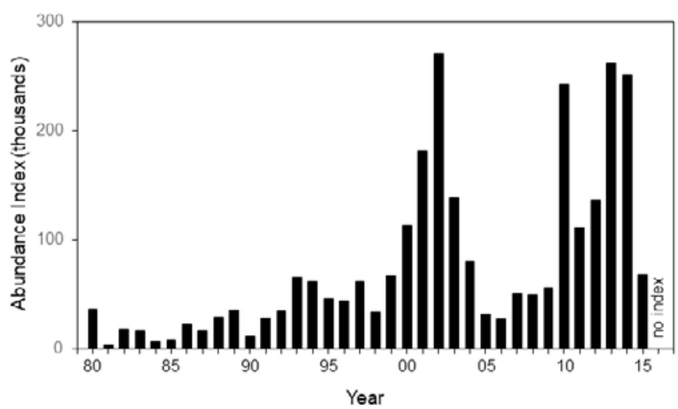
The Speckled Sanddab (*Citharichthys stigmaeus*) is one of the most abundant flatfishes in the estuary. From 2012 to 2016 it was the most commonly collected fish in the otter trawl (Table 2) and the most common flatfish collected each year. It is a short-lived species with an estimated maximum age between 36 and 42 months. In Southern California, spawning occurs along the coast and is coincident with a sudden drop in bottom temperature due to upwelling (Ford 1965). Larvae may be pelagic for many months, riding ocean currents first offshore then onshore, before settling to the bottom in or near coastal and estuary rearing areas, generally in less than 40 m of water (Ford 1965, Kramer 1990). Juveniles rear for up to a year in the estuary before immigrating to the ocean.

Speckled Sanddab abundance indices (all sizes) were very high in 2013 and 2014, the 2nd and 3rd highest indices for the study period (Figure 23). The 2012 index was relatively high, well above the study-period mean, while the 2015 index decreased to just below the study-period mean. However, the 2015 index ranked 11th of the 36 years, reflective of the very low indices through the 1980s. Based on the mean May to July CPUE, abundance increased slightly in 2016 (Table 3). The 10 highest indices have been since 2000, during the cold-water regime, and all but 1 of the lowest 10 indices were before 1992, during the warm-water regime. Clearly, Speckled Sanddab abundance increased in years with colder ocean temperatures and stronger upwelling. If decreasing ocean temperatures associated with the onset of upwelling triggers spawning, years with earlier and stronger upwelling may have larger and protracted reproductive events. There was some evidence of protracted spawning in 2013, with relatively large numbers of small Speckled Sanddab (20-39 mm TL) from January to June. In 2014, another high abundance year, the largest catches of fish 20-39 mm were in May and June.

Speckled Sanddab were collected every month sampled from 2012 to 2015, with peak abundance in late spring and summer, from April or May until July or August. Abundance was occasionally high in other months, especially winter. The lowest seasonal abundance was in fall in 2012, 2013, and 2015 and in January of 2014.

Speckled Sanddab were collected from South to lower Suisun bays every year, with 1 fish from the channel station near Chipps Island (#535) in 2014. Distribution was centered in Central Bay every month, with just over 180 fish per tow collected for 3 months of 2013. Catches were consistently highest at the shoal stations near Treasure Island (#211) and at Southampton Shoal (#243) and the 2 channel stations near Angel Island (#214 and #215), all in Central Bay. Although less abundant in South and San Pablo bays, Speckled Sanddab were always collected in these regions. From 2012 to 2015, the highest monthly South Bay CPUE was 35 fish per tow and the highest San Pablo Bay CPUE was 32 fish per tow. There was a consistent seasonal movement of Speckled Sanddab from South and San Pablo bays to Central Bay through summer and from the Central Bay shoals to channels in fall and winter.

Figure 23. Annual abundance of Speckled Sanddab (all sizes), Bay Study otter trawl, February-October, 1980-2015.

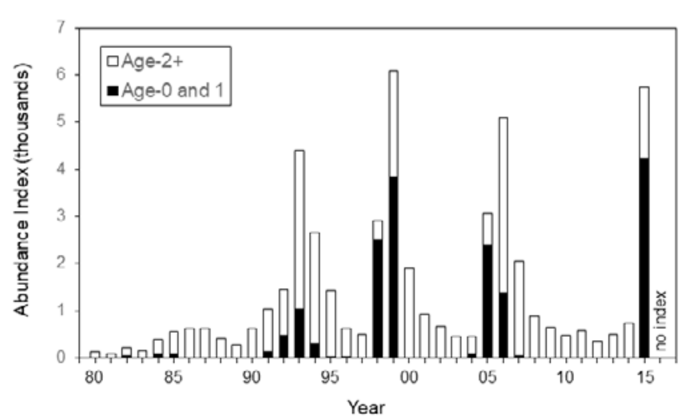


California Halibut

The California Halibut (*Paralichthys californicus*) is a member of the subtropical faunal group that is common in the Southern California Bight, but ranges to British Columbia. It spawns in shallow coastal waters and juveniles rear in very shallow subtidal and intertidal areas of bays and estuaries, and to a much lesser extent on the open coast (Allen 1988). It ranked 17th of the all fishes and 4th of flatfishes collected by the otter trawl from 2012 to 2016 (Table 2).

After 7 years of consecutive zeros, the 2015 juvenile (age-0 and 1) California Halibut index was the highest since 1980 (Figure 24). The 2016 May to July mean CPUE juvenile was approximately twice the 2015 CPUE (Table 3), leading to the conclusion that the 2016 juvenile California Halibut abundance was the highest for the study period. From the length data, there appeared to be multiple cohorts in the estuary as of late 2014. California Halibut reportedly reproduce in Southern California when temperatures are warmer than 13°C (Gadomski and Caddell 1991, Gadomski and Caddell 1996). SSTs in the Gulf of the Farallones were above 13°C from mid-2014

Figure 24. Annual abundance of juvenile (age-0 and age-1) and age-2+ California Halibut, Bay Study otter trawl, February-October, 1980-2015.



through 2016, except for several months in spring of 2015 and 2016 (Figure 6).

Juvenile California Halibut were collected every month sampled in 2015 and 2016 and in January, November and December 2013 and November and December 2014, all months outside of the index period. There were 4 abundance peaks in 2015: February, April and May, July, and November and December. Monthly abundance was high every month sampled in 2016 (May to July and November and December), with highest abundance in July and December. Usually our largest cohorts are from late summer and fall reproductive events, as SSTs are warmer for the longest period after upwelling stops in summer.

When abundant, juvenile California Halibut ranged from South Bay to Suisun Bay, with 1 fish collected near Sherman Island on the lower Sacramento River in 2015. South Bay shoal stations, the shoal station near Treasure Island (#211), and several shoal stations in San Pablo Bay had the highest catches, with 2 to 4 fish per tow in 2016. Not surprisingly, annual CPUE was highest in South Bay every year, followed by either Central or San Pablo bay. There was no apparent movement between embayments, but any movement could have been masked by the multiple cohorts. In 2015, the highest monthly CPUE was in Central Bay during December (2.8 fish per tow) and in 2016 (incomplete sampling), it was in South Bay in December (3.3 fish per tow). CPUE was consistently higher at the shoals than the channels in all months and embayments, except for Suisun Bay. The preference for shoals was strongest in South and San Pablo bays. For example, in 2015, the South Bay shoal CPUE was 1.5 fish per tow vs. 0.2 fish per tow for the channel.

The 2012, 2013, and 2014 age-2+ California Halibut indices were very modest, with a trend of slowly increasing indices through 2014 (Figure 24). However, the 2015 index was more than double the 2014 index and the highest index since 2007. Seasonal abundance of age-2+ California Halibut was not consistent, with the highest abundance in summer and fall of 2012, late fall and winter of 2013, spring of 2014, and summer and winter of 2015. We collected age-2+ California Halibut from South to Suisun bays, but they were most common at several South and Central bay stations, including the shoal stations near Candlestick Point (#106) and Treasure Island (#211), and the channel stations near Angel Island (#214) and Red Rock (#216). Most age-2+ fish we collected were 240 to 500 mm, well below the minimum length for recreational harvest (559 mm). These fish may have migrated from near shore coastal rearing areas, possibly from the south, as the last substantial in-bay recruitment was in 2005 and 2006 and juveniles from 2015-16 would not be age-2+ until 2017.

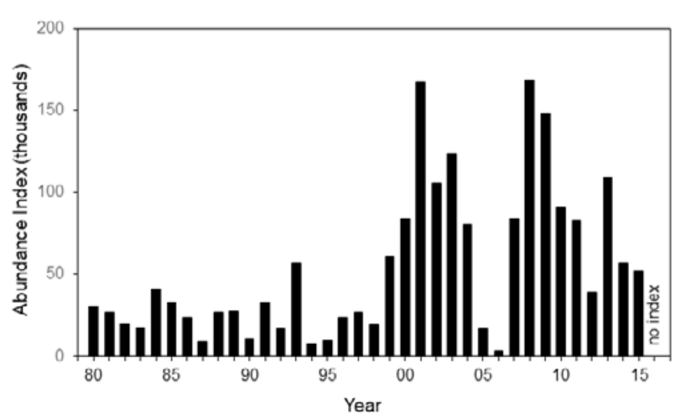
English Sole

The English Sole (*Pleuronectes vetulus*) is a common flatfish that spawns along the coast in winter and rears in both the coastal ocean and estuaries (Jow 1969, Toole 1980). It is a cold-temperate species, ranging from Baja California to northwest Alaska (Miller and Lea 1972), but is most common north of Point Conception (Emmett et al. 1991). It was the 4th most common fish and the 3rd most common flatfish collected by the otter trawl from 2012 to 2016 (Table 2).

The 2012 age-0 English Sole abundance index was the lowest in 5 years, with a steady decline from 2008 to 2012 (Figure 25). The 2013 index increased to the 5th highest on record, then the 2014 and 2015 indices decreased to near the study-period mean. In general, English Sole abundance was higher in years with cold ocean temperatures and lower with warm temperatures. The relatively high abundance of English Sole in recent years was possibly due to increased egg and larval survival, increased spawning stock adjacent to the San Francisco Estuary, or some combination of factors. In Oregon coastal waters, gonadal development was positively related to colder summer bottom temperatures, as driven by upwelling (Kruse and Tyler 1983).

Age-0 English Sole were first collected over a wide range of months: December 2011 for the 2012 year class, December 2012 for the 2013 year class, October 2013 for the 2014 year class, and March 2015 for the 2015 year class. From 2012 to 2015, the smallest English Sole juveniles, 20-29 mm TL, were collected for 6 to 9 months, but only for 4 months in 2015. English Sole spawning is protracted and highly variable (Jow 1969, Laroche and

Figure 25. Annual abundance of age-0 English Sole, Bay Study otter trawl, February-October, 1980-2015.



Richardson 1979), leading to a wide range of settlement dates and multiple cohorts in some years. Irrespective of the first settlement date, age-0 English Sole abundance peaked from April to June and decreased through summer and fall to a seasonal minimum in winter. 2015 was noteworthy, as only 14 age-0 English Sole were collected from August to October, none in November, and 16 in December.

The late settlement and near disappearance of English Sole in 2015 was a unique pattern for the study period. 1983 and 1998, years with large El Niño events and higher freshwater outflow, had very late settlement in July and May, but fish remained in the estuary through summer. Several years from the late 1980s through early 1990s, when we had smaller El Niño events and periodic warm SSTs (Figure 6), had very low English Sole catches after July, but early and somewhat protracted settlement. We propose that the warm ocean temperatures in 2014 and 2015 not only delayed English Sole reproduction in 2015, but the age-0 fish quickly emigrated from the estuary in summer, when Central Bay temperatures exceeded 18°C and almost reached 20°C in upper Central Bay (Figure 7). This is supported by Yoklavich (1982), who found that juvenile English Sole growth declined as temperatures approached 17.5°C. She concluded that juveniles emigrated from Elkhorn Slough to the ocean in late summer and early fall, when temperatures reached 17 to 20°C, because of thermal tolerance.

Age-0 English Sole were collected from South Bay to upper Suisun Bay, near Chipps Island, from 2012 to 2016. They were most commonly collected from several Central Bay stations, including the shoal stations near Treasure Island (#211), the Berkeley Pier (#212), and Paradise Cay (#244) and the channel station near Angel Island (#214). In 2013, an average of 152 age-0 English Sole per tow was collected from the channel station near Angel Island, with over 100 fish collected there per month for 7 months. The highest annual CPUE was consistently in Central Bay all years, followed by either San Pablo Bay (2013, 2014, and 2015) or South Bay (2012). Age-0 fish were more common at shoal stations than channel stations for all regions and years, but there was a seasonal shift from the shoals to channel of Central Bay in late summer and fall, coincident with emigration. In 2015 it was not only a shift, but as discussed above, a dramatic decline in catch in August.

Age-1+ English Sole were also common in Central Bay tows, especially in 2012 and 2014, years following high age-0 abundance. Most age-1+ fish emigrated from the estuary by May, as temperatures start to increase (Figure 7). Age-1+ English Sole strongly preferred channel stations and most were collected from the 2 channel stations near Angel Island (#214 and #215).

California Tonguefish

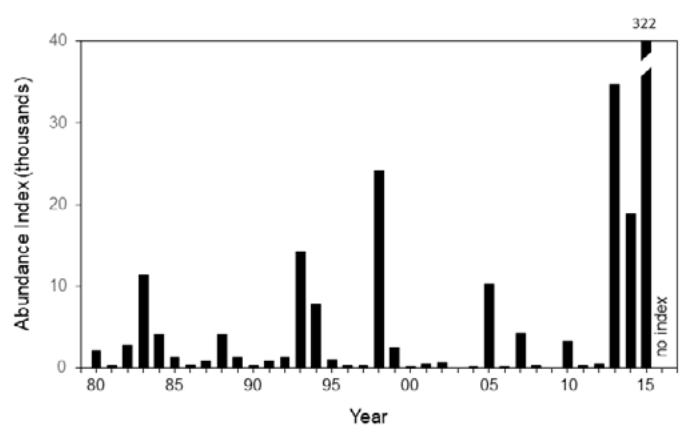
The California Tonguefish (*Symphurus atricaudus*) is a small flatfish of the subtropical faunal group. Spawning occurs from May through October (Goldberg 1981) and the larvae have an extended pelagic duration, settling at approximately 25 to 29 mm (Kramer 1991).

The 2 highest California Tonguefish (all sizes) abundance indices occurred in 2013 and 2015, with the 2015 index almost 7 times higher than the 2013 index (Figure 26). The 2014 index ranked 4th for the study period, while the 2012 index was very low. Based on the May to June CPUE, abundance was also high in 2016 (Table 3), but not nearly as high as in 2015. California Tonguefish expanded its northern distribution during the 1982 to1983 El Niño event (Dinnel and Rogers 1986) and responded similarly to the 2014-2015 marine heatwave and 2015-2016 El Niño event. Note that California Tonguefish abundance increased in San Francisco Estuary in 2013, before higher SSTs were reported in the Gulf of the Farallones (Figure 6). The marine heatwave developed in the North Pacific near Alaska in 2013, but did not extend throughout the CCS until 2014 (Bond et al. 2015), so the northward movement or transport of California Tonguefish in 2013 was unexpected.

California Tonguefish were first collected in May 2012, and collected all months sampled through 2016, except for September 2012. Peak abundance was between May and August of all years, with a second smaller peak in December 2014.

California Tonguefish were collected from South to Suisun bay from 2013 to 2016, but only to San Pablo Bay

Figure 26. Annual abundance of age-0 California Tonguefish (all sizes), Bay Study otter trawl, February-October, 1980-2015.



in 2012, the low abundance year. One fish was collected from the channel station near Chipps Island (#535) in July 2015. The highest catches were from the South Bay channel stations, including the southernmost station near the Dumbarton Bridge (#140), the channel station near Angel Island in Central Bay (#214), and the channel stations near the Richmond-San Rafael Bridge (#345) and Point Pinole (#325) in San Pablo Bay. In 2015, we collected an annual average of over 100 fish per tow at 3 stations: Hunter's Point channel (127 per tow), Angel Island (114 per tow), and Point Pinole (154 per tow). The annual CPUE was highest in South Bay all years except for 2012, with an average of 50 fish per tow in 2015, followed by either Central (2013) or San Pablo bays (2014 and 2015). California Tonguefish were more common at the channels than shoals in all regions and months, except for higher shoal CPUE in South Bay in spring 2013 and San Pablo Bay in summer 2013.

Noteworthy Fishes

From 2012 to 2016, the Bay Study collected several subtropical pelagic and demersal fish species that are usually uncommon to the San Francisco Estuary. For the first time since 1993, California Lizardfish (*Synodus lucioceps*) were collected consecutively each year, with the bulk of the catches in 2013 (n=634), before the onset of the marine heatwave. This species is usually most common south of Point Conception, but has a prolonged larval period (Moser 1996) that could result in transport of larvae north when there is a strong south to north current. In 2015 and 2016, we collected several California Lizardfish <100 mm FL, which indicated local spawning. Another first since 1993 was 3 Jack Mackerel (*Trachurus symmetricus*) collected in 2015; 1 was from San Pablo Bay and 2 from South Bay.

We also collected the first Halfmoon (*Medialuna californiensis*) in the study's history at the shoal station near Oakland Airport (#104) in May 2012 and the first Pacific Bonito (*Sarda chiliensis*) from the shoal station near Treasure Island (#211) in September 2015.

One of the most interesting catches was a Tubesnout (*Aulorhynchus flavidus*) collected at the Carquinez Strait shoal station (#447) in January 2013. It is only the second caught in the study's history, with the first one collected in 1995 in Central Bay. Two Queenfish (*Seriphus politus*) were collected in January 2015 at a South Bay channel station (#108); previously we collected 10 Queenfish from 1985 to 2003. We collected 21 Spotted Cusk-Eel (*Chilara taylori*) in 2015 and 2016 from several Central Bay channel stations. Prior to 2015, we collected 225 cusk-eels from 1984 to 1999, 32 from 2003 to 2008, but none from 2009 to 2014.

Pacific Sardine (*Sardinops sagax*) catches have been low since 2008, a trend that continued from 2012 to 2016, with only 36 collected. In 2015 and 2016, 3 California Grunion (*Leuresthes tenuis*) were collected, all from Central Bay. First collected by the Bay Study in 2001, 686 California Grunion were collected from 2001 to 2007, followed by none from 2008-2013 and 1 in 2014. In May 2013, 1 White Seabass (*Atractoscion nobilis*) was collected in San Pablo Bay. This was the 7th White Seabass collected by the Bay Study; all the others were collected from 1997 to 2008.

Notes

- Dayflow data from water.ca.gov/dayflow/
- PDO indices from research.jisao.washington.edu/pdo/PDO.latest
- NPGO indices from www.o3d.org/npgo/data/NPGO.txt
- Upwelling indices and anomalies from www.pfeg.noaa.gov/products/PFEL/modeled/indices/upwelling/NA/data_download.html
- Sea Surface Temperatures for SE Farallon Island from scripps.ucsd.edu/programs/shorestations/shore-stations-data/data-farallon/
- San Francisco Bay water temperature data from the San Mateo, Richmond-San Rafael, and Benicia bridges from ca.water.usgs.gov/projects/baydelta/index.html
- Fort Point water temperature data from ndbc.noaa.gov/station_page.php?station=FTPC1
- Buoy 142 water temperature data from ndbc.noaa.gov/station_page.php?station=46237

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Bay Study Shrimp Status and Trends Report for the San Francisco Estuary, 2012-2016

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This report summarizes annual abundance trends and distribution for the most commonly collected caridean shrimp from San Francisco Estuary from 1980 through 2016, with a focus on 2012 to 2016. The shrimp data is from the San Francisco Bay Study (Bay Study) otter trawls, with additional *Exopalaemon modestus* data from the UC Davis Suisun Marsh otter trawl survey and the United States Fish and Wildlife Service (USFWS) Beach Seine survey. This is a companion report to the Bay Study's 2012-2016 Fishes and Crabs Status and Trends report, also published in this issue of the IEP Newsletter (see pages 3 and 43 of this issue).

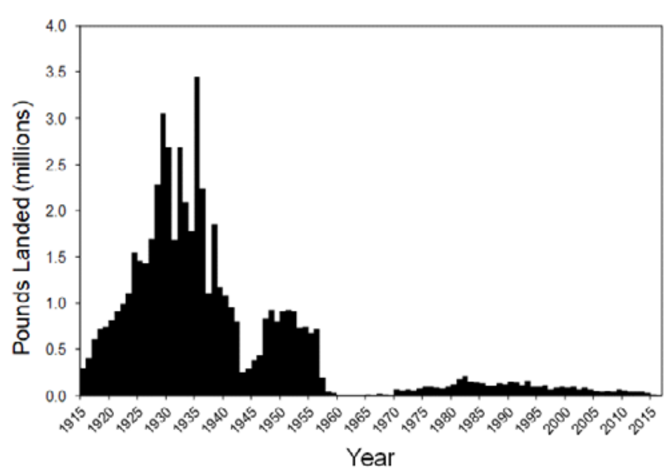
Six species of Caridean shrimp are common in the San Francisco Estuary: *Crangon franciscorum*, *C. nigricauda*, *C. nigromaculata*, *Heptacarpus stimpsoni*, *Palaemon macrodactylus*, and *Exopalaemon modestus*. The 3 species of *Crangon* and *Heptacarpus* are native while *Palaemon* and *Exopalaemon* are introduced. The life histories, predators, prey, and salinity and temperature preferences of *Crangon*, *Heptacarpus*, and *Palaemon* were reviewed in CDFG 1987 and Hieb 1999.

Bay Study otter trawl data was used to describe abundance trends and distributional patterns of juvenile, adult, ovigerous, and total (all sizes and sexes) of shrimp. Sizes of maturity were developed for male and female *C. franciscorum*, *C. nigricauda*, and *C. nigromaculata* from the literature (Israel 1936, Krygier and Horton 1975, and Kinnetic Laboratories 1987) and California Department of Fish and Wildlife (CDFW) data, which allowed us to separate juveniles and adults. For other species, I reported annual indices for the total catch and used ovigerous data for seasonal abundance trends and distributional patterns. Annual and monthly abundance indices (core 35 stations only) were used for annual and seasonal abundance for all species except for *E. modestus*. Annual catch-per-unit-effort (CPUE, catch per 5-minute tow) for only the stations upstream of Carquinez Strait was used for *E. modestus* abundance trends, as it was rare downstream of Carquinez Strait and very common upstream of the "core" stations. Suisun Marsh annual *E. modestus* CPUE was mean catch per 5 minute tow for all stations. Mean Bay Study CPUE was used for distribution by station, region, and channel-shoal for all species, while USFWS beach seine total catch was used for upstream distribution of *E. modestus*.

In 2016, sampling was limited to May to July, which was only a portion of the index period for most species, and November and December, months not used for most indices. Therefore, I calculated May to July CPUE to compare 2016 abundance to previous years for the common shrimp species. Additional methods and the physical data results, including ocean climate indices, upwelling indices, sea surface temperature, and San Francisco Estuary water temperatures are in the Bay Study's Fishes Status and Trends Report in this issue (page 3 of this issue). The Bay Study station map is Figure 1 of the Bay Study Fishes report.

Crangon spp. are commonly referred to as "Bay shrimp" or "grass shrimp" and are fished commercially by trawl fishermen in the lower estuary, downstream of Suisun Bay. Bay shrimp are primarily sold as bait for sport fishermen and *C. franciscorum* is targeted because of its relatively large size and abundance. Earlier in this century, when there was a large market for dried shrimp, over 3 million pounds per year were landed (Figure 1). Landings declined over the past 3 decades, averaging 112,600 pounds per year in the 1990s, 64,800 pounds per year in the 2000s, 40,500 pounds per year from 2010-2014, 13,000 pounds in 2015, and 5,400 pounds in 2016 (Figure 1). Landings dropped substantially in

Figure 1. Annual commercial landings of Bay Shrimp, primarily *Crangon* spp., in San Francisco Bay, 1915-2016. Landing data from Reilly et al. 2001 and the CDFW 2000-2016 California Commercial Landings, Table 10 (see www.wildlife.ca.gov/Fishing/Commercial/Landings).



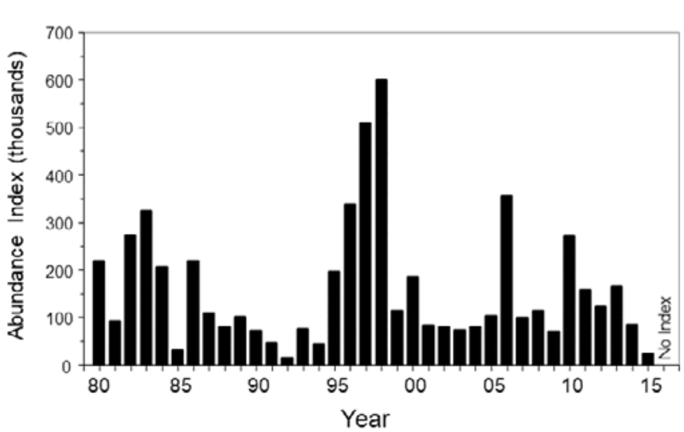
2015 and 2016 due to low shrimp abundance, with only 2 active trawlers, but increased in 2017 and 2018, with 6 active trawlers (A. Weltz, personal communication, see “Notes”).

Crangon franciscorum

Crangon franciscorum, the California bay shrimp, ranges from southeastern Alaska to San Diego (Jensen 2014) and is the dominant caridean shrimp in most Pacific coast estuaries north of San Francisco Bay (Emmett et al. 1991). It is an estuary-dependent species that rears only in estuaries, not in the ocean. Larvae hatch in winter and spring from eggs carried by the females in higher salinity waters (>25‰) of the lower estuary, and, in high outflow years, the nearshore coastal area. Some females hatch more than one brood of eggs during the reproductive season (Israel 1936, Hatfield 1985). Small juveniles (5-10 mm total length, TL) migrate upstream to the shallow brackish water nursery area primarily in spring, where they grow for 4 to 6 months, and maturing and adult shrimp migrate downstream to cooler, higher salinity waters in fall and winter to complete the life cycle. *C. franciscorum* mature at 1 year and have a short life span, with males living 1 to 1.5 years and females 1.5 to 2 years. It is the largest of the common shrimp found in the estuary, with males reaching 69 mm TL and females 87 mm TL (unpublished CDFW data).

The 2012 and 2013 juvenile *C. franciscorum* abundance indices were very similar (Figure 2) and close to the study-period mean. Abundance decreased in 2014 and 2015, with the 2015 index the 2nd lowest for the 37-year study period; only the 1992 index was lower (Figure 2). Although we did not sample enough surveys in 2016 to calculate an index, the mean May to July CPUE indicated that juvenile *C. franciscorum* abundance was the lowest for the study period by a factor of 4 in 2016 (Table 1). Based on the total (all sizes) index, *C. franciscorum* was the 2nd most abundant shrimp species in the estuary every year from 2012 to 2015 (Table 2).

Figure 2. Annual abundance indices of juvenile *Crangon franciscorum*, May to October, otter trawl, 1980-2016.



Low juvenile *C. franciscorum* abundance from 2012 to 2015 was predicted based on low freshwater outflow during spring (see Table 1 and Figure 2, Bay Study Fishes Status and Trends report, page 5 of this issue). March to May outflow continued to have a strong positive relationship with juvenile *C. franciscorum* abundance (both variables log transformed, $r^2 = 0.501$, n=36; Figure 3). The extremely low abundance of 2015 (and likely 2016) during the extended drought was also expected, as

Table 1. May to July mean CPUE (catch per tow) for the most common shrimp and life stages (juvenile and adult), 1980-2016. 2008 and 2014 had a missing survey, but there were no adjustments. *Crangon franciscorum* (Cf), *C. nigricauda* (Cn), *C. nigromaculata* (Cnm), *Heptacarpus stimpsoni* (Hs), *Palaemon macrodactylus* (Pm), *Exopalaemon modestus* (Em).

Year	Cf Juv	Cf Adult	Cf	Cn Juv	Cn Adult	Cn	Cnm Juv	Cnm Adult	Cnm	Hs	Pm	Em
1980	373.3	84.0	457.3	96.6	36.0	132.6	1.5	1.6	3.1	1.7	32.6	
1981	406.9	115.0	521.9	14.6	6.2	20.8	0.3	0.3	0.6	0.4	30.7	
1982	747.3	418.2	1165.5	15.8	12.9	28.6	2.1	0.7	2.8	0.2	12.8	
1983	710.7	107.1	817.8	15.4	6.9	22.3	3.8	0.4	4.2	0.1	2.2	
1984	739.4	369.3	1108.7	10.2	18.0	28.1	18.7	4.0	22.7	8.7	13.5	
1985	139.0	80.5	219.5	12.8	22.7	35.5	1.5	1.3	2.8	3.5	15.1	
1986	512.6	227.5	740.1	53.9	25.0	78.9	2.8	0.7	3.5	4.3	13.0	
1987	555.5	225.4	780.9	33.5	26.1	59.6	2.4	0.7	3.1	2.1	9.4	
1988	330.9	115.3	446.2	218.2	91.6	309.8	7.2	3.0	10.2	9.4	9.5	
1989	440.8	91.5	532.3	153.2	64.1	217.3	12.5	6.1	18.5	31.1	26.1	
1990	218.3	31.0	249.3	261.4	59.6	321.0	23.6	8.5	32.1	23.4	18.2	
1991	192.7	38.8	231.5	163.4	89.2	252.6	39.5	11.0	50.5	37.6	10.3	
1992	71.3	17.4	88.7	171.8	80.0	251.8	53.2	15.3	68.4	19.2	16.7	
1993	302.4	57.4	359.8	230.0	74.1	304.1	125.6	22.8	148.4	24.7	11.3	
1994	132.5	49.3	181.8	112.2	65.1	177.3	40.7	18.3	59.1	20.8	9.7	
1995	345.6	92.2	437.8	61.2	15.1	76.3	44.4	1.7	46.1	2.6	10.8	
1996	912.6	83.3	995.9	151.3	58.4	209.7	33.6	4.7	38.4	14.0	8.3	
1997	1244.4	192.4	1436.8	156.5	81.7	238.2	73.3	10.9	84.1	10.8	15.7	
1998	1772.4	231.3	2003.7	71.6	48.4	120.1	46.7	3.7	50.4	2.2	31.9	
1999	341.2	137.5	478.7	69.8	82.7	152.5	36.8	8.2	45.0	17.1	13.9	
2000	530.1	46.9	577.0	223.6	148.8	372.4	19.3	9.9	29.2	52.9	8.3	0.0
2001	295.5	63.4	359.0	190.7	197.3	388.0	10.0	3.1	13.1	38.2	13.4	0.0
2002	332.5	130.7	463.2	569.7	418.0	987.7	17.6	4.2	21.7	87.6	16.7	4.1
2003	182.5	51.1	233.6	150.8	285.9	436.7	14.0	3.5	17.5	61.1	5.9	3.1
2004	278.4	73.0	351.4	347.4	197.7	545.2	23.8	5.9	29.7	33.5	4.8	1.2
2005	120.6	29.8	150.4	263.6	100.4	364.0	13.0	3.6	16.6	6.5	7.9	1.1
2006	504.6	106.3	610.9	118.2	191.0	309.2	27.5	12.5	40.0	2.4	16.0	0.5
2007	239.5	60.3	299.8	420.9	426.0	847.0	10.8	7.5	18.3	36.6	14.9	2.1
2008	359.1	82.2	441.3	670.4	410.8	1081.2	0.8	2.6	3.4	154.7	10.1	2.3
2009	185.4	53.3	238.7	452.8	488.3	941.0	7.0	2.9	9.9	158.1	3.8	2.2
2010	378.3	57.7	436.0	389.6	430.8	820.4	10.8	11.1	22.0	131.3	9.1	1.8
2011	227.5	73.7	301.2	54.9	142.7	197.7	3.0	2.3	5.3	19.8	6.2	1.2
2012	172.0	28.6	200.5	412.4	246.3	658.6	3.8	5.7	9.5	93.5	14.1	1.2
2013	252.2	130.2	382.5	98.9	325.2	424.1	5.9	15.9	21.8	106.8	21.0	2.4
2014	145.6	46.1	191.7	254.7	137.8	392.5	8.3	10.8	19.0	207.7	15.9	1.9
2015	45.6	24.5	70.1	9.7	52.0	61.7	43.7	27.4	71.1	84.4	25.8	1.9
2016	11.6	8.7	20.3	4.7	9.9	14.6	32.8	23.7	56.5	16.4	24.7	4.7

abundance steadily decreased during the 1988 to 1992 drought (Figure 2). Since *C. franciscorum* is estuary-dependent and rears in shallow brackish water, I have hypothesized that this relationship is partially due to the amount of low-salinity shoal habitat, which increases and decreases with outflow (CDFG 1992). San Pablo Bay has more shoal area than upstream embayments and is an important nursery area, especially in high outflow years. *C. franciscorum* juvenile CPUE at San Pablo Bay shoal stations averaged only 23.2 per tow from June to August 2015, compared to 1,461 per tow for the same months in 2006, when outflow and the annual index were much higher.

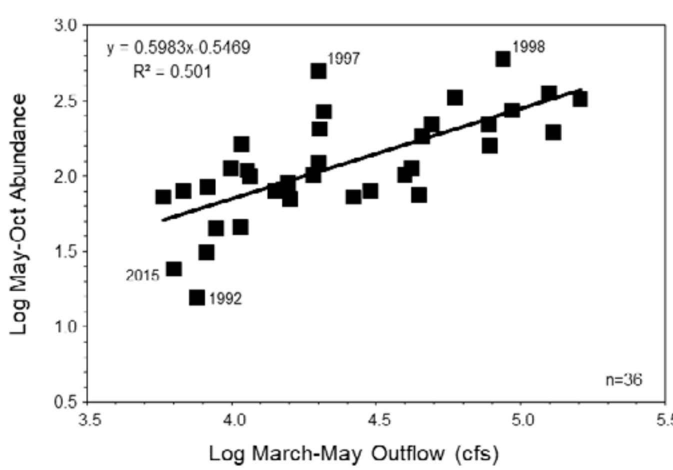
Table 2. Annual abundance indices (thousands) of the 6 most common shrimp species and all shrimp species combined, February to October, otter trawl. The indices include all sizes (juveniles and adults) for each species. Bolded indices are adjusted for missing surveys.

Year	*C. franciscorum*	*C. nigricauda*	*C. nigromaculata*	*Heptacarpus*	*Palaemon*	*Exopalaemon*	*All species*
1980	225.8	46.5	1.7	1.0	4.7		279.7
1981	119.3	22.1	0.5	0.5	5.1		147.4
1982	366.3	16.0	1.4	0.2	3.0		386.9
1983	328.5	38.8	16.0	0.6	1.3		385.2
1984	330.9	14.7	7.8	3.1	7.0		363.5
1985	57.8	19.7	3.1	3.1	3.9		87.6
1986	258.6	55.6	6.7	2.9	5.5		329.3
1987	142.9	75.5	9.6	6.8	2.4		237.2
1988	98.6	111.8	10.7	8.6	1.7		231.4
1989	**100.2**	**116.0**	**20.6**	**26.4**	**4.6**		**267.8**
1990	67.3	168.6	44.8	19.9	3.5		304.1
1991	51.4	190.3	63.0	41.1	4.7		350.5
1992	24.8	134.7	66.5	18.5	4.6		249.0
1993	70.5	128.1	78.6	25.4	4.0		306.7
1994	48.0	102.0	56.0	15.9	2.1		224.0
1995	**180.5**	**71.7**	**36.0**	**5.2**	**3.9**		**297.3**
1996	287.0	159.3	35.3	14.9	2.2		498.7
1997	444.5	163.9	43.4	9.1	4.9		665.9
1998	544.2	128.9	53.1	4.8	9.0		740.0
1999	159.7	134.0	42.0	13.2	4.1		352.9
2000	158.2	250.7	22.3	43.1	3.1	0.0	477.3
2001	**92.9**	**261.1**	12.5	59.7	**5.3**	**0.3**	**431.6**
2002	96.1	652.9	15.0	78.0	4.9	2.0	848.9
2003	77.3	379.5	15.7	67.5	1.5	1.9	543.4
2004	91.8	333.7	20.5	29.0	1.9	1.0	477.9
2005	106.0	365.4	46.8	17.9	4.1	1.1	541.3
2006	395.2	268.3	34.1	10.1	7.6	0.6	715.8
2007	148.6	446.7	17.2	31.5	7.9	2.1	654.1
2008	123.9	**781.1**	**41.4**	**216.9**	6.8	**0.9**	**1171.1**
2009	86.3	741.0	18.5	134.0	1.4	1.2	982.4
2010	231.8	787.8	21.6	146.4	3.0	0.8	1191.5
2011	173.9	221.5	9.0	30.6	2.3	1.1	438.3
2012	137.9	531.3	19.3	122.4	5.2	1.2	817.2
2013	208.2	321.3	33.5	100.5	8.6	1.6	673.6
2014	**113.1**	**268.6**	**22.8**	**97.9**	**7.3**	**1.7**	**511.4**
2015	40.4	36.0	60.7	36.1	11.5	0.6	185.3
2016	No Index	No Index	No Index	No Index	No Index	No Index	No Index
Mean Index	171.9	237.4	28.0	40.1	4.6	1.1	482.4

Juvenile *C. franciscorum* were consistently most abundant between May and October, although recruitment often occurred over a broader period, with the smallest shrimp (11-15 mm total length, TL) collected almost every month in some years. This smallest size class was collected from February through October 2012, April through December 2013, March through September 2014, but only from March through June 2015. As annual abundance decreased from 2012 to 2015 (and 2016), recruitment was restricted to a small single cohort in spring. Juvenile *C. franciscorum* abundance peaked from July to September 2012, July and August 2013, June 2014 (note: no July 2014 sampling), and June 2015.

Adult *C. franciscorum* are usually most abundant from late fall through early spring; however, our index period is from February to April due to missed winter sampling for several years in the 1990s. The annual abundance indices were at or slightly above the study-period mean from 2012 to 2014, but declined to the lowest index since 2006 in 2015 (Figure 4). The 2016 adult *C. franciscorum* index would likely have been the lowest for the reporting period, but we did not sample from January to April. Although not the optimal period for comparison, the 2016 mean May to June adult *C. franciscorum* CPUE was the lowest for the study period (Table 1). I predict

Figure 3. Annual abundance indices of juvenile Crangon franciscorum, May to October, vs. March to May outflow, 1980-2015. Both axes are log transformed.



that the 2017 adult *C. franciscorum* index will be at or near the study-period low due to poor recruitment in 2016.

Adult *C. franciscorum* were most common from January through March 2012, September 2012 through February 2013, July and August 2013, February 2014 and 2015, and June 2015. The winter abundance peaks were primarily age-1 shrimp, approximately 10 to 12 months old, while the summer and early fall peaks were composed of maturing shrimp hatched that year and older shrimp from the previous year. December male *C. franciscorum* mean size was from 37.2 to 39.1 mm TL from 2012 to 2014, but increased to 44.6 and 48.7 mm TL in 2015 and 2016, respectively (male *C. franciscorum* mature at 36 mm TL). Females had a similar pattern, with a December mean size ranging from 41.9 to 43.9 mm TL from 2012 to 2014 and increasing to 54.9 and 58.6 mm TL in 2015 and 2016 (female *C. franciscorum* mature at 47 mm TL). This substantial increase in the December mean size in 2015 and 2016 was primarily due to unimodal recruitment, with no or extremely small cohorts of juvenile *C. franciscorum* after the main spring reproductive event.

Crangon franciscorum primarily reared from upper San Pablo Bay through the confluence of the Sacramento and San Joaquin rivers from 2012 through 2016, with juvenile CPUE highest in Suisun Bay, followed by the confluence area or San Pablo Bay every year (Figure 5a). Catches were also relatively high south of the San Mateo Bridge in South Bay (stations #101 and #140), where salinities were reduced due freshwater discharge from tributary creeks and sewage treatment plants.

Juvenile *C. franciscorum* were consistently collected as far upstream as the shoal station in the Sacramento River near the upper end of Decker Island and the channel station just upstream of the Antioch Bridge on the San Joaquin River from 2012 through 2015. In 2016, when freshwater outflow increased (Figure 2, Bay Study Fishes Status and Trends report, page 5 of this issue), they were rarely collected upstream of the confluence. However, in 2016 we did not sample from August through October, when *C. franciscorum* were usually found the furthest upstream. Juvenile *C. franciscorum* were collected from the river stations, upstream of the confluence, earlier each year as the drought persisted. For example, *C. franciscorum* were first collected from the river stations in August 2013, but in May 2014 and April 2015.

There was a seasonal shift of juvenile *C. franciscorum* from the shoals to the channel in San Pablo and Suisun bays, as they were most common at shoal stations through June or July, then at channel stations through December. This pattern was not detected upstream, where fewer shoal areas are sampled. Except for several months, channel CPUE was consistently higher than shoal CPUE at the confluence and lower Sacramento and San Joaquin river areas from 2012 to 2016. In South Bay, juvenile *C. franciscorum* strongly favored the channel all months and

Figure 4. Annual abundance indices of adult *Crangon franciscorum*, February to May, otter trawl, 1980-2016.

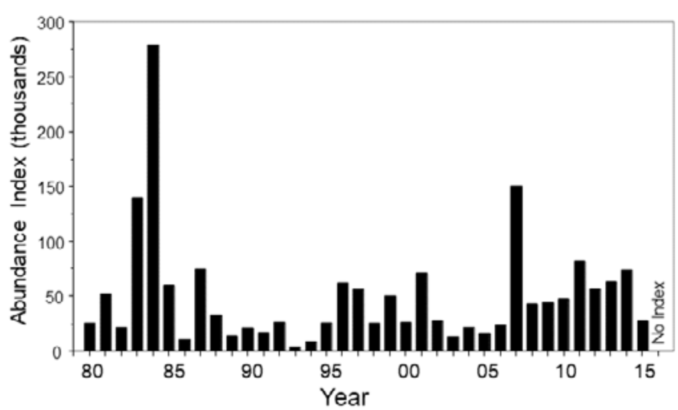
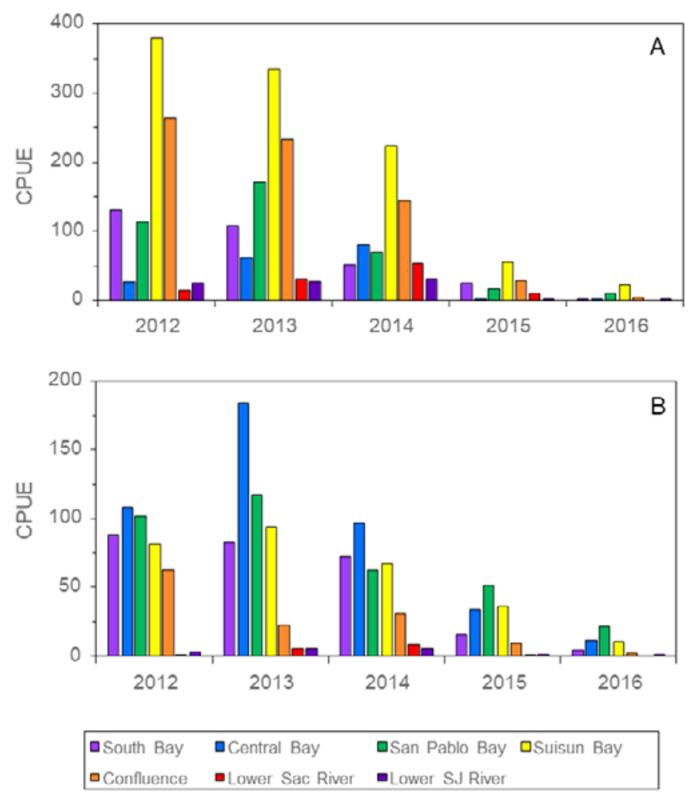


Figure 5. *Crangon franciscorum* annual distribution (CPUE, catch/tow): A) Juveniles and B) Adults. Annual CPUE is for all stations and months sampled; there was no sampling in July 2014 and from January to April and August to October 2016.



years, with annual ratios of juveniles to adults ranging from 18:1 to 60:1. In Central Bay, the general trend was for juvenile *C. franciscorum* CPUE to be higher at the shoals from late spring through October and higher at the channels from November through March, but there were notable exceptions to this pattern. For example, in 2013, channel CPUE was higher than shoal CPUE all months except for April.

From 2012 to 2014, adult *C. franciscorum* CPUE was highest in Central Bay all years, followed by San Pablo or South Bay and Suisun Bay (Figure 5b). As the drought progressed, CPUE increased in San Pablo Bay relative to Central Bay, such that by 2015, adult *C. franciscorum* CPUE was highest in San Pablo Bay, followed by Suisun Bay and Central Bay (Figure 5b). Adult *C. franciscorum* had the broadest distribution in winters of the drought years, when areas upstream of Central Bay were cool with relatively high salinity. Through spring and summer, as temperatures increased, adult *C. franciscorum* moved downstream and were most common in Central Bay and lower San Pablo Bay. For all years and regions, adult *C. franciscorum* CPUE was highest in the channels, although there were a few months when shoal CPUE was highest.

Crangon nigricauda

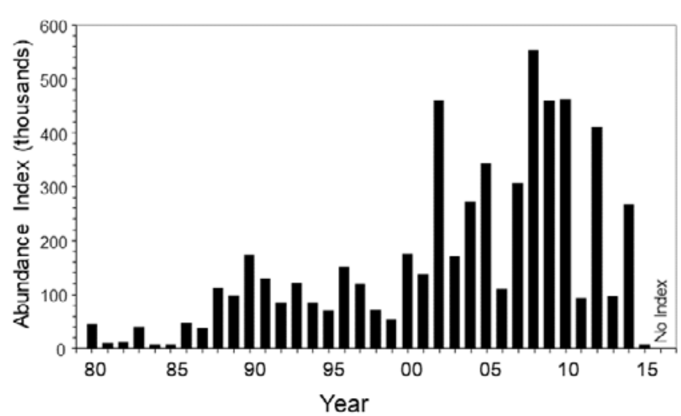
Crangon nigricauda, the blacktail bay shrimp, ranges from Alaska to Baja California (Jensen 2014) and is usually the 2nd most common caridean shrimp in San Francisco Estuary. It is smaller than *C. franciscorum*, reaching a maximum size of 60 mm TL for males and 75 mm TL for females in the estuary (CDFW unpublished data). Similar to juvenile *C. franciscorum*, juvenile *C. nigricauda* migrate to warmer, lower salinity areas to rear and adults migrate back to cooler, higher salinity areas for reproduction. However, all life stages of *C. nigricauda* are found in cooler, higher salinity areas than *C. franciscorum* and *C. nigricauda* is not considered to be an estuary-dependent species. Peak reproduction is usually in spring, and multiple cohorts are common.

C. nigricauda juvenile abundance increased in 2012 to the 5th highest for the study period (Figure 6), decreased in 2013, increased again in 2014, then decreased in 2015 to the lowest index of the study period. Abundance likely decreased even further in 2016, as the 2016 May to July mean CPUE was about 50% of the 2015 CPUE (Table 1). *C. nigricauda* was the most common shrimp in the estuary from 2012 to 2014, but ranked 4th in 2015 (Table 2), with an annual index very similar to Heptacarpus stimpsoni. *C. nigricauda* comprised almost 65% of the total shrimp index in 2012, but only 19% in 2015, and likely even less in 2016.

We have hypothesized that low freshwater outflow and higher salinities, such as during the drought, coupled with favorable ocean conditions, especially cooler water temperatures, benefited *C. nigricauda* recruitment (Cloern et al. 2010). Conversely, years with high freshwater outflow or warm ocean temperatures, such as during major El Niño events, were unfavorable to *C. nigricauda* recruitment. The highest juvenile *C. nigricauda* abundance indices were from 2000 to 2014 (Figure 6), concurrent with cold ocean temperatures and strong upwelling, and the lowest indices from 1980 to 1999 and in 2015 and 2016, years with frequent and strong El Niño events and a significant marine heat wave (Figures 5A and 5B, Bay Study Fishes Status and Trends report, page 7 of this issue). This abundance pattern was noted for several demersal marine fishes, including English Sole, Bay Goby, Plainfin Midshipman, and Speckled Sanddab. Although this group of species do not share reproductive traits (some spawn in the ocean, others in the estuary), all rear in cooler, higher salinity areas of the estuary.

Over the study period, juvenile *C. nigricauda* abundance usually peaked from May through September, although earlier and later cohorts resulted in abundance peaks as early as April and as late as December. Juvenile *C. nigricauda* abundance was highest from June through August 2012, in May, June, and October 2013, in May, June and August (no July sampling) 2014, and from April to July in 2015. The smallest juveniles, 11-12 mm TL,

Figure 6. Annual abundance indices of juvenile *Crangon nigricauda*, April to October, otter trawl, 1980-2016.

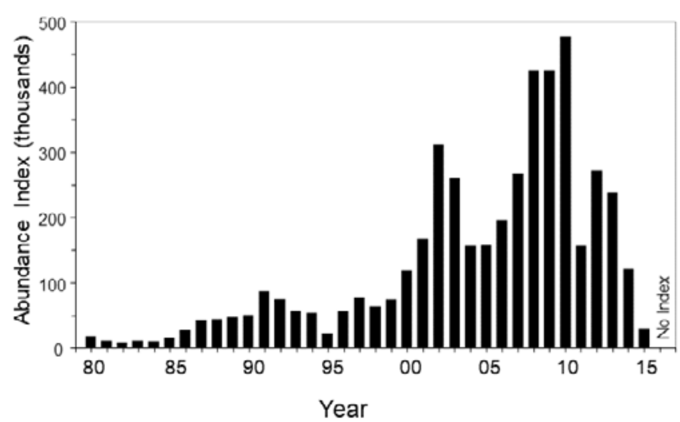


were collected in nearly every month of 2012 through 2014, evidence of multiple cohorts these years. However, this size class of juvenile *C. nigricauda* was collected only from March through September 2015, with 1 or 2 small cohorts. In November and December 2015, we collected 205 *C. nigricauda*, by far the lowest catch for these months in the study period (the mean November and December catch was almost 15,000 for 1980-2014). The 2nd lowest November and December *C. nigricauda* catch was in 2016 (n=445), further evidence that *C. nigricauda* abundance remained very low in 2016.

Adult *C. nigricauda* abundance slowly decreased from 2012 through 2014 and substantially decreased in 2015 to the lowest index since 1995 (Figure 7). From 2000 to 2014, adult *C. nigricauda* abundance was remarkably stable, with the highest index only 4 times the lowest index (Figure 7). It was somewhat surprising that the adult index decreased in 2015 concurrent with the juvenile index, not a year later. However, adult and juvenile *Crangon nigricauda* abundance had similar, but not identical, trends in the past. Based on the mean May to June CPUE (Table 1), adult *C. nigricauda* abundance continued to decrease in 2016.

Adult *C. nigricauda* had a bimodal abundance pattern, with peaks in winter and summer, or a peak in only winter or summer. The general trend was for larger winter abundance peaks when ocean temperatures were warm (1980s and 1990s) and larger summer peaks when ocean temperatures were cool (2000s). From 2012 to 2015, adult *C. nigricauda* abundance peaked in late spring and summer, between April and August, with smaller winter peaks each year.

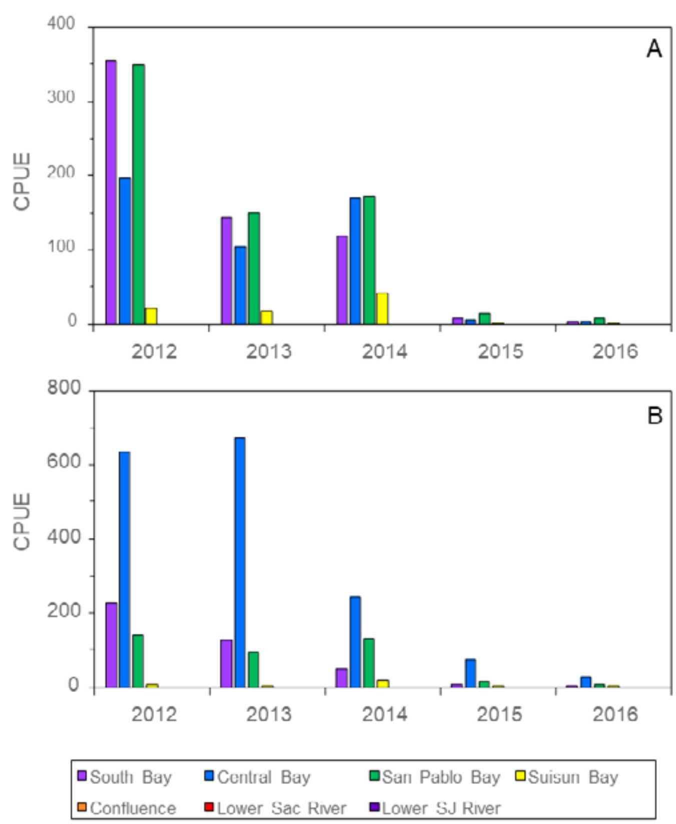
Figure 7. Annual abundance indices of adult *Crangon nigricauda*, February to October, otter trawl, 1980-2016.



Similar to *C. franciscorum*, the mean size of *C. nigricauda* increased in December 2015 and 2016 from previous years. From 2012 to 2014, the mean size of male *C. nigricauda* ranged from 27.7 to 29.2 mm TL, but increased to 33.0 mm and 33.9 mm TL in 2015 and 2016. The mean size of female *C. nigricauda* ranged from 33.8 to 38.5 mm TL from 2012 to 2014, and increased to 46.1 and 47.5 m TL in 2015 and 2016. This was further evidence of poor recruitment in 2015 and 2016, with little or no reproduction after spring. Note that many *C. nigricauda* were adults by December, with size of maturity at 27 mm TL for males and 32 mm TL for females.

Juvenile *C. nigricauda* were collected from South Bay through Carquinez Strait in each year reported, with the annual CPUE for South, Central, and San Pablo bays very similar most years (Figure 8A). The highest annual catches were from: 1) The channel (#101) and shoal (#102) stations just south of the San Mateo Bridge, 2) The 4 channel stations from Coyote Point to the Bay Bridge

Figure 8. *Crangon nigricauda* annual distribution (CPUE, catch/tow): A) Juveniles and B) Adults. Annual CPUE is for all stations and months sampled; there was no sampling in July 2014 and from January to April and August to October 2016.



(#107, 108, 109, and 110), 3) The 3 shoal stations near the Richmond-San Rafael Bridge (#244, 317, and 323), and 4) The channel station near Point Pinole (#325). Monthly CPUE was sporadically highest in Central Bay, such as in January 2013 and June and August 2014, but there did not appear to be a seasonal movement of juvenile *C. nigricauda* from South and San Pablo bays to Central Bay. Juvenile *C. nigricauda* were collected in Carquinez Strait most months, with a gradual increase in catches through winter and spring with cooler water temperatures and the lowest catches from late summer to fall, when temperatures were the highest.

Multiple cohorts made it difficult to discern a seasonal channel-shoal distributional pattern, but in general, juvenile *C. nigricauda* CPUE was highest in the shoals in spring and in the channels in summer and fall. In November and December, as temperatures decreased, shoal CPUE often, but not always, increased. This pattern was strongest when there was a substantial fall cohort of juvenile *C. nigricauda*.

Adult *C. nigricauda* were also collected from South Bay through Carquinez Strait, but were overall most common in Central Bay, followed by South or San Pablo bays (Figure 8B). In 2012 and 2013, when adult abundance was highest for the reporting period, mean annual CPUE was over 1,000 shrimp per tow at several Central Bay channel stations (#110, 214, and 215). Note that CPUE at these same stations often exceeded 2,000 shrimp per tow from 2001 to 2010 and was 4,477 shrimp per tow at station #214 near Angel Island in 2010. There was a seasonal movement of adult *C. nigricauda* from South and San Pablo bays to Central Bay through summer and fall, as shrimp matured and moved downstream to cooler, higher salinity water. The preference for channel stations was strongest through fall and channel and shoal CPUE was closest to 1:1 in winter, when the shoals were the coolest.

Crangon nigromaculata

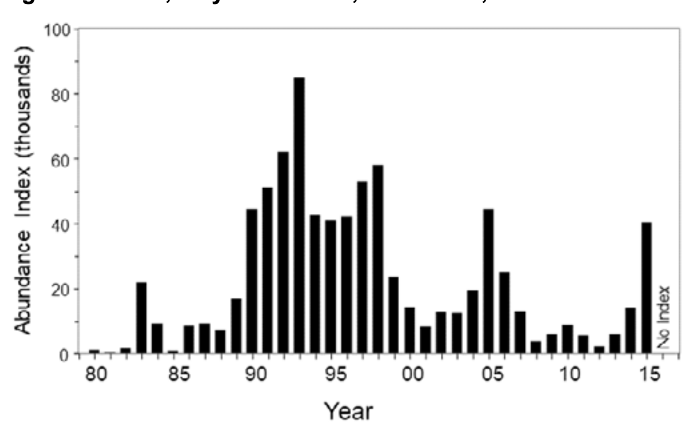
Crangon nigromaculata, the blackspotted bay shrimp, ranges from Washington to Baja California, but is not common north of San Francisco Bay (Jensen 2014). It is found in cooler, higher salinity water than either *C. franciscorum* or *C. nigricauda* and is the most common shrimp collected in the nearshore ocean area adjacent to the estuary (SFWQB 2003). It is slightly smaller than *C. franciscorum*, with males reaching 62 mm TL and females 80 mm TL in San Francisco Estuary (CDFW unpublished data).

After peaking in the early 1990s, juvenile *C. nigromaculata* abundance cycled up and down at somewhat lower levels through 2015 (Figure 9). Juvenile *C. nigromaculata* abundance was very low in 2012 and 2013, increased slightly in 2014 and then increased substantially in 2015 to the highest index since 2005 (Figure 9). The mean 2016 May to July juvenile CPUE was slightly lower than in 2015 (Table 1), indicating that juvenile *C. nigromaculata* abundance remained high in 2016. The largest cohorts of small *C. nigromaculata* (11 to 20 mm TL) occurred in winter 2012-2013, late fall 2013, fall 2014, and spring, summer, and early fall of 2015. As with *C. nigricauda*, the highest juvenile abundance index was a result of multiple cohorts recruiting over several months rather than a single cohort. *C. nigromaculata* ranked 4th from 2012 to 2014, but was the most abundant shrimp in 2015 (Table 2), a first for the 37-year study.

Adult *C. nigromaculata* abundance was also cyclic, with the highest index in 2015 (Figure 10), followed by 2008, 2013, and 1994. The 2012 and 2014 indices were lower than 2013 and 2015 (Figure 10), but still above the study-period mean. Based on the May to July mean CPUE, adult *C. nigromaculata* abundance remained high in 2016 (Table 1), following the trend of juvenile abundance.

Because *C. nigromaculata* is most common in coastal areas south of the San Francisco Estuary, I expected that its abundance here would increase with ocean temperature. The highest juvenile *C. nigromaculata* abundance corresponded with high SSTs in the 1990s,

Figure 9. Annual abundance indices of juvenile *Crangon nigromaculata*, May to October, otter trawl, 1980-2016.



2005, and 2015 (Figure 5B, Bay Study Fishes Status and Trends Report, page 7 this issue), due to El Niño events and the marine heat wave. However, higher SSTs in the early 1980s, associated with a strong El Niño event, resulted in only modest juvenile *C. nigromaculata* abundance in 1983. Adult *C. nigromaculata* abundance trends appeared to be influenced by ocean temperatures and outflow, as the highest indices were towards the end of the 1987-1993 drought (which had several El Niño events), in several low outflow, but cool SST years (2008, 2013), and in 2015, which had very high SSTs with low outflow. High abundance with warm SSTs and low outflow would be expected for adult *C. nigromaculata*, while high abundance with cold SSTs was unexpected.

Juvenile *C. nigromaculata* were most common in the winters of 2012, 2013, and 2014, but in summer of 2015 (Figure 11), when abundance increased substantially. Adult *C. nigromaculata* had a similar seasonal pattern, but also had an abundance peak in April and May 2013 (Figure 11). From the limited sampling in 2016, juvenile *C. nigromaculata* were most abundant in summer while adults were more abundant in November and December (Figure 11).

Juvenile *C. nigromaculata* were collected from South through San Pablo bays from 2012 to 2016 (Figure 12A), with sporadic catches in Carquinez Strait, usually in late fall and winter, when water temperatures were the coolest. However, in 2015, the year with the highest abundance, juvenile *C. nigromaculata* were collected in Carquinez Strait regularly from June to December. The highest catches were consistently from our Treasure Island station (#211) and the 2 channel stations near and just upstream of Angel Island (#214 and #215), where annual average catches of over 100 shrimp per tow were common. Catches were also high at several South Bay channel stations, including the station near the San Mateo Bridge (#101), and the Southampton and Paradise Cay shoal stations in Central Bay (#243 and #244), especially in 2015.

Figure 10. Annual abundance indices of adult *Crangon nigromaculata*, February to October, otter trawl, 1980-2016.

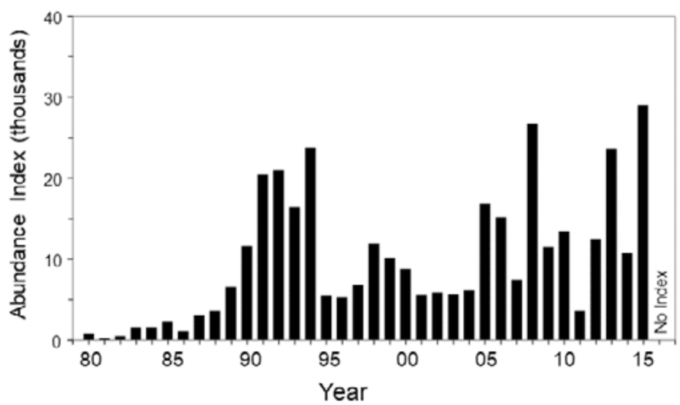


Figure 11. Monthly abundance indices of juvenile and adult *Crangon nigromaculata*, January 2012 to December 2016. There was no sampling in July 2014 and from January to April and August to October 2016.

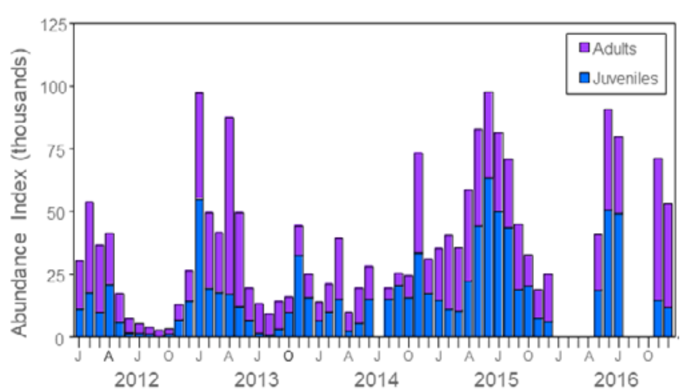
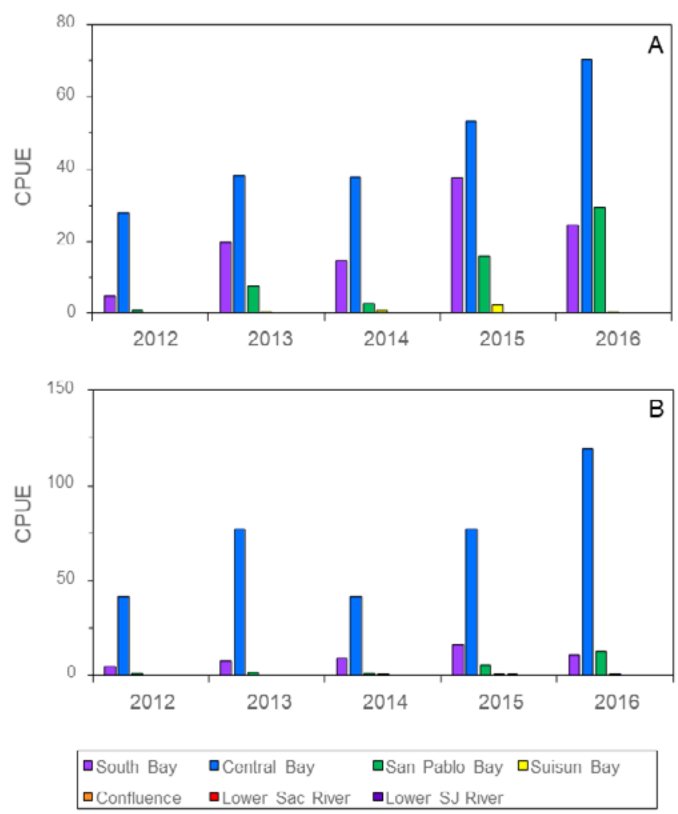


Figure 12. *Crangon nigromaculata* annual distribution (CPUE, catch/tow): A) Juveniles and B) Adults. Annual CPUE is for all stations and months sampled; there was no sampling in July 2014 and from January to April and August to October 2016.



There was some seasonal movement of juvenile *C. nigromaculata* between the Central Bay channel and shoals. From 2012 to 2014, Central Bay CPUE was highest at the shoal stations from January through July, highest at the channel stations from August through October, then highest at the shoal stations again in November and December. The summer-fall movement to the channel corresponded with the maximum monthly water temperatures (see Figure 7, Bay Study Fishes Status and Trends Report, page 8 of this issue); therefore, I assumed that juvenile *C. nigromaculata* moved to coolest water available in the estuary. In 2015, with warmer Central Bay temperatures due to the marine heat wave, juvenile *C. nigromaculata* CPUE was highest at the channel stations for all months except for June, when channel-shoal CPUEs were nearly equal. When juvenile *C. nigromaculata* were present in South Bay, they were almost always collected from channel stations.

Adult *C. nigromaculata* were collected from South through San Pablo bays in 2012 and 2013, with a few collected in Carquinez Strait in 2014, 2015, and 2016 (Figure 12B). The highest catches were regularly from the 2 channel stations near and just upstream of Angel Island (#214 and #215), such that adult *C. nigromaculata* CPUE was highest in Central Bay every year. With few exceptions, adult *C. nigromaculata* CPUE was also highest at channel stations each month. There was no seasonal trend to the channel-shoal distribution; for example, Central Bay shoal CPUE was higher than channel CPUE in April and December 2012 and November 2014 and close to 1:1 in June of 2013 and 2015.

Heptacarpus stimpsoni

Heptacarpus stimpsoni, Stimpson's coastal shrimp, ranges from Alaska to Baja California (Jensen 2014) and is common over soft bottoms and eelgrass beds in the higher salinity regions of the estuary. It is a small shrimp, with a maximum size of 35 mm TL (Jensen 2014). After a substantial increase in 2012, *H. stimpsoni* abundance slowly decreased from 2013 to 2015 (Figure 13); however, the 2012 to 2014 indices were still well above the study-period mean and ranked 4th to 6th. Based on the mean May to July CPUE, abundance in 2016 was lower than 2015 (Table 1). *H. stimpsoni* was less common than the 3 *Crangon* species through the 1980s and 1990s (Table 2), but when abundance increased in the 2000s, it often ranked 3rd, and in 2008 and 2009 it ranked 2nd of all species (Table 2). *H. stimpsoni* abundance may be related in part to ocean temperature (Cloern et al. 2010), with the lowest abundance during the 1980s and 1990s, a period with frequent El Niño events and warm SSTs (Figure 5B, Bay Study Fishes Status and Trends Report, page 7 of this issue), and the highest abundance when SSTs were cooler in the 2000s. Abundance also decreased in 2005 and 2015 with warmer SSTs. In addition, abundance corresponded with outflow, as it increased or was well above average during the extended droughts of 1988 to 1992, 2007 to 2010, and 2012 to 2014.

Seasonal *H. stimpsoni* abundance trends are somewhat erratic over the study period, with highest abundance in winter-spring, summer, and occasionally both. However, from 2012 to 2015, abundance was highest between April and August, with additional peaks in February and March 2012 and December 2013 (Figure 14). Non-ovigerous

Figure 13. Annual abundance indices of *Heptacarpus stimpsoni*, February to October, otter trawl, 1980-2016.

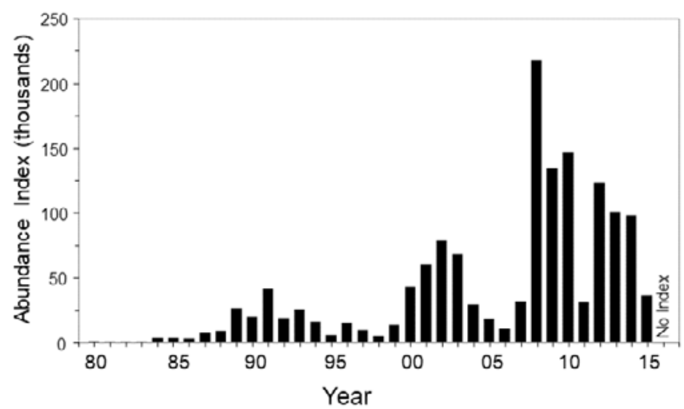
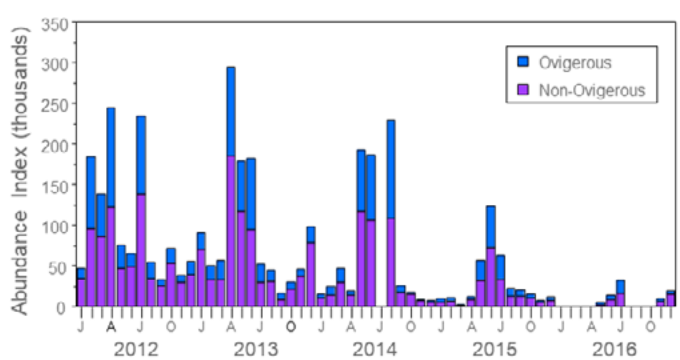


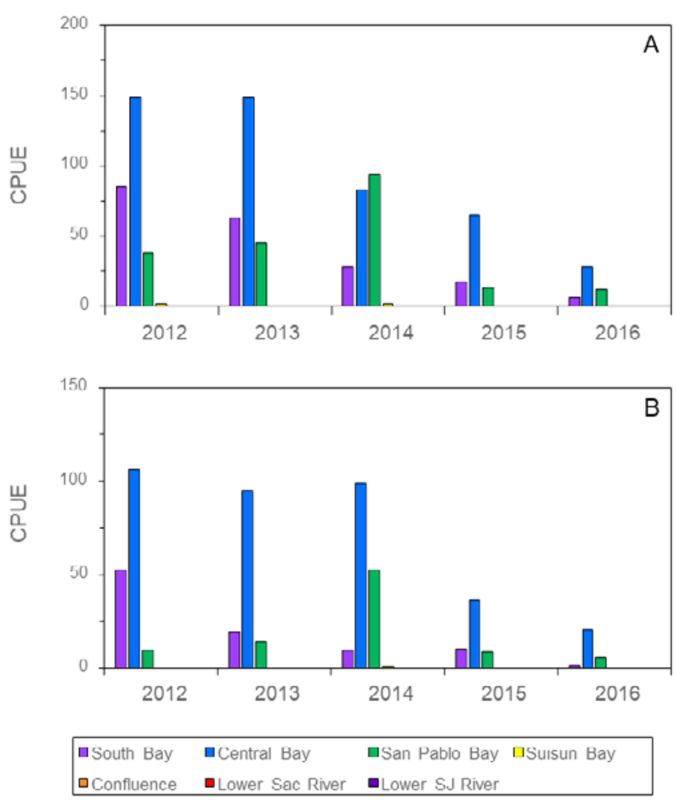
Figure 14. Monthly abundance indices of ovigerous and non-ovigerous *Heptacarpus stimpsoni*, January 2012 to December 2016. There was no sampling in July 2014 and from January to April and August to October 2016.



and ovigerous *H. stimpsoni* had very similar seasonal trends.

H. stimpsoni was collected from all the South Bay, Central Bay, and most San Pablo Bay stations for all years reported. A few were also collected in Carquinez Strait and Suisun Bay, primarily in 2014. Non-ovigerous *H. stimpsoni* were most common in Central Bay for all years except for 2014, when San Pablo Bay CPUE was slightly higher than Central Bay CPUE (Figure 15A). Ovigerous *H. stimpsoni* were most common in Central Bay every year (Figure 15B), followed by South or San Pablo bays. Annually, the highest catches were from the 2 channel stations south of Yerba Buena Island (#109 and #110), the shoal station near Alameda (#142), the 2 channel stations near and just upstream of Angel Island (#214 and #215), and the shoal station near Paradise Cay (#244). The highest annual average catches were from 400 to over 700 shrimp per tow at several of these stations from 2012 to 2014. In 2014, when *H. stimpsoni* was found further upstream, catches were also high at several San Pablo Bay stations between the Richmond-San Rafael Bridge and Point Pinole. There was some evidence of seasonal movement, as South Bay CPUE was usually highest from winter through early spring and decreased through summer with increasing temperatures, while Central Bay CPUE was highest from April or May through fall.

Figure 15. *Heptacarpus stimpsoni* annual distribution (CPUE, catch/tow): A) Non-ovigerous and B) Ovigerous. Annual CPUE is for all stations and months sampled; there was no sampling in July 2014 and from January to April and August to October 2016.

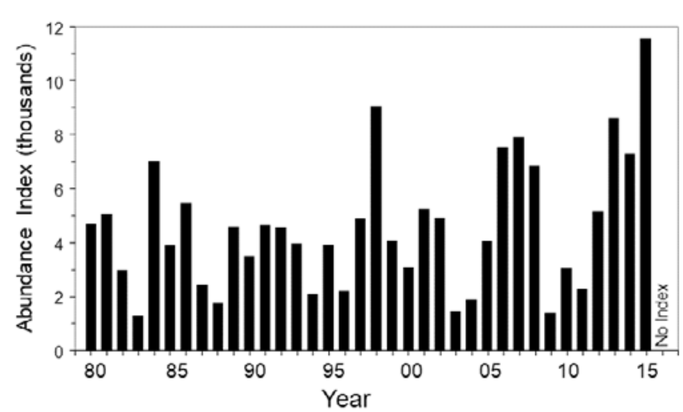


Palaemon macrodactylus

Palaemon macrodactylus, the oriental shrimp, was introduced from Asia in the 1950s (Newman 1963). It is found in tidal brackish and freshwater areas, preferring shallow habitats with structure, such as vegetation and pilings. Since these habitats are not sampled well by trawls, *P. macrodactylus* is likely more common in the estuary than our sampling indicates. *P. macrodactylus* reproduces in summer and ovigerous females migrate downstream to higher salinities to brood and release their larvae. Abundance increased from 2012 to 2015, with the highest index for the study period in 2015 (Figure 16). The 2016 mean May to July CPUE was similar to 2015 (Table 1), indicating that abundance may have remained relatively high in 2016. However, *P. macrodactylus* was overall the 5th most abundant shrimp in the estuary and a minor component of our total shrimp catch, although in several years it ranked 3rd or 4th (Table 1). Previously we observed that *P. macrodactylus* abundance increased in high outflow years (1998, 2006), probably because shrimp moved into the sampling area in response to high outflow or reduced salinity. However, abundance also increased in the study area during the 2012 to 2015 drought; no mechanism for this trend is proposed.

P. macrodactylus was most abundant in our study area from April through October, which corresponds with the reproductive period and when ovigerous shrimp move

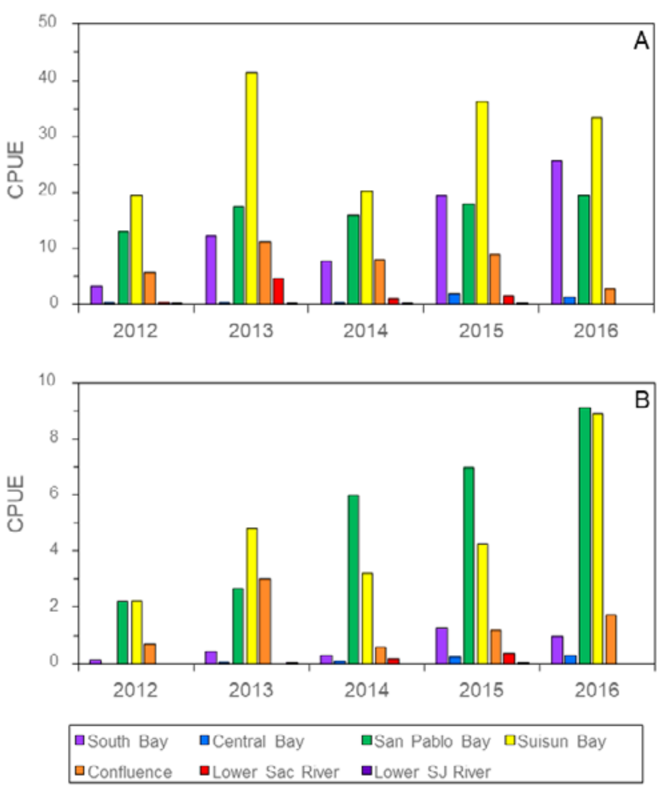
Figure 16. Annual abundance indices of *Palaemon macrodactylus*, February to October, otter trawl, 1980-2016.



downstream. It is surely most abundant in the estuary during late fall and winter, when juvenile shrimp are rearing in areas that we do not sample. *P. macrodactylus* abundance increased in winters with high outflow, such as January 1982 and 1983, December 1997, and February 1998, when shrimp moved or were carried downstream by flows.

Non-ovigerous *P. macrodactylus* was collected from South Bay through the lower rivers from 2012 to 2015, with annual CPUE consistently highest in Suisun Bay, followed by either San Pablo or South bays (Figure 17A). It was most common at the 2 channel stations near the Dumbarton and San Mateo Bridges (#101 and #140), at several San Pablo Bay stations, and in Suisun Bay. Within the Sacramento River, it was most common at our 3 stations closest to the confluence and uncommon or absent from the 4 upstream stations. The trend was similar in the San Joaquin River, where it was collected more frequently at the 2 stations closest to Antioch and uncommon or not collected from the 3 upstream stations. Ovigerous female *P. macrodactylus* was most common in San Pablo or Suisun Bay (Figure 17B), usually at the shoal stations closest to the Petaluma River (322 and #323) and in Carquinez Strait.

Figure 17. *Palaemon macrodactylus* annual distribution (CPUE, catch/tow): A) Non-ovigerous and B) Ovigerous. Annual CPUE is for all stations and months sampled; there was no sampling in July 2014 and from January to April and August to October 2016.



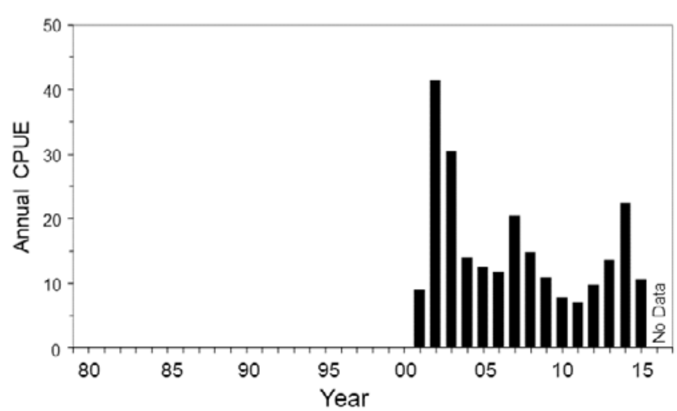
Exopalaemon modestus

Exopalaemon modestus, the Siberian prawn, is another introduced shrimp from Asia. It was first detected by the Bay Study in 2000 and is common in tidal brackish and freshwater areas of the estuary as well as in rivers and sloughs upstream of the delta. *E. modestus* and *Palaemonetes kadiakensis*, a small introduced species limited to the delta, are the only shrimp species in the estuary that can complete their life cycle in freshwater. Because *E. modestus* is most common at the upstream stations added in the 1990s, mean CPUE for all stations upstream of Carquinez Strait was used to describe abundance trends instead of annual abundance indices.

E. modestus abundance increased rapidly after it was first collected in 2000. The highest abundance per the Bay Study was in 2002, followed by a slow decline to 2011, a steady increase from 2012 to 2014, and another decrease in 2015 (Figure 18). Based on the mean May to July CPUE (Table 1), abundance may have increased in 2016. Although it was a very minor component of the total shrimp abundance (Table 2), the abundance indices in this table are for the core stations, which exclude the river stations where *E. modestus* is most common. The annual Suisun Marsh *E. modestus* CPUE from UC Davis was near their study period mean in 2012, decreased in 2013, then steadily increased through 2016 (Figure 19).

E. modestus was far more common than *P. macrodactylus* in the lower Sacramento and San Joaquin

Figure 18. Annual CPUE (catch/tow) of *Exopalaemon modestus*, Carquinez Strait upstream, otter trawl, 1980-2016.



rivers from 2012 to 2015, but *C. franciscorum* catches were higher than *E. modestus* catches at and just upstream of the confluence, as it moved upstream during the drought. In higher outflow years, such as 2006 and 2011, *E. modestus* outnumbered *C. franciscorum* and *P. macrodactylus* in the lower rivers. *E. modestus* was the most common caridean shrimp in Suisun Marsh per the UC Davis otter trawl survey for all but 4 years since it was first recorded in March 2002 (O'Rear and Moyle 2018). As *E. modestus* abundance increased in the marsh from 2014 to 2016, *C. franciscorum* decreased and was the lowest for their 37-year study period in 2016 (O'Rear and Moyle 2018).

E. modestus catch usually peaked from September to December in the Bay Study and from August to December in the Suisun Marsh trawls. *E. modestus* reproduces in summer, so this seasonal pattern probably resulted from either juvenile shrimp moving into the sampling area or reaching a size effectively retained by the otter trawls. We have collected relatively few ovigerous *E. modestus* since 2000, with only 4.9% (n=1,314) of all females ovigerous. However, the percentage of ovigerous females was 11.3 % in 2015 and ranged from 4.9 to 6.7% the other years reported here. By comparison, 38.7% of all *P. macrodactylus* females collected were ovigerous. *E. modestus* reproductive areas are in freshwater, primarily upstream of our study area, and in Suisun Marsh (Brown and Hieb 2014).

E. modestus was most common in the Bay Study trawls near Sherman and Decker islands and Rio Vista in the lower Sacramento River channel and near Antioch in the San Joaquin River. Annual CPUE was highest either at the confluence or lower Sacramento River region (Figure 20), but it was found throughout Suisun, Grizzly, and Honker bays to Carquinez Strait, with 1 *E. modestus* collected in San Pablo Bay in 2012. The 3 lower Sacramento River stations (#736, #750, and #751) consistently had the highest catches, with an average annual catch of over 100 shrimp per tow common. The highest annual catch was 195 shrimp per tow in 2014 at the channel station near Sherman Island but this was driven by one catch of 1324 shrimp. *E. modestus* was collected at all the Suisun Marsh trawl stations, but was most common in Denverton, Peytonia, Boynton, and Nurse sloughs and the upper most Suisun Slough stations from 2012 to 2016. All of these stations are in the northernmost area of the marsh. Annual mean catches of over 100 *E. modestus* per tow occurred at several Suisun Marsh stations in several years.

E. modestus did not expand its upstream distribution from 2012 to 2016 according to the available data. As of late 2016, *E. modestus* had been collected by the USFWS beach seine survey from Colusa State Park on the Sacramento River in the north to near Grayson (Stanislaus County) on the San Joaquin River in the south (USFWS unpublished data). *E. modestus* was collected by another USFWS survey in 2003 even further south in Mud Slough (Merced County), a tributary of the San Joaquin River (W. Beckon, personal communication, see "Notes").

Subtropical Species

In 2015 and 2016, we collected 2 subtropical shrimp species that we had never collected before, even during

Figure 19. Annual CPUE (catch/tow) of *Exopalaemon modestus*, Suisun Marsh otter trawl, 2002-2016.

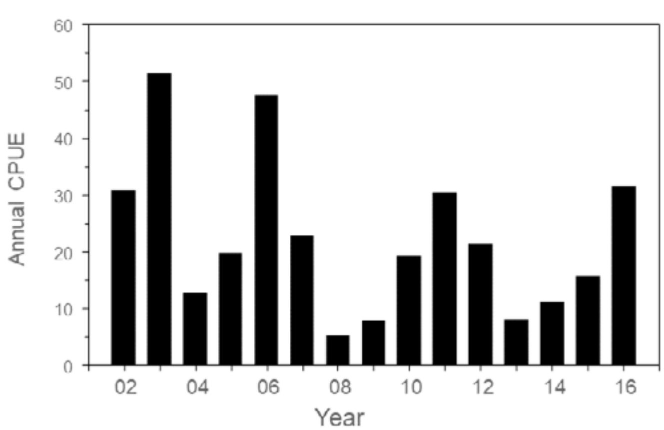
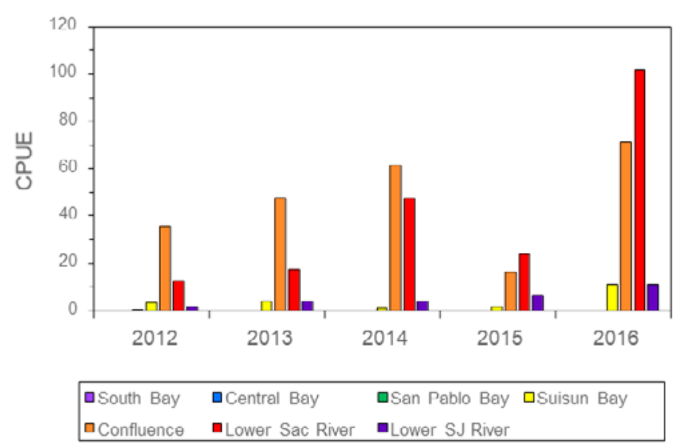


Figure 20. *Exopalaemon modestus* annual distribution (CPUE, catch/tow), all sizes. Annual CPUE is for all stations and months sampled; there was no sampling in July 2014 and from January to April and August to October 2016.



the large El Niño events of 1982-83 and 1997-98. In 2015, we collected 2 *Farfantepenaeus californiensis* (the yellowleg shrimp), which ranges from Callao, Peru to San Francisco Bay (Jensen 2014) and is an important commercial species in Mexico. Both were collected from South Bay shoal stations in summer, at salinities from 31.7 to 32.5‰ and temperatures from 21.2 to 21.8°C. One was 140 mm TL, the other 197 mm TL (excluding the rostrum). We also collected 20 *Sicyonia penicillata* (the target prawn), which usually ranges from Costa Rica to Ensenada, Baja California (Jensen 2014), with a possible range extension to the Southern California Bight in the late 1990s (Montagne and Cadien 2001). The first 2 *S. penicillata* were collected in December 2015 and were 22 and 27 mm TL. We did not sample again until May 2016, when we collected 5 *S. penicillata* ranging from 62 to 77 mm TL. We collected 7 *S. penicillata* in June 2016 (71 to 88 mm TL) and 6 in July 2016 (75 to 92 mm TL). None were collected after July 2016, but we did not sample from August to October 2016. From the sizes, I concluded that 1 cohort of *S. penicillata* settled near or was transported to San Francisco Estuary in 2015. All of the shrimp were collected from South Bay and Central Bay, between Candlestick Point and Angel Island. Salinities ranged from 24.7 to 32.3‰ (mean 30.0‰) and temperatures from 12.4 to 17.7°C (mean 15.6°C).

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Notes

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William Beckon, USFWS, email, March 27, 2003.

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2012 to 2016 Status and Trends Report: Common Crabs of the San Francisco Estuary

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Introduction

This report summarizes abundance trends and distributional patterns of the 4 most common *Cancer* crabs and *Eriocheir sinensis*, the Chinese mitten crab, from 2012 through 2016 in the San Francisco Estuary. The data is primarily from the San Francisco Bay Study (Bay Study) otter trawl, with additional *E. sinensis* data from the UC Davis Suisun Marsh otter trawls, the Central Valley Project (CVP) and State Water Project (SWP) fish salvage facilities, and the Marine Science Institute (MSI) South Bay otter trawls. Indices of relative abundance were used for Bay Study annual and seasonal abundance, while catch-per-unit-effort (CPUE) as crabs per 5-minute tow was used for Bay Study regional and channel-shoal distribution. Due to limited sampling in 2016, we calculated an abundance index only for age-0 Dungeness crab (*Cancer magister*) but used 2016 data to describe distribution of all species. UC Davis and MSI mitten crab CPUE was also catch per tow, while the fish facilities data was the estimated number of adult crabs salvaged in fall. More information about the Bay Study sampling methods, including a station map, and the referred to ocean climate, temperature, and upwelling figures can be found in the companion Bay Study Fishes Status and Trends Report, page 3 of this issue.

Cancer Crabs

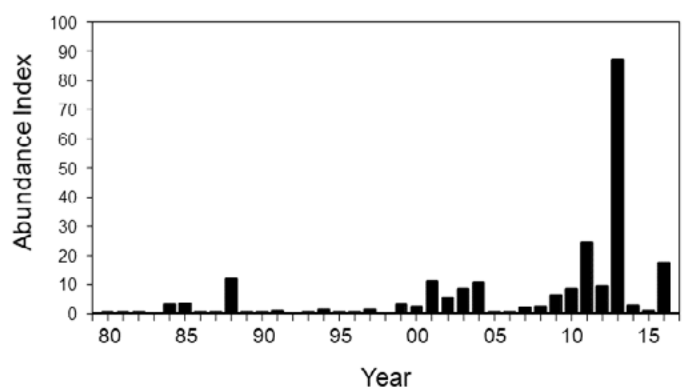
Cancer magister

Cancer magister, the Dungeness crab, is a valuable sport and commercial species that reproduces in the ocean in winter and rears in nearshore coastal areas and estuaries. Small juvenile *C. magister*, 5-10 mm carapace width (CW), immigrate to the San Francisco Estuary in spring, rear for 8 to 10 months, and then emigrate from the estuary when approximately 100 mm CW. Estuary-reared crabs reach legal size (the commercial minimum is 146 mm CW) at the end of their 3rd year, 1 to 2 years before ocean-reared crabs. This faster growth is hypothesized to be due to warmer temperatures and more abundant prey resources in the estuary (Tasto 1983).

Cancer magister recruitment is episodic and cyclic, with several extremely strong year classes often followed by poor year classes or no recruitment. The 2012 to 2016 indices certainly followed this pattern, with the highest index for the study period in 2013, followed by 2 low indices (Figure 1). The 2012 and 2016 indices were moderate compared to 2013, although the 2016 index was the 3rd highest for the study period. The importance of ocean temperatures and currents on the hatching success, survival, and distribution *C. magister* larvae has been well documented. Cooler ocean temperatures have been hypothesized to increase egg and larval survival, while warmer temperatures decrease survival (Lough 1976, Wild et al. 1983). In the laboratory, the lowest egg mortalities and highest hatching success was at 10°C, with the upper lethal limit for *C. magister* eggs likely from 16 to 17°C (Wild 1983). Infrequent winter storms result in a weak northward-flowing surface (Davidson) current and retention of *C. magister* larvae and megalopae (the last larval stage, which is planktonic for many weeks) in the Gulf of the Farallones (GOF), while frequent winter storms result in a strong Davidson current and loss of larvae from the GOF. Since the inception of the Bay Study, winters with warm sea surface temperatures (SSTs) or frequent winter storms have resulted in poor recruitment of *C. magister* to the San Francisco Estuary (Hieb 1999, Hieb 2012).

The study-period high *C. magister* index in 2013 resulted from GOF SSTs that were 0.5 to 1°C warmer than the long-term mean in November and December 2012,

Figure 1. Annual abundance indices of age-0 *Cancer magister*, Bay Study otter trawl, May to July, 1980-2016.



reaching 13.8°C in November. However, from February to April 2013, SSTs were approximately 1.5°C cooler than the long-term mean, ranging from 9.8 to 10.7°C (Figures 5B and 6, Bay Study Fishes Status and Trends Report, page 7 of this issue). Infrequent storms in winter and spring of 2012-2013 would have favored retention of *C. magister* larvae and megalopae in the GOF. From this combination of mixed winter SSTs and weaker surface currents in 2013, we expected moderate recruitment of age-0 C. magister to the estuary, not the study-period high index reported. We still believe that winter and early spring ocean conditions are the primary drivers of *C. magister* recruitment to the estuary. We plan to expand our analyses of *C. magister* recruitment to include the date of the Spring Transition (start of the upwelling season) and the spring upwelling index, similar to analyses by Alan Shanks at University of Oregon (Shanks et al. 2010, Shanks 2013).

In addition to a moderate 2013 year class, we expected moderate *C. magister* recruitment in 2012 and 2014 and poor recruitment in 2015 and 2016, primarily based on late fall and winter SSTs in the GOF. However, the 2014 year class was weak and the 2016 year class strong, which did not match expectations. SSTs decreased rapidly in November 2015, but were still about 1°C warmer than average through March 2016 (Figures 5B and 6, Bay Study Fishes Status and Trends Report, page 7 of this issue). It is possible that bottom ocean temperatures, where ovigerous *C. magister* were present, were not as high as the surface temperatures. Although we have no bottom ocean temperature data from the GOF, winter 2015-16 water temperatures were slightly cooler than average at a Monterey Bay buoy, especially from 100-200 m (Chavez 2016). Frischknecht et al. (2017) concluded that upwelling winds in fall 2015 damped the temperature anomalies to less than 1°C in Southern and Central California, weakening and shortening the 2015-16 El Niño event in that portion of the California Current System (CCS). McClatchie et al. (2016) also reported that the effects of the 2015-16 El Niño on hydrographic properties were not as strong as the 1997-98 El Niño, especially in Southern and Central California. Some unique feature of the 2015-16 El Niño in fall and winter likely resulted in the unexpectedly strong 2016 *C. magister* year class in the San Francisco Estuary.

The first age-0 *C. magister* were collected in April of all years, except for 2013, when a few were collected in March, and 2016, when we did not sample from January to April. Peak abundance was in June and July 2012, May and June of 2013 and 2015, and June 2014 (no July 2014 sampling). Abundance typically decreased after July or August through the end of the year, but sometimes increased in fall and then decreased again. The fall increase was likely due to upstream age-0 crabs that moved from shallow subtidal areas to the channels, as they staged for emigration from the estuary. Abundance of age-1 crabs peaked from February through April or May and decreased rapidly through spring and summer. Age-1 crabs were collected until August to December of the year following settlement.

Age-0 *C. magister* were collected from south of the Dumbarton Bridge in South Bay to near Ryer Island in Suisun Bay in all years except for 2015, when they were not collected from the most of South Bay and as far upstream in Suisun Bay. Catches were highest at all the Central Bay channel stations, the channel stations in lower San Pablo Bay and near Point Pinole (#345 and #325), and several San Pablo Bay shoal stations. The smallest age-0 crabs were most common in the Central Bay channels when they first entered the estuary in spring. As they migrated upstream to rear, catches increased in San Pablo and Suisun bays through summer. Based on the discontinued Bay Study crab ring net survey and older DFW special studies, we assumed that age-0 *C. magister* were also common in the lower Napa River and Napa-Sonoma Marsh, areas currently not sampled by the Bay Study trawls.

Age-0 *C. magister* typically reared in San Pablo and Suisun bays, although there were often age-0 crabs in Central Bay through summer and fall. As expected based on water temperature, the upstream group grew faster than the Central Bay group, although the Central Bay group may have had constant recruitment of slower growing ocean-reared crabs. A size difference of 10 to 20 mm was common for these 2 regions. For example, in December 2016, the mean size of *C. magister* collected in Central Bay was 54 mm CW (n=13), while the mean size of crabs collected in Suisun Bay was 74 mm CW (n=40).

From 1999 to 2013, there was a trend of more age-0 *C. magister* collected in Central Bay in summer and early fall, especially at the Alcatraz Island station (#213), than other regions. Except for 2009 and 2012, 72% to 100% of the June to October age-0 catch was from Central Bay (Table 1) and in several years, more than half of the catch was from the Alcatraz Island station. In 2014 and 2015, approximately 40% of the June to October catch was from Central Bay (Table 1). Although we did not sample in fall of 2016, from the summer and winter catches, it appears that more *C. magister* reared upstream than in Central Bay, continuing the trend of fewer age-0 crabs in Central Bay in 2014 and 2015.

Table 1. June to October Central Bay and total catch of age-0 *Cancer magister*, with percent collected in Central Bay, 1980-2016.

Year	*Central Bay*	*Total*	*Percent Central Bay*
1980	1	19	5.3%
1981	5	24	20.8%
1982	11	16	68.8%
1983	0	1	0.0%
1984	246	445	55.3%
1985	269	559	48.1%
1986	0	5	0.0%
1987	14	55	25.5%
1988	140	669	20.9%
1989	12	28	42.9%
1990	2	8	25.0%
1991	57	148	38.5%
1992	0	0	
1993	6	7	85.7%
1994	25	240	10.4%
1995	28	31	90.3%
1996	6	15	40.0%
1997	98	143	68.5%
1998	0	0	
1999	376	437	86.0%
2000	373	463	80.6%
2001	1035	1359	76.2%
2002	703	963	73.0%
2003	893	1058	84.4%
2004	670	817	82.0%
2005	10	10	100.0%
2006	2	2	100.0%
2007	190	224	84.8%
2008	222	309	71.8%
2009	464	764	60.7%
2010	1369	1606	85.2%
2011	2314	2860	80.9%
2012	659	1471	44.8%
2013	3683	4934	74.6%
2014	106	264	40.2%
2015	28	74	37.8%
2016	No data	No data	No data

We have hypothesized that the large *C. magister* age-0 summer and fall catches from Central Bay in many years since 1998 were related to cold ocean temperatures and strong summer upwelling (Hieb 2012). Summer SSTs were very cool for most of 1999 to 2013, while 2014 to 2016 had the warmest SSTs since 1998 (Figure 6, Bay Study Fishes Status and Trends Report, page 7 of this issue). Central Bay age-0 *C. magister* were smaller than upstream crabs collected in the same month, leading to the conclusion that many of the Central Bay crabs had recently emigrated from the ocean. However, they did not migrate to San Pablo and Suisun bays to rear through the summer and fall as newly settled *C. magister* do in spring. One hypothesis is that Central Bay served as a warm-water refuge for coastal crabs in years with the coldest summer ocean temperatures. Central Bay summer temperatures were 2 to 4°C warmer than the GOF through 2013 (Figure 8b, Bay Study Fishes Status and Trends Report, page 8 this issue). We reported similar summer distributional trends for English Sole, Speckled Sanddab, Plainfin Midshipman, and several other demersal marine fishes (see the Bay Study Fishes Status and Trends Report, this issue).

Consistent with the immigration of small, newly settled crabs from the ocean, age-0 *C. magister* channel CPUE was higher than shoal CPUE in Central Bay in all years reported, ranging from 1 to 154 crabs per tow in the channels and 0.3 to 37 crabs per tow in the shoals (April to December). South and San Pablo bays channel-shoal CPUE was mixed, with CPUE higher in the channels some years and higher in the shoals in other years. This was due to a shift of *C. magister* from the shoals in spring to the channels in summer and fall, with slight differences in abundance and timing. Suisun Bay channel CPUE was higher than shoal CPUE in all years.

Age-1 *C. magister* were most common in Central Bay most months, with some consistently collected in San Pablo Bay and Carquinez Strait through summer. Age-1 crabs often emigrate from the estuary with pulses of freshwater outflow in winter and spring, but there was no outflow pulse large enough to trigger a significant migration from 2012 to 2015. There possibly was an outflow pulse large enough in spring 2016 to trigger migration, but we did not sample from January to April.

In addition, the 2015 year class was very small, with very few crabs remaining in the estuary by December. As expected, age-1 crabs were more common in the channels than the shoals in all regions and years, except for South Bay in 2012 and 2013. We collected age-1 crabs at South Bay shoal stations in winter and spring of these years, with lower CPUE in the channel.

Cancer antennarius

Cancer antennarius, the brown rock crab, is common to rocky areas and other areas with structure. It and *C. productus*, the red rock crab, are targeted by sport anglers fishing from piers and jetties in the higher salinity areas of the estuary. *C. antennarius*, *C. productus* and *C. gracilis* (the graceful rock crab) reproduce in the nearshore ocean and higher salinity areas of the San Francisco Estuary, primarily in winter, although ovigerous females and larvae have been collected through summer. Therefore, estuarine and ocean conditions may control larval survival, distribution, and ultimately recruitment of these 3 species.

The 2012 and 2013 age-0 *C. antennarius* abundance indices were very low, well below the study-period mean, while the 2014 index increased modestly, and the 2015 index was the highest for the study period (Table 2). We previously hypothesized that *C. antennarius* abundance in the estuary was related to ocean temperatures, as the highest abundance was often, but not always, in years with the coldest winter-spring SSTs. SSTs in winter and spring of 2011-2012 and 2012-2013 were generally cooler than the long-term mean, with a month or 2 of warmer temperatures (Figure 5B, Bay Study Fishes Status and Trends Report, page 7 of this issue). Winter 2013-14 was also cooler, but it warmed rapidly in March 2014 and SSTs remained well above average through summer 2015, except for a few months when upwelling was strong (Figure 5A, Bay Study Fishes Status and Trends Report, page 7 of this issue). The SSTs and age-0 *C. antennarius* trends were mostly opposite of what we predicted based on previous data, as there was low abundance in 2012 and 2013, 2 cool years, and record high abundance in 2015, a warm year. Carroll and Winn (1989) reported that *C. antennarius* is most common south of San Francisco Estuary to Baja California. This more southerly distribution within the CCS indicates that *C. antennarius* may be better suited for warmer ocean conditions than *C.*

Table 2. Annual abundance indices of age-0 *Cancer* crabs from the Bay Study otter trawl, 1980-2016. The index period is from May to October for *C. antennarius* and *C. gracilis* and from April to October for *C. productus*.

Year	*C. antennarius* *age-0*	*C. gracilis* *age-0*	*C. productus* *age-0*
1980	102	17	0
1981	76	152	6
1982	0	87	4
1983	28	151	4
1984	50	154	41
1985	20	216	38
1986	0	59	89
1987	71	93	79
1988	21	223	138
1989	29	203	30
1990	113	159	160
1991	171	656	128
1992	60	371	62
1993	398	616	71
1994	603	1,017	166
1995	367	227	40
1996	1,126	411	198
1997	351	1,131	86
1998	718	1,621	149
1999	90	222	249
2000	849	251	93
2001	276	1,921	142
2002	119	796	238
2003	424	522	140
2004	1,765	112	139
2005	144	132	57
2006	46	81	71
2007	987	418	58
2008	1,703	543	50
2009	556	471	68
2010	630	321	193
2011	83	82	33
2012	38	349	54
2013	55	179	212
2014	334	428	128
2015	1,993	699	160
2016	No Index	No Index	No Index
1980-2015 Average	400	419	99

magister or *C. productus*, which are most common north of Point Conception.

Age-0 *C. antennarius* abundance peaked in June of 2012 and 2013, August and September of 2014 (no July sampling), and from June through August of 2015. Small (<10 mm CW), newly settled juveniles were collected sporadically in several months of 2012 and 2013, all months in 2014 except for February, April and June, with most in December, and all months of 2015 except for February and April, with most in July and August. This variable pattern of settlement is not unusual for *C. antennarius*, although settlement is typically in late summer and fall when recruitment is strong.

Age-0 *C. antennarius* was collected from South Bay, near Coyote Point, through lower San Pablo Bay from 2012 to 2016, although distribution changed with abundance. Distribution was broadest in 2015, the high abundance year, and restricted to South and Central bays in 2012, a low abundance year. The highest age-0 catches were from shoal stations near the Alameda rock wall (#142), Berkeley Marina (#212), Paradise Cay in upper Central Bay (#244), and in San Pablo Bay (#318 and #323) and the channel station near Hunter's Point in South Bay (#109). CPUE was highest in Central Bay in 2014, 2015, and 2016, and nearly equal in South and Central bays in 2012 and 2013. Age-0 *C. antennarius* were more common at shoal stations in every region in every year, with no evidence of movement to deeper water through summer and fall. For example, CPUE was 14.2 crabs per tow at the shoals and only 0.7 crabs per tow at the channels of Central Bay in 2015 (January to December), with ratios of 50:1 in July and August, when abundance of small juveniles was the highest. This lack of a late-summer and fall migration of age-0 *C. antennarius* to deeper water is likely because this species often settles in summer and fall, not in spring. However, larger age-1+ crabs have a strong preference for deeper water. From 2012 to 2016, 90% of *C. antennarius* <40 mm CW (n=1,240) were collected from shoals, while 88% of crabs ≥ 40 mm CW (n=40) were collected from the channels.

Cancer gracilis

Cancer gracilis, the graceful rock crab, is the smallest of the 4 *Cancer* crab species reported here, rarely exceeding 85 mm CW. It is common in open sandy or sand-mud habitats rather than rocky areas; researchers have hypothesized that because of its small size it cannot compete with the rock crabs for the more "preferred" protected habitats with structure. Age-0 *C. gracilis* abundance was relatively consistent from 2012 to 2015, varying about fourfold (Table 2), in contrast to the episodic recruitment of *C. magister* and *C. antennarius* to the estuary. The lowest index was in 2013, the highest in 2015, with the 2012 and 2014 indices near the study-period mean. Age-0 abundance was highest from January to May and in November and December of 2012 and 2013, from February through August of 2014, and from June to November of 2015. Recently settled juvenile *C. gracilis*, <10 mm CW, were collected in winter and spring of 2012, 2013, and 2014, but there was no seasonal pattern to their collection in 2015. It appears that reproduction was in late fall and winter until the fall and winter of 2014-2015, when SSTs increased substantially. Note that only 1 small *C. gracilis* was collected in 2016, in December, but we did not sample January to April and August to October.

From 2012 to 2016, *C. gracilis* was collected from near the San Mateo Bridge in South Bay to near Point Pinole in San Pablo, with 77% (n=908) of all crabs collected from Central Bay. The highest catches were from the channel stations near the Bay Bridge, Angel Island, and the Richmond-San Rafael Bridge (#110, #215, #216) and the shoal stations near Berkeley Marina (#212) and Paradise Cay (#244) in Central Bay. There was a seasonal channel-shoal pattern, with crabs more common in the channels in winter and the shoals from spring to fall. This pattern was most apparent when small *C. gracilis* recruited to the estuary in winter, such as in 2012 and 2013, and less apparent when there was no single recruitment event, as in 2015.

Cancer productus

Cancer productus, the red rock crab, is overall the least common of the 4 *Cancer* crabs collected by the otter trawl in the estuary, reflecting its strong preference for rocky intertidal and subtidal marine habitats with structure not sampled by the trawl. In a survey conducted by CDFG from 1982 to 1994 with baited ringnets at piers, it was the 2nd most common *Cancer* crab collected. The 2012 to 2015 age-0 *C. productus* abundance indices did not vary much compared to the *C. magister* and *C. antennarius* indices. The 2012 index was low, about half of the study-period mean, while the 2013 index increased about 4 times from the 2012 index. The 2014 and 2015 indices decreased, but remained above the study-period mean (Table 2).

Seasonal abundance trends of age-0 *C. productus* were not consistent, likely due to the relatively low abundance. Abundance peaked in January 2012, April and May of 2013 and 2014, and in June and August of 2015. Overall, abundance was lowest in late fall and winter. Recently settled *C. productus* (<10 mm CW) were collected in winter and spring of 2012 to 2014, but in 2015, they were collected from May through October. This is similar to the settlement pattern reported for *C. antennarius* and *C. gracilis*, with settlement very delayed in 2015 or not detected.

Age-0 *C. productus* were collected from near Coyote Point in South Bay to Point Pinole in San Pablo Bay from 2012 to 2016, with 63% (n=169) from Central Bay. Most were collected from the channel station near Hunter's Point (#109), the shoal station near the Alameda rock wall (#142), and the Alcatraz Island channel station (#213). We often bring up cobble or rocks in the tows at these 2 channel stations. They were occasionally collected at 2 stations near San Leandro in South Bay (#104, #105) and 1 station near Point Pinole in San Pablo Bay (#318) with dead oyster shells as the substrate. Juvenile *C. productus* reportedly settle on spatially complex substrates and move to areas with more open space as they grow (Orensanz and Gallucci 1988). Because we tow over soft substrates rather than rocky areas, we are likely not able to detect this type of distributional pattern. Over most months and years, age-0 *C. productus* favored channels over shoals in Central Bay, but shoal CPUE was often higher than channel CPUE in South and San Pablo bays. Larger (≥ 40 mm CW) *C. productus* strongly favored channels, with 93% (n=55) collected from channels from 2012 to 2016.

Ocean Conditions and Recruitment of *Cancer* Species

Winter ocean conditions have been hypothesized to be important for *C. antennarius*, *C. gracilis*, and *C. productus* recruitment to the estuary (Hieb 2012), as peak larval hatching of all 3 species is reportedly in winter. For the 5 years of this report, winters had either cold SSTs with a weak Davidson Current and possibly little northward advection (2011-12, 2012-13, and 2013-14) or warm SSTs and possibly greater northward advection (2014-15 and 2015-16). Surprisingly, the highest abundance of *C. antennarius* for the entire study period and the highest *C. gracilis* abundance in over a decade was in 2015 (Table 2), following a winter with warm SSTs due to the marine heatwave. Settlement of *C. antennarius* and *C. productus*, based on our collections of the smallest juveniles, was delayed in 2015 from winter-spring to summer. There was no discernable settlement pattern for *C. gracilis* in 2015, with small juveniles collected most months. We do not know if reproduction was delayed or if there was a prolonged planktonic period – either could have resulted in late settlement. We know that *C. antennarius* and *C. gracilis* can have multiple broods (Carroll 1982, Orensanz et al. 1995) and megalopae of these species have been collected in San Francisco Estuary in seasons other than winter (Hieb 1999), so winter-spring settlement is not always the norm.

Eriocheir sinensis

Eriocheir sinensis, the Chinese mitten crab, was first collected in the estuary in the early 1990s, but was likely introduced to South San Francisco Bay in the late 1980s. After several years of rapid population growth and expanding distribution, the *E. sinensis* population peaked in 1998 (Table 3). All data sources indicate that the population steadily declined after 2001, with few or no crabs collected from 2005 through 2010 and no crabs collected from 2011 to 2016. The last confirmed collections were 3 adult *E. sinensis* salvaged at USBR's Central Valley Project facility in 2010. No crabs were collected by CDFW's San Francisco Bay Study since 2005 or by the UC Davis Suisun Marsh trawl survey since 2002 (O'Rear, personal communication, see "Notes") in the northern estuary. No adult *E. sinensis* were collected in South Bay trawls conducted by the Marine Science Institute (Seiff, personal communication, see "Notes") since at least 2007. There were also no public reports of *E. sinensis* in recent years, but because of the population crash, we have not maintained the toll-free reporting line and the online reporting form. It is possible that there is still an *E. sinensis* population in the San Francisco Estuary, but at such a low level that we cannot detect it.

E. sinensis have planktonic larvae, which have minimal or no estuary-retention mechanisms (Hanson and Sytsma 2008) and would be transported from the

Table 3. Annual adult *Eriocheir sinensis* trawl CPUE and estimated total salvage, 1996-2016. Bay Study CPUE is from October (year) to March (year+1), Suisun Marsh CPUE is from July to December, MSI CPUE is from October (year) to May (year+1), and Central Valley Project (CVP) and State Water Project (SWP) fish facilities salvage is from September to November.

Year	Bay Study CPUE	Suisun Marsh CPUE	MSI CPUE	CVP salvage	SWP salvage
	(#/tow)	(#/tow)	(#/tow)	est. total	est. total
1996	0.02	0.00	0.11	50	not counted
1997	0.34	0.07	0.18	20,000	not counted
1998	2.51	0.89	0.17	750,000	not counted
1999	0.96	1.08	0.38	90,000	34,000
2000	0.93	0.02	0.37	2,500	4,700
2001	3.25	0.17	0.71	27,500	7,300
2002	1.07	0.04	0.24	2,400	1,200
2003	0.15	0.00	?	650	90
2004	0.12	0.00	?	750	370
2005	0.01	0.00	?	0	18
2006	0.00	0.00	?	12	0
2007	0.00	0.00	0.00	0	0
2008	0.00	0.00	0.00	0	0
2009	0.00	0.00	0.00	0	0
2010	0.00	0.00	0.00	3	0
2011	0.00	0.00	0.00	0	0
2012	0.00	0.00	0.00	0	0
2013	0.00	0.00	0.00	0	0
2014	0.00	0.00	0.00	0	0
2015	0.00	0.00	0.00	0	0
2016	0.00	0.00	0.00	0	0

estuary to the coast in years with high freshwater outflow. From laboratory studies, successful development of *E. sinensis* larvae occurred only at temperatures >12°C, with the highest survival at 18°C (Anger 1991). I have proposed that ocean conditions may control *E. sinensis* recruitment to the San Francisco Estuary (Hieb 2009). With cool ocean SSTs for much of the past decade, we expected no or poor *E. sinensis* recruitment. The warm SSTs from 2014 to 2016, often >13°C (Figure 6, Bay Study Fishes Status and Trends Report, page 7 this issue), would have favored *E. sinensis* larval survival, if larvae were present. However, I have concluded that very low or no adult stock and low freshwater outflow resulted in no larvae transported to the coastal ocean to take advantage of the warmer SSTs from 2014 to 2016. This has been supported by no reports or collections of *E. sinensis* in recent years, including 2017.

Notes

Teejay O'Rear, UC Davis, email, August 16, 2017.

Marylou Seiff, Marine Science Institute, email, August 17, 2017

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Zooplankton Monitoring 2016

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Introduction

Zooplankton provide a vital trophic link between primary producers and fish, making them an important component of the pelagic food web. They are primary consumers of phytoplankton, and serve as a food source for secondary consumers, such as other zooplankton, aquatic insects, and fish. Most larval and juvenile fish eat zooplankton while some smaller fish, such as Delta Smelt and Longfin Smelt, rely on zooplankton for food throughout their lives. To assess trends in fish food resources, the Zooplankton Study has provided abundance estimates of zooplankton in the upper San Francisco Estuary (SFE) since 1972 and has assisted with the detection and monitoring of introduced zooplankton. Substantial changes in the zooplankton community composition and abundance have been linked to the decline of several pelagic fish species in the upper SFE (Sommer et al. 2007, Winder and Jassby 2011). Documenting these lower food web changes has helped scientists understand the ecology of the SFE. Here, zooplankton abundance indices are presented from 1974 through 2016 for the most common copepods, cladocerans, rotifers, and mysids.

Methods

Zooplankton were sampled monthly from 1974 through 2016 at 20 fixed stations in the upper SFE, extending from eastern San Pablo Bay through the Delta (Figure 1). Sixteen stations were used to calculate annual and seasonal abundance indices, including 14 fixed stations sampled consistently since 1974 (Figure 1) and two non-fixed stations sampled where bottom specific conductance was 2 and 6 millisiemens per centimer (approximate salinity of 1 and 3 psu). At each station, three gear types were used to collect zooplankton of various sizes: 1) a pump for sampling smaller zooplankton, including rotifers, copepod nauplii, and copepods of the genus *Limnoithona*; 2) a modified Clarke-Bumpus (CB) net for sampling mid-sized zooplankton, including cladocerans and most juvenile and adult copepods (net mesh 160 micron opening); and 3) a mysid net for sampling mysid shrimp (net mesh 505 micron opening). Abundance indices were calculated using data from the gear type that most effectively captured each organism and reported here as the mean number collected per cubic meter of water sampled (catch-per-unit-effort, CPUE). Copepod abundance indices included adults only, as juveniles were not always identified to species and were therefore not counted separately. All other taxa reported included juveniles and adults combined.

For long-term trend analyses, annual abundance was calculated as the mean March through November CPUE, because these months were consistently sampled throughout the entire study period. Seasonal abundance was calculated as the mean CPUE for each season: 1) winter: previous December through February, 2) spring: March through May, 3) summer: June through August, and 4) fall: September through November. Winter months were not sampled consistently until 1995; therefore, long-term trends for winter are shown from 1995 through 2016 only. Geographic distribution was described as the mean CPUE for each season of 2016 for each geographic region. The geographic regions were defined as San Pablo Bay (stations D41 and D41A), Suisun Bay (stations D6 and 28), Suisun Marsh (stations 32 and S42), Confluence (stations 48 and 54), West Delta (stations 60, 64, and 74), Central Delta (D16, D19, 86, and D28), and East Delta (stations 92, and M10).

Results and Discussion

Calanoid Copepods- Community Changes

Calanoid copepods in the upper SFE include *Eurytemora affinis*, *Acartia* spp., *Sinocalanus doerrii*, *Pseudodiaptomus forbesi*, *Tortanus* spp., and *Acartiella sinensis*. When monitoring began in the 1970s, *E. affinis* and *Acartia* spp. were the most abundant adult copepods (Figure 2). *E. affinis* was once a major food source for larval and juvenile fishes of many species and adult planktivores, such as Delta Smelt and Threadfin Shad. However, annual abundance of *E. affinis* and *Acartia* spp. has declined since the late 1970s (Figure 2), as new species were introduced and became established in the estuary.

One of the first zooplankton species introductions to the estuary was *Sinocalanus doerrii*, a freshwater calanoid copepod initially recorded by this study in late 1978 (Orsi et al. 1983). By summer 1979, *S. doerrii* abundance surpassed *E. affinis* summer abundance, and *S. doerrii* was the most abundant calanoid copepod in the upper estuary in most years from 1979 through 1984 (Figure 2).

In the late-1980s two more introductions occurred that further changed the copepod community in the upper SFE. In 1986 the overbite clam, *Potamocorbula amurensis*, was introduced (Carlton et al. 1990) and in 1987, another calanoid copepod, *Pseudodiaptomus forbesi*, was introduced (Orsi and Walter 1991). Both *P. amurensis* and *P. forbesi* graze on phytoplankton and thus compete with *E. affinis* for food (Kimmerer and Orsi 1996). Additionally, *P. amurensis* also graze on copepod nauplii in the water column, thereby further reducing *E. affinis* abundance through predation (Kimmerer et al. 1994). The introductions of these species also affected the seasonal

Figure 1. Map of fixed Zooplankton Study stations.

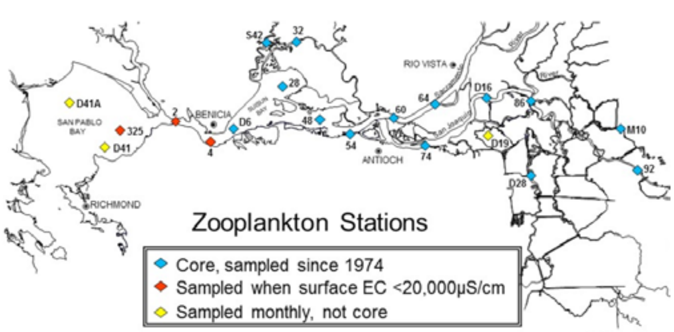
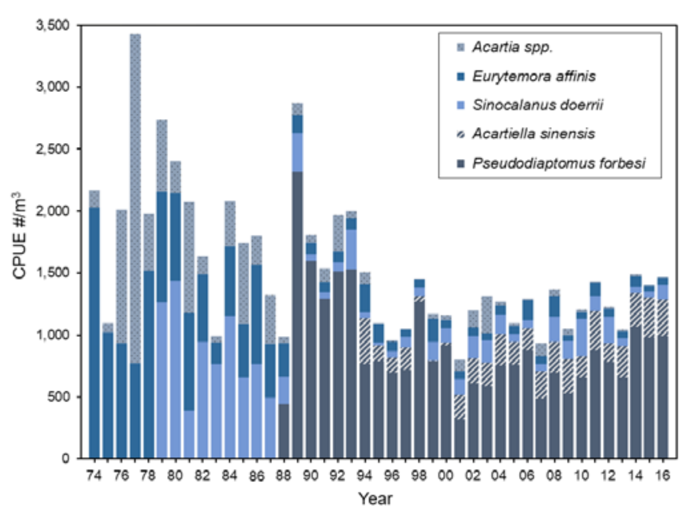


Figure 2. Annual (March through November) mean adult calanoid copepod CPUE (catch-per-unit-effort in number m^{-3}) from the Zooplankton Study's Clarke-Bumpus net for the most abundant calanoid copepods in the upper San Francisco Estuary from 1974 through 2016.



abundance of *E. affinis*, in the upper estuary. Prior to these introductions, *E. affinis* was common year-round and peaked in abundance during summer. However, since 1987, abundance has been highest in spring and drops abruptly in summer, when both *P. forbesi* abundance and *P. amurensis* grazing rates increase.

Additional species introductions occurred in 1993 with the establishment of two predatory calanoid copepods, *Tortanus dextrilobatus* and *Acartiella sinensis* (Orsi and Ohtsuka 1999). By 1994, *A. sinensis* became the second most abundant calanoid copepod in the upper estuary (Figure 2) with the highest abundance in the low salinity zone during summer and fall (Orsi and Ohtsuka 1999). New evidence indicates that *A. sinensis* limits the seaward distribution of *P. forbesi* through predation on *P. forbesi* nauplii (Kayfetz and Kimmerer 2017). The large brackish water copepod, *T. dextrilobatus* peaks in abundance further downstream in higher salinities and generally has lower abundance than other calanoid copepods in the study area of this project (Orsi and Ohtsuka 1999).

Calanoid Copepods- 2016 Abundance and Distribution

Pseudodiaptomus forbesi was the most abundant calanoid copepod in 2016, which is consistent with all the years since its introduction in 1987 (Figure 2). In 2016, *P. forbesi* was also the most abundant calanoid copepod in each season (Figures 3, 4, 5, and 6), which was the first year since 1996 that it was the most abundant calanoid copepod in all seasons. Winter abundance of *P. forbesi* increased substantially in 2016 and was the highest winter abundance recorded for this species (Figure 3). In 2016, *P. forbesi* CPUE was highest in the East Delta in spring, summer, and fall (Figure 7). CPUE was also high in the Central Delta in summer and fall and in the West Delta in summer (Figure 7).

Acartiella sinensis was the second most abundant calanoid copepod in 2016 and has been in most years since its introduction in 1993 (Figure 2). *A. sinensis*

Figure 3. Mean winter (previous December through February) adult calanoid copepod CPUE (catch-per-unit-effort in number m^{-3}) from the Zooplankton Study's Clarke-Bumpus net for the most abundant calanoid copepods in the upper San Francisco Estuary from 1995 through 2016.

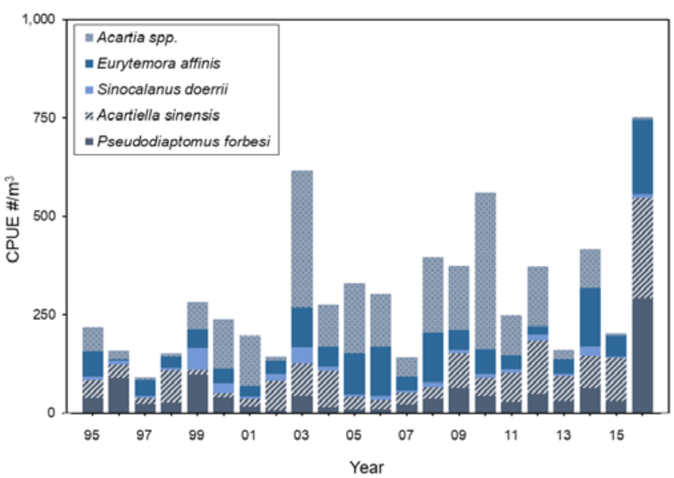


Figure 4. Mean spring (March through May) adult calanoid copepod CPUE (catch-per-unit-effort in number m^{-3}) from the Zooplankton Study's Clarke-Bumpus net for the most abundant calanoid copepods in the upper San Francisco Estuary from 1974 through 2016.

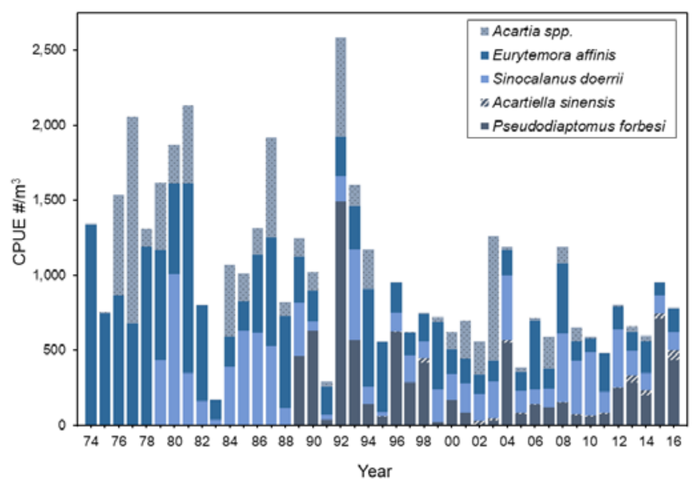
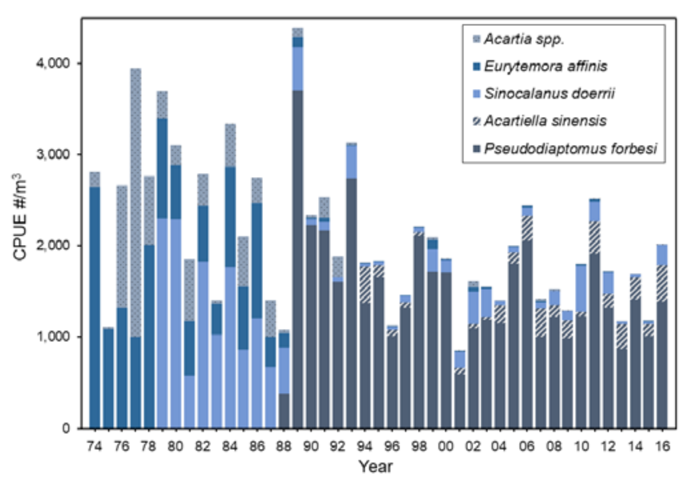


Figure 5. Mean summer (June through August) adult calanoid copepod CPUE (catch-per-unit-effort in number m^{-3}) from the Zooplankton Study's Clarke-Bumpus net for the most abundant calanoid copepods in the upper San Francisco Estuary from 1974 through 2016.



abundance was highest during summer and fall 2016 (Figures 5 and 6). Winter abundance increased substantially in 2016 and was the highest winter abundance recorded for this species (Figure 3). In 2016, *A. sinensis* CPUE was highest during summer and fall in the West Delta (Figure 7). CPUE was also high in Suisun Marsh, Suisun Bay, and the Confluence during most seasons (Figure 7).

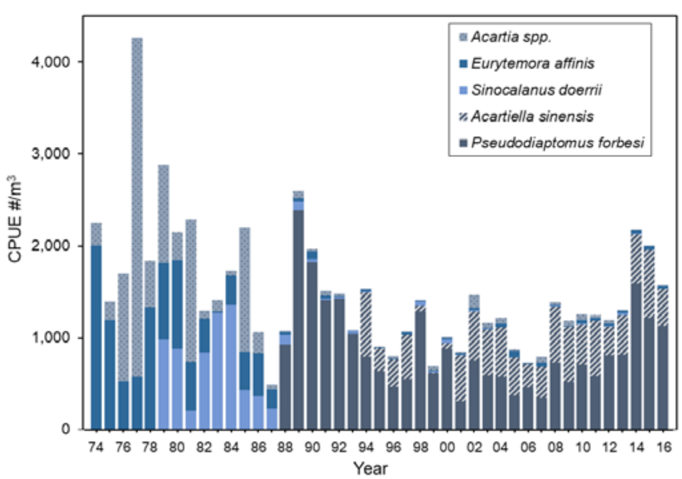
Sinocalanus doerrii was the third most abundant calanoid copepod in 2016 (Figure 2). *S. doerrii* abundance was highest during summer 2016 (Figure 5). Spring 2016 *S. doerrii* abundance was similar to 2013 through 2015 (Figure 4). In 2016, *S. doerrii* CPUE was highest in spring and summer in the West, Central, and East Delta (Figure 7).

Eurytemora affinis was the fourth most abundant calanoid copepod in 2016 (Figure 2). Although usually most abundant in spring, *E. affinis* seasonal abundance in 2016 was highest in winter (Figure 3), which was the first time winter abundance exceeded abundance in the other seasons (Figures 3, 4, 5, and 6). In 2016, *E. affinis* CPUE was highest in winter and spring in Suisun Marsh and the East Delta (Figure 7).

Cyclopoid Copepods- Community Changes

Cyclopoid copepods in the upper SFE include the introduced *Limnoithona sinensis* and *Limnoithona tetraspina*, and the much less abundant native genera Acanthocyclops and Cyclops, which are not reported here.

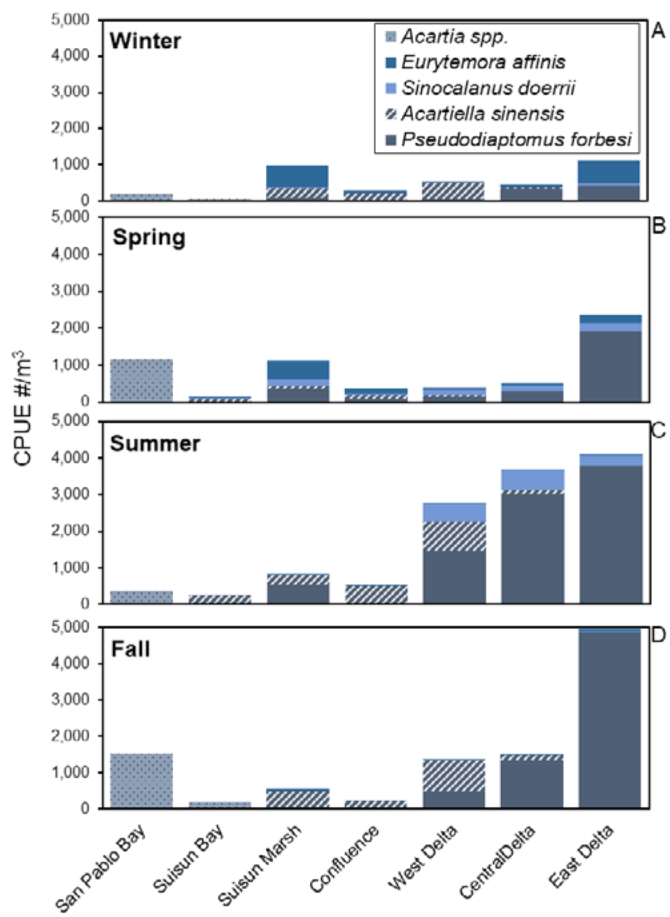
Figure 6. Mean fall (September through November) adult calanoid copepod CPUE (catch-per-unit-effort in number m^{-3}) from the Zooplankton Study's Clarke-Bumpus net for the most abundant calanoid copepods in the upper San Francisco Estuary from 1974 through 2016.



In 1979, the cyclopoid copepod *L. sinensis* was introduced (Ferrari and Orsi 1984). Much smaller than the calanoid copepods that inhabited the estuary, *L. sinensis* was not retained well by the CB net, but abundance indices from the pump samples quickly became comparable to *E. affinis* and *S. doerrii* abundance indices from the CB samples (Figure 8). Abundance indices for the two species of *Limnoithona* are reported together until 2007, when they were identified and enumerated separately.

Limnoithona tetraspina, another small cyclopoid copepod, was first recorded by this study in 1993 (Orsi and Ohtsuka 1999). It replaced the historically common and slightly larger *L. sinensis* and became the numerically dominant copepod in the upper estuary by 1994 (Figures 2 and 8). Despite extremely high densities of *L. tetraspina*

Figure 7. Mean regional 2016 CPUE (catch-per-unit-effort in number m^{-3}) of adult calanoid copepods from the Zooplankton Study's Clarke-Bumpus net for the most abundant calanoid copepods in the upper San Francisco Estuary during winter (A, previous December through February), spring (B, March through May), summer (C, June through August), and fall (D, September through November).



in the estuary, it may not be a readily available food source for visual predators like Delta Smelt, due to its small size and relatively motionless behavior in the water column (Bouley and Kimmerer 2006).

Cyclopoid Copepods- 2016 Seasonal Abundance and Distribution

Limnoithona tetraspina has been the most abundant copepod in the upper estuary since 1994, and mean annual abundance in 2016 was the second highest recorded (Figure 8). In 2016, abundance of both species of *Limnoithona* together was highest during summer and fall (Figure 9). Although summer abundance was lower in 2016 than in 2015, summer abundance in 2016 was the third highest recorded (Figure 9). Fall 2016 abundance continued the increase that started in 2015, and was the highest fall abundance recorded for this genus (Figure 9). In 2016, CPUE of both *Limnoithona* species together was highest in Suisun Marsh, Suisun Bay, the Confluence, and the West Delta during summer and fall (Figure 10).

Cladocerans

Bosmina, *Daphnia*, and *Diaphanosoma* are the most abundant cladoceran genera in the upper SFE. Combined, cladocerans have had an overall downward trend since the early 1970s (Figure 11). In 2016, annual abundance increased for the second year in a row and was the highest since 2007 (Figure 11). Winter abundance, although always much lower than the other seasons, increased and was the second highest recorded in 2016 (Figure 12). After a record low in 2014, spring abundance increased in 2015 and 2016, and in 2016 was the highest recorded since 2007 (Figure 12). Summer abundance continued

Figure 8. Annual March through November mean adult cyclopoid copepod CPUE (catch-per-unit-effort in number m^{-3}) from the Zooplankton Study's pump samples for the most abundant cyclopoid copepods in the upper San Francisco Estuary from 1974 through 2016. *Limnoithona sinensis* was originally recorded as *Limnoithona* spp., then in 1993 *Limnoithona tetraspina* was introduced and mostly supplanted *L. sinensis*, however the genus wasn't identified to species in samples until 2007.

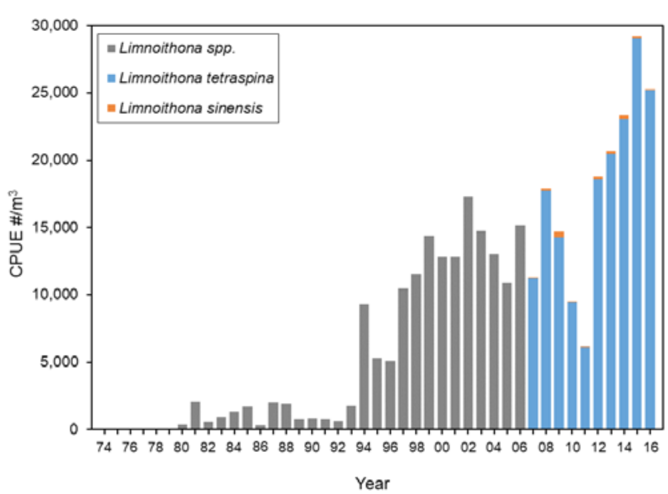


Figure 9. Seasonal mean CPUE (catch-per-unit-effort in number m^{-3}) of adult copepods of the genus *Limnoithona* from the Zooplankton Study's pump samples from 1974 through 2016 for winter (previous December through February), spring (March through May), summer (June through August), and fall (September through November).

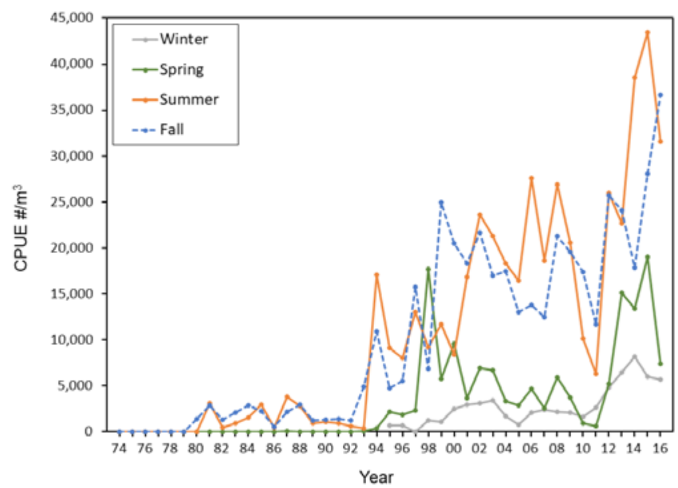
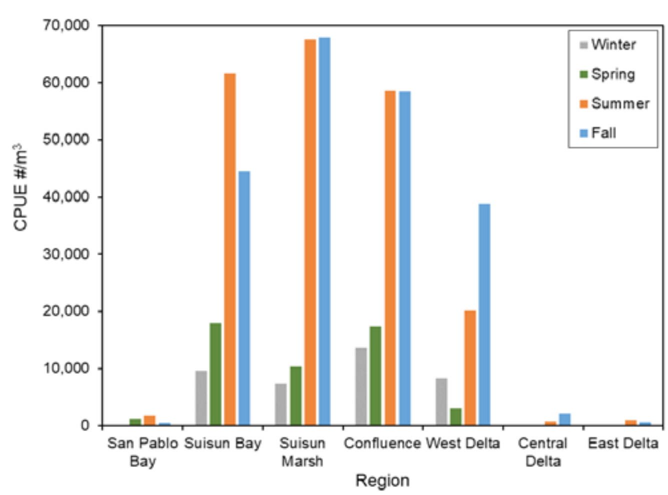


Figure 10. Mean regional 2016 CPUE (catch-per-unit-effort in number m^{-3}) of adult cyclopoid copepods of the genus *Limnoithona* in the upper San Francisco Estuary from the Zooplankton Study's pump samples during winter (previous December through February), spring (March through May), summer (June through August), and fall (September through November).



the increase that started in 2012, and in 2016 summer abundance was the highest observed since 1986 (Figure 12). Although fall abundance decreased slightly in 2016 from 2015, it was the second highest fall abundance observed since 1992 (Figure 12). In 2016, cladocerans were found throughout the Delta in every season with the highest CPUE occurring in the East Delta in summer (Figure 13).

Figure 11. Annual March through November mean cladocerans CPUE (catch-per-unit-effort in number m^{-3}) in the upper San Francisco Estuary from the Zooplankton Study's Clarke-Bumpus net from 1974 through 2016.

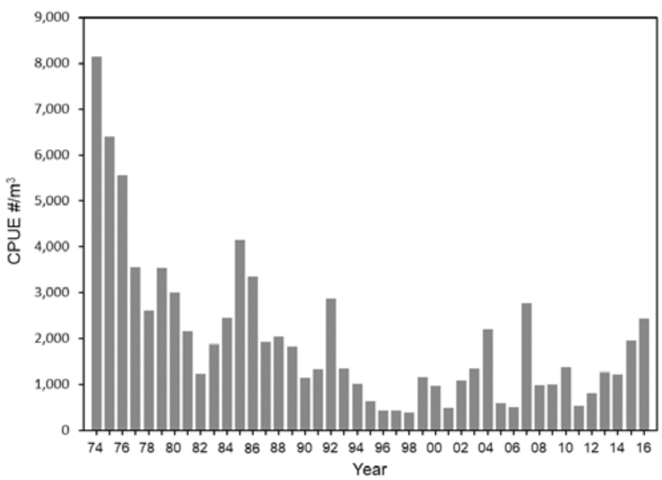
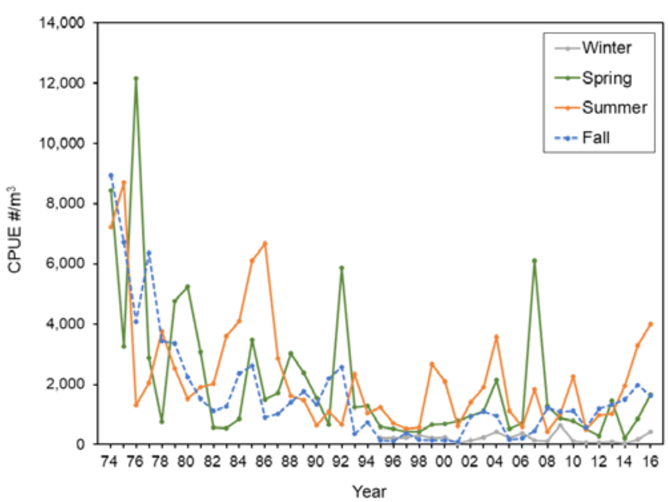


Figure 12. Seasonal mean cladocerans CPUE (catch-per-unit-effort in number m^{-3}) in the upper San Francisco Estuary from the Zooplankton Study's Clarke-Bumpus net from 1974 through 2016 for winter (previous December through February), spring (March through May), summer (June through August), and fall (September through November).



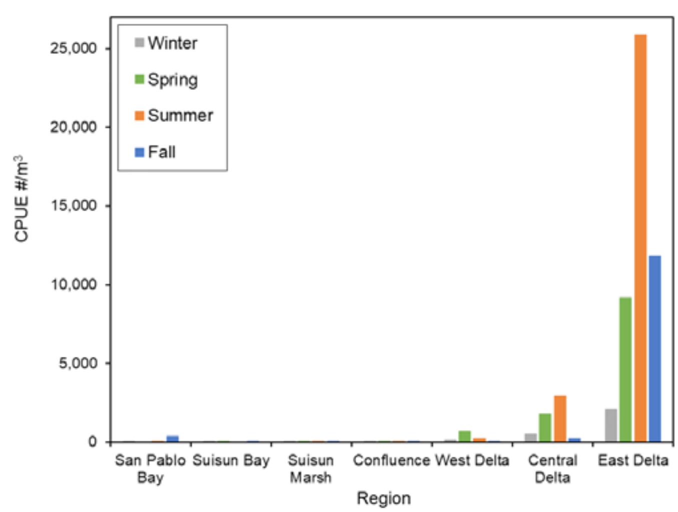
Rotifers

Rotifers in the upper SFE include the freshwater *Asplanchna* spp., *Keratella* spp., *Polyarthra* spp., *Synchaeta* spp., and *Trichocerca* spp.; as well as the brackish-water *Synchaeta bicornis*. Similar to past zooplankton status and trends reports, the rotifers are reported here as *Synchaeta bicornis* and other rotifers for brevity.

Synchaeta bicornis is a native brackish-water rotifer that is usually most abundant in the upper estuary in summer and fall, when salinity increases. The long-term annual abundance of *S. bicornis* has declined since the 1970s (Figure 14). In 2011 annual abundance was higher than it had been since 1985, however annual abundance returned to previously low levels from 2012 through 2016 (Figure 14). In 2016, *S. bicornis* fall abundance continued to increase for the second year in a row and exceeded summer abundance (Figure 15). *S. bicornis* CPUE was highest in Suisun Bay in summer 2016 (Figure 16). As salinities increased in fall, distribution spread further upstream from Suisun Bay into the Confluence and the West Delta (Figure 16).

Abundance of all other rotifers declined from the early 1970s through the 1980s, but stabilized after the early 1990s (Figure 14). In 2011 and 2016, annual abundance was higher than it had been since 1989 (Figure 14). Although rotifer abundance usually peaks in spring,

Figure 13. Mean regional 2016 CPUE (catch-per-unit-effort in number m^{-3}) of cladocerans in the upper San Francisco Estuary from the Zooplankton Study's Clarke Bumpus net from winter (previous December through February), spring (March through May), summer (June through August), and fall (September through November).



abundance in 2016 peaked in summer and was the highest summer abundance since 1978 (Figure 17). Rotifers were common throughout the study area in every season in 2016 (Figure 18), with the highest CPUE in summer in the East Delta (Figure 18).

Mysids- Community Changes

Mysids in the upper SFE include the native species *Neomysis mercedis* and *N. kadiakensis*, as well as the

Figure 14. Annual March-November mean CPUE (catch-per-unit-effort in number m^{-3}) of rotifers in the upper San Francisco Estuary from the Zooplankton Study's pump samples from 1974 through 2016.

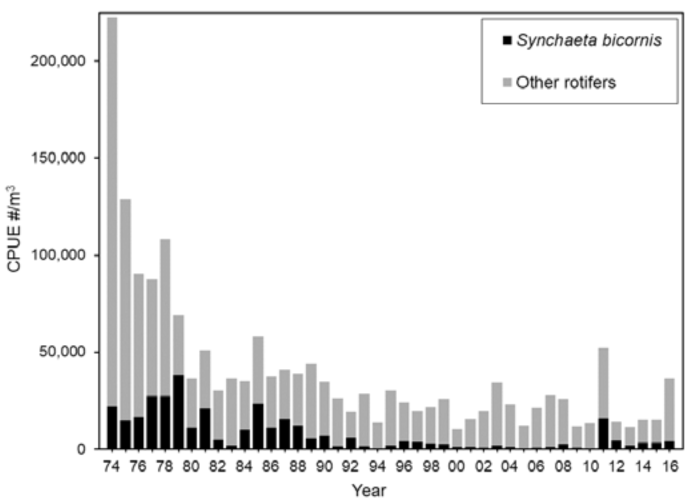
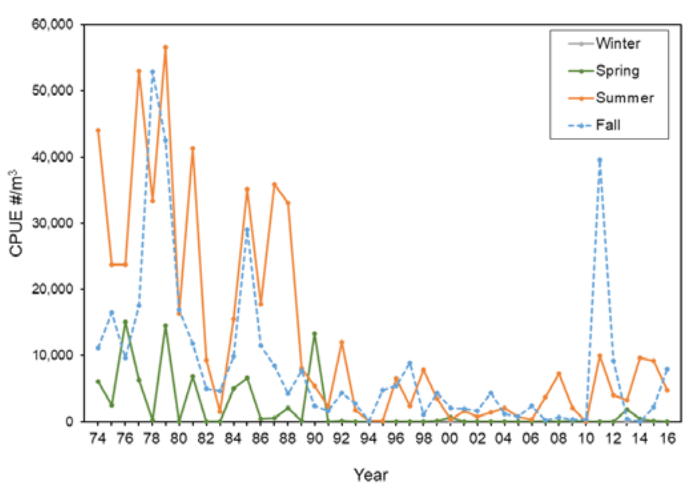


Figure 15. Seasonal mean CPUE (catch-per-unit-effort in number m^{-3}) of *Synchaeta bicornis* in the upper San Francisco Estuary from the Zooplankton Study's pump samples from 1974 through 2016 for winter (previous December through February), spring (March through May), summer (June through August), and fall (September through November).



introduced species, *Hyperacanthomysis longirostris*, and three lesser abundant species not reported here. When monitoring for mysids began in the 1970s, *N. mercedis* was the only mysid commonly found in the upper estuary (Figure 19). Since then, *N. mercedis* abundance decreased in the late 1980s and early 1990s, after the overbite clam, *P. amurensis*, was introduced

Figure 16. Mean regional CPUE (catch-per-unit-effort in number m^{-3}) of *Synchaeta bicornis* in the upper San Francisco Estuary from the Zooplankton Study's pump samples from winter (previous December through February), spring (March through May), summer (June through August), and fall (September through November).

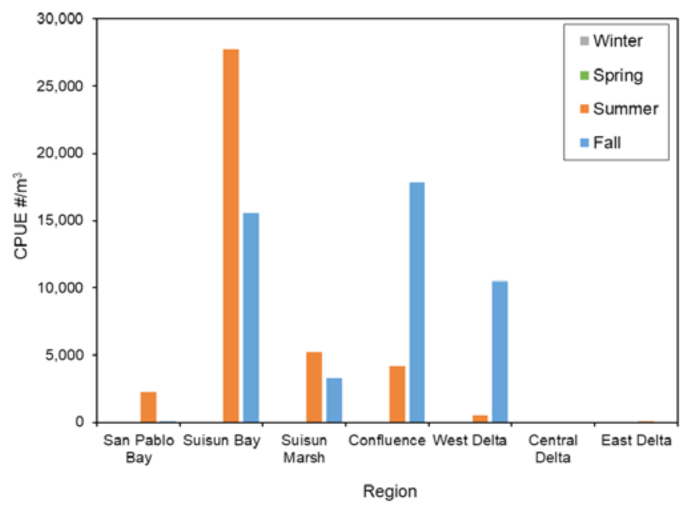
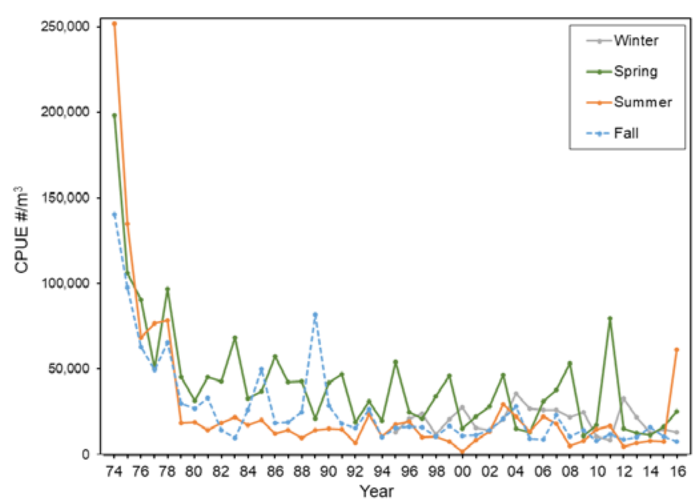


Figure 17. Seasonal mean CPUE (catch-per-unit-effort in number m^{-3}) of all other rotifers without *Synchaeta bicornis* in the upper San Francisco Estuary from the Zooplankton Study's pump samples from 1974 through 2016 for winter (previous December through February), spring (March through May), summer (June through August), and fall (September through November).



(Figure 19). *P. amurensis* competes with *N. mercedis* for phytoplankton, which contributed to the decline of the native mysid species (Orsi and Mecum 1996). Shortly after *N. mercedis* abundance declined, *H. longirostris* (formerly *Acanthomysis bowmani*) was introduced and first collected by this study in 1993 (Modlin and Orsi 1997). *H. longirostris* abundance increased rapidly after its introduction became the most abundant mysid in the upper estuary by 1994 (Figure 19).

Figure 18. Mean regional 2016 CPUE (catch-per-unit-effort in number m^{-3}) of all other rotifers without *Synchaeta bicornis* in the upper San Francisco Estuary from the Zooplankton Study's pump samples from winter (previous December through February), spring (March through May), summer (June through August), and fall (September through November).

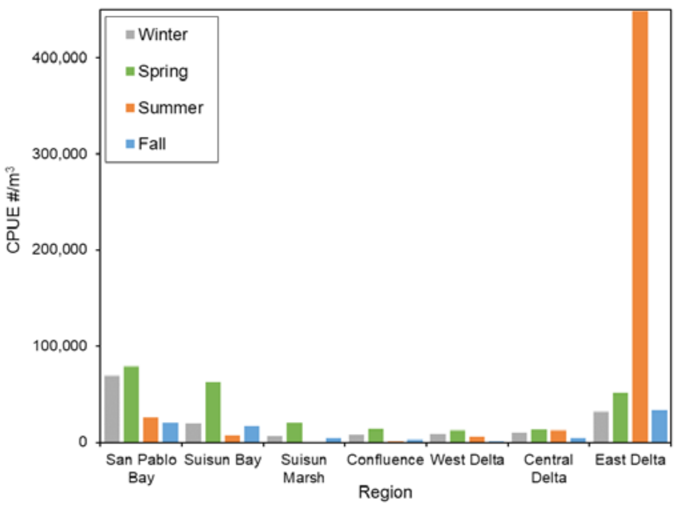
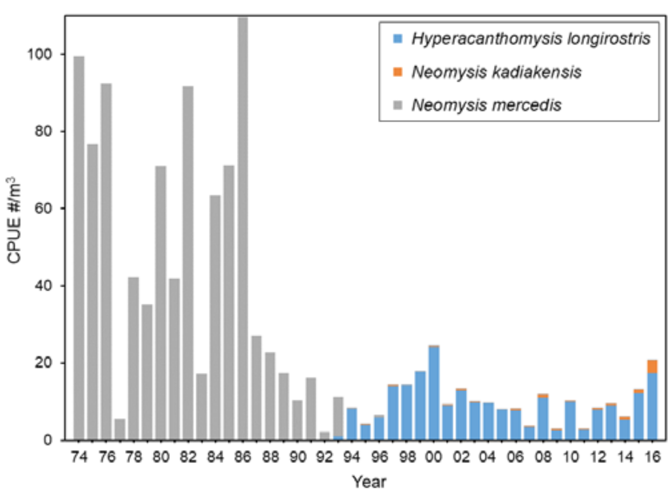


Figure 19. Annual March-November mean mysids CPUE (catch-per-unit-effort in number m^{-3}) in the upper San Francisco Estuary from the Zooplankton Study's mysid samples from 1974 through 2016.

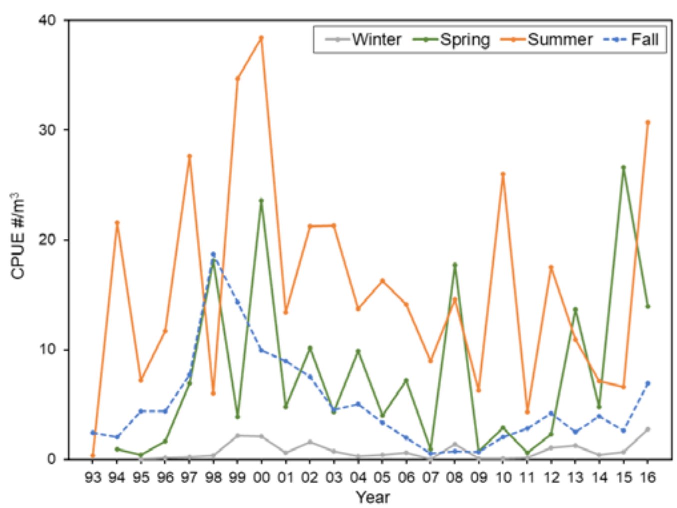


Mysids- 2016 Seasonal Abundance and Distribution

Hyperacanthomysis longirostris was the most abundant mysid in 2016, as it had been since 1994 (Figure 19). Annual abundance increased for the second year in a row, and in 2016 annual abundance was the highest since 2000 (Figure 19). After record-low summer abundance in 2014 and 2015, summer abundance increased sharply in 2016 and was the third highest recorded (Figure 20). Although fall and winter abundance increased slightly from 2015 to 2016, spring abundance decreased (Figure 20). In 2016, *H. longirostris* CPUE was highest during spring and summer in Suisun Marsh and the Confluence, and in summer and fall in the West Delta (Figure 21).

Neomysis kadiakensis is a native brackish-water mysid that regularly appeared in mysid samples beginning in 1995. Since 2001, it has been the second most abundant mysid in the upper SFE (Figure 19). Annual *N. kadiakensis* abundance continued to increase in 2016, as it had since 2011, and annual abundance in 2016 was the highest recorded (Figure 19). Summer abundance increased sharply in 2016 from 2015, and was the highest recorded abundance in summer (Figure 22). Fall abundance also increased in 2016 from 2015, and was the highest fall abundance recorded (Figure 22). In 2016, *N.*

Figure 20. Seasonal mean CPUE (catch-per-unit-effort in number m^{-3}) of *Hyperacanthomysis longirostris* in the upper San Francisco Estuary from the Zooplankton Study's mysid samples from 1993 through 2016 for winter (previous December through February), spring (March through May), summer (June through August), and fall (September through November).



kadiakensis CPUE was highest during summer in Suisun Marsh, the Confluence, and the West Delta (Figure 23).

Neomysis mercedis, historically the most abundant mysid before 1994, was the third most abundant mysid in 2016 (Figure 19). In 2016, *N. mercedis* was most abundant in summer, followed by fall (Figure 24). Although summer abundance remained much lower than it was historically, 2016 summer abundance was the highest recorded since 1996 (Figure 24). Fall abundance increased slightly in 2016 from 2015, and was the highest fall abundance since 1991 (Figure 24). Since 1996, mean seasonal abundance has been less than 1 m^{-3} in every season, rendering *N. mercedis* inconsequential as a reliable food source in most open-water areas of the upper estuary. In 2016, the highest CPUE occurred in summer in the West Delta (Figure 25).

Figure 21. Mean regional 2016 CPUE (catch-per-unit-effort in number m^{-3}) *Hyperacanthomysis longirostris* in the upper San Francisco Estuary from the Zooplankton Study's mysid samples from winter (previous December through February), spring (March through May), summer (June through August), and fall (September through November).

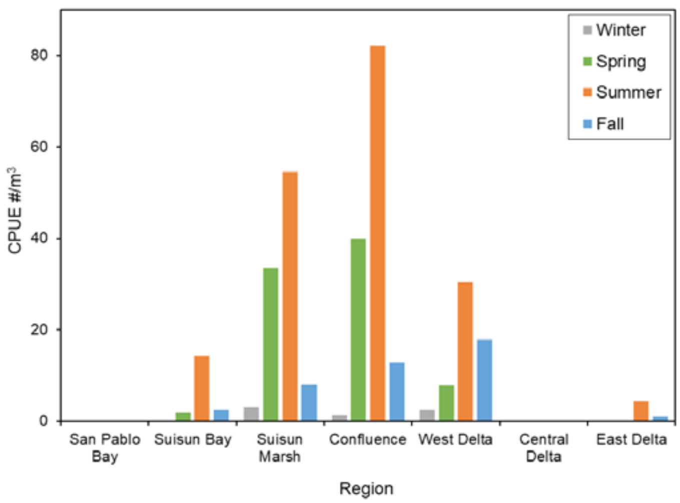
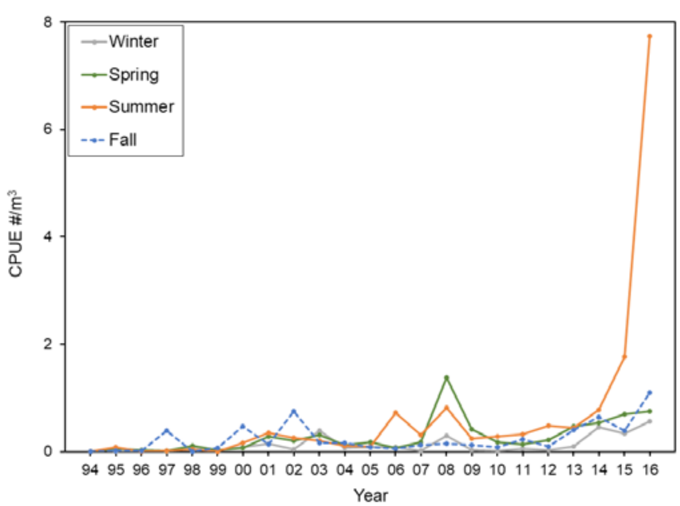


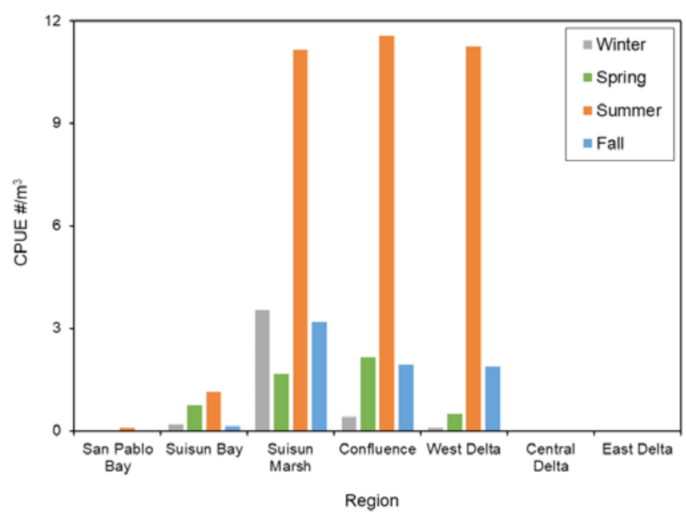
Figure 22. Seasonal mean CPUE (catch-per-unit-effort in number m^{-3}) of *Neomysis kadiakensis* in the upper San Francisco Estuary from the Zooplankton Study's mysid samples from 1994 through 2016 for winter (previous December through February), spring (March through May), summer (June through August), and fall (September through November).



Conclusion

In 2016, the Zooplankton Study observed increases in mysids, rotifers, cladocerans, and calanoid copepods, as well as a slight decrease in the cyclopoid copepod *Limnoithona tetraspina* in the upper SFE compared to 2015. During winter 2016, most copepod abundances increased to some of the highest ever recorded for winter, while mysid abundance increased slightly and other zooplankton taxa (cladocerans and rotifers) had similar winter abundance in 2015 and 2016. During spring 2016, most zooplankton abundances changed very little from 2015. In contrast, most zooplankton abundances increased in summer 2016; cladocerans and rotifers had the highest abundances observed since the 1970s and 1980s, while mysids and most copepods abundance also increased slightly. By fall 2016, abundances of most

Figure 23. Mean regional 2016 CPUE (catch-per-unit-effort in number m^{-3}) *Neomysis kadiakensis* in the upper San Francisco Estuary from the Zooplankton Study's mysid samples from winter (previous December through February), spring (March through May), summer (June through August), and fall (September through November).



zooplankton decreased from 2015, except for mysids, which increased slightly, and *Limnoithona*, which had the highest fall abundance ever recorded in 2016. The regions with the highest zooplankton CPUE in 2016 were Suisun Marsh, the Confluence, and the West and East Delta, particularly during summer.

Figure 24. Seasonal mean CPUE (catch-per-unit-effort in number m^{-3}) of *Neomysis mercedis* in the upper San Francisco Estuary from the Zooplankton Study's mysid samples from 1974 through 2016 for winter (previous December through February), spring (March through May), summer (June through August), and fall (September through November). Inset shows 1995 through 2016 on a smaller scale.

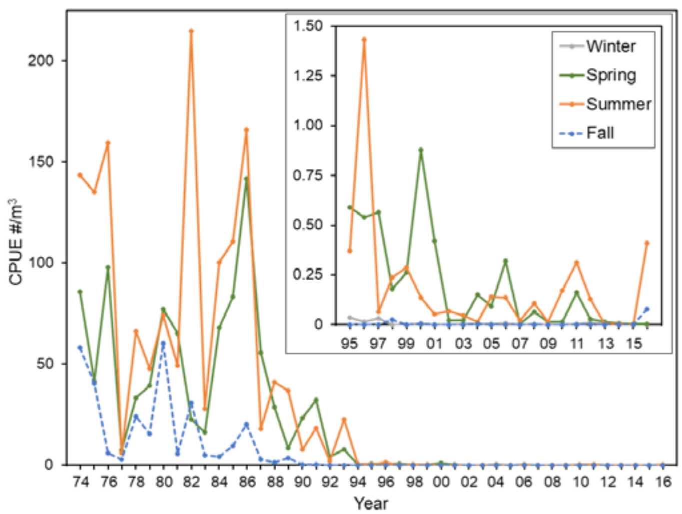
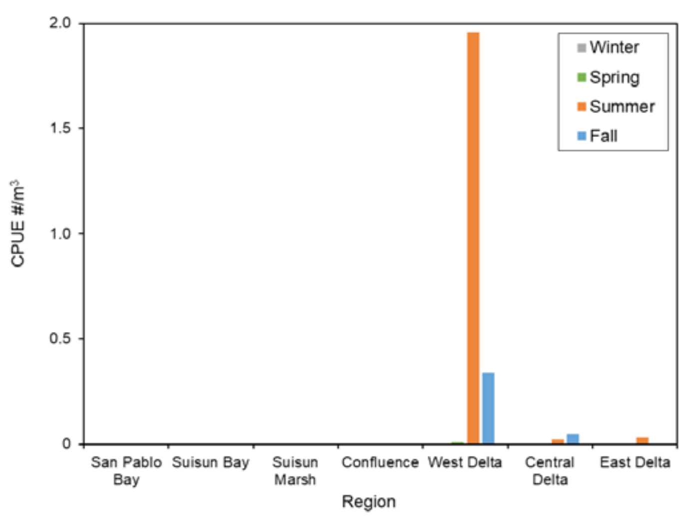


Figure 25. Mean regional 2016 CPUE (catch-per-unit-effort in number m^{-3}) *Neomysis mercedis* in the upper San Francisco Estuary from the Zooplankton Study's mysid samples from winter (previous December through February), spring (March through May), summer (June through August), and fall (September through November).



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Issue	*Article Submission Deadline*
Issue 1 (Winter)	January 15, 2019
Issue 2 (Spring)	April 15, 2019
Issue 3 (Summer)	July 15, 2019
Issue 4 (Fall)	October 15, 2019

Submit articles to Sarah Lesmeister.

2017 Status and Trends Report for Pelagic Fishes of the Upper San Francisco Estuary

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Introduction

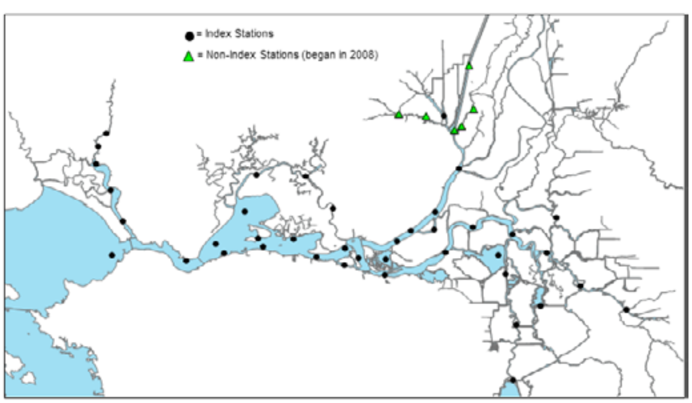
The 2017 Pelagic Fishes Status and Trends Report presents abundance trends for pelagic fishes using data from four of the Interagency Ecological Program's (IEP) long-term fish monitoring surveys: 1) 20-mm Survey, 2) Summer Townet Survey (STN), 3) Fall Midwater Trawl (FMWT), and 4) US Fish and Wildlife Service (USFWS) Beach Seine Survey (Honey et al. 2004). The Status and Trends Report also normally includes data from the San Francisco Bay Study (SFBS), however SFBS data are not included in this year's report due to data gaps resulting from vessel breakdowns. Abundance indices, as well as long-term trends in abundance and distributional information, are presented for seven 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*). Four of these species, Threadfin Shad, Delta Smelt, Longfin Smelt, and age-0 Striped Bass, rely on the upper estuary for spawning and rearing, and have undergone significant population declines (Sommer et al. 2007).

Methods

Sampling Background

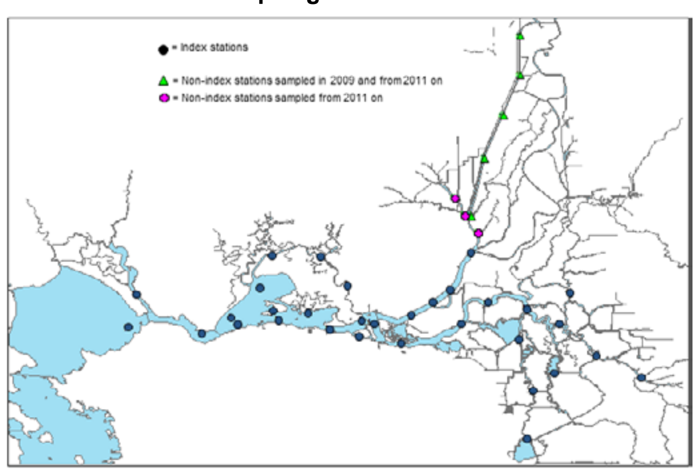
The California Department of Fish and Wildlife (CDFW) 20-mm Survey monitors distribution and relative abundance of larval and juvenile Delta Smelt throughout its historical spring range (Fig. 1). This includes the entire Delta and downstream to eastern San Pablo Bay and the lower Napa River. The survey name refers to the size of the Delta Smelt that the survey gear targets, which corresponds to the size at which Delta Smelt are readily identifiable and counted at the State Water Project and Central Valley Project fish salvage facilities. Since 1995, the 20-mm Survey has conducted surveys on alternate weeks from early March through early July, completing nine surveys per year since 2009. Three tows are conducted at each of the 47 stations (Fig. 1) using a fixed-mouth, 1,600 µm mesh net (Dege and Brown 2003). The survey added five Napa River stations in 1996. In 2008, two stations each were added in Lindsey Slough, Miner Slough, and the Sacramento River Deep Water Ship Channel (SRDWSC). A <60 mm fork length (FL) criterion is used to select length data for age-0 Delta Smelt, which are then averaged by survey for all stations sampled to determine when mean fork length reaches or surpasses 20 mm. The four surveys in which mean FL of Delta Smelt bound 20 mm (two surveys before and two after) are used to calculate the annual abundance index. From this subset of surveys, Delta Smelt catch per unit effort (CPUE) is calculated for each of the 41 index stations (Fig. 1). CPUE for each tow is calculated by dividing catch by the volume (m^3) filtered during the sample and multiplying by 10,000 to obtain a whole number. CPUE is then averaged across tows for each index station. The resulting mean station CPUE values are incremented by one and then $\log_{10}$ transformed (i.e., $\log_{10}(x+1)$). These transformed values are averaged within each survey and then the mean values are back transformed (i.e., 10^x), to return them to their original scale. Finally, one is subtracted from each value and then these values are summed across the four surveys to obtain the 20-mm Survey annual abundance index.

Figure 1. Map of 20-mm Survey stations. Index stations have been sampled since survey inception in 1995. Data collected at index stations are used to calculate survey and annual abundance indices. Non-Index stations were added to the survey in 2008 to better assess the distribution of Delta Smelt and other pelagic fishes.



The Summer Townet Survey (STN) began in 1959 and its data have been used to calculate age-0 Striped Bass indices for all years since, except 1966, 1983, 1995, and 2002. Delta Smelt indices have also been calculated for the period of record, except for 1966 through 1968. Historically, STN conducted between two and five surveys annually, depending on when the mean FL of age-0 Striped Bass exceeded 38.1mm, at which time the index could be set and sampling terminated for the year. In 2003, CDFW standardized sampling to six surveys per year, beginning in early June and continuing every other week into August (Hieb et al. 2005). STN samples 32 historic stations, one of which is located in the Napa River and is excluded from index calculations due to historically infrequent sampling. Index stations are distributed from eastern San Pablo Bay to Rio Vista on the Sacramento River and to Stockton on the San Joaquin River (Fig. 2). In 2011, STN added eight supplemental stations in the Cache Slough and SRDWSC regions to increase spatial coverage and better describe Delta Smelt range and habitat (Fig. 2). A minimum of two tows are completed at historic stations, and a third is conducted if fish of any species are caught during either of the first two tows. Three tows are conducted at the San Pablo Bay station (STN 323) regardless of catch due to the large volume of water represented by this station. Two tows are completed at supplemental stations in the Cache Slough-SRDWSC

Figure 2. Map of the Summer Townet Survey stations. Index stations have been sampled since survey inception in 1959 and their data are used for calculating survey and annual abundance indices. Non-index stations were added as indicated in the legend to better assess the distribution of Delta Smelt and other pelagic fishes.



region unless ten or more Delta Smelt are captured at during the first tow at a station. In these instances, a second tow is not completed.

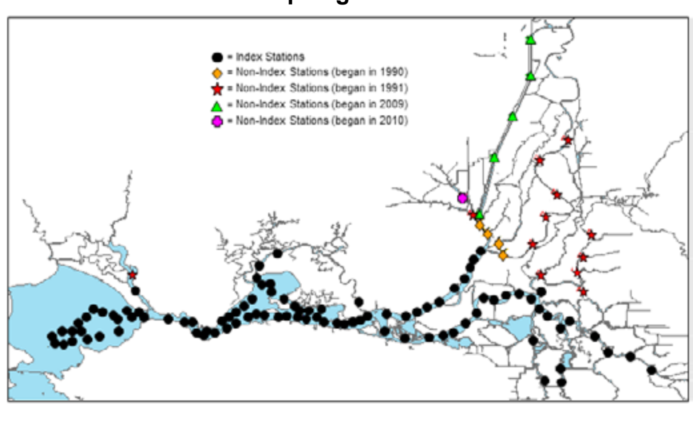
Catch per tow data from the 31 STN index stations are used to calculate annual abundance indices for age-0 Striped Bass and Delta Smelt. First, the catch of a species is summed across tows at each station. Then, the sum is multiplied by a volume-weighting factor (i.e., the estimated volume (thousand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

The Fall Midwater Trawl Survey (FMWT) began in 1967 and has been conducted in all years except 1974 and 1979. CDFW established the FMWT survey to examine age-0 Striped Bass relative abundance and distribution in the upper estuary (Stevens 1977). Later, FMWT developed abundance and distribution information for other upper-estuary pelagic fishes, including American Shad, Threadfin Shad, Delta Smelt, Longfin Smelt, and Splittail. The FMWT survey currently conducts single tows at 122 stations monthly from September through December. Trawl sampling ranges from western San Pablo Bay to Hood on the Sacramento River, and from Sherman Lake to Stockton on the San Joaquin River (Fig. 3). The annual abundance index calculation uses catch per tow data from 100 of 122 stations (Stevens 1977). The remaining 22 stations were added in 1990, 1991, 2009, and 2010 to improve understanding of Delta Smelt distribution and habitat use (Fig. 3). To calculate survey abundance indices, the 100 index stations are grouped into 17 regions. Monthly indices are calculated by averaging index-station catch-per-tow in each region, multiplying these regional means by their respective weighting factors (Chadwick 1964), and summing these products. Annual abundance indices are the sum of the four (September – December) monthly indices.

The San Francisco Bay Study (SFBS) data are not included in this year's report due to data gaps in 2017 resulting from vessel breakdowns. See Hieb et al. (2018) in this issue for fish and abundance trend information through 2016.

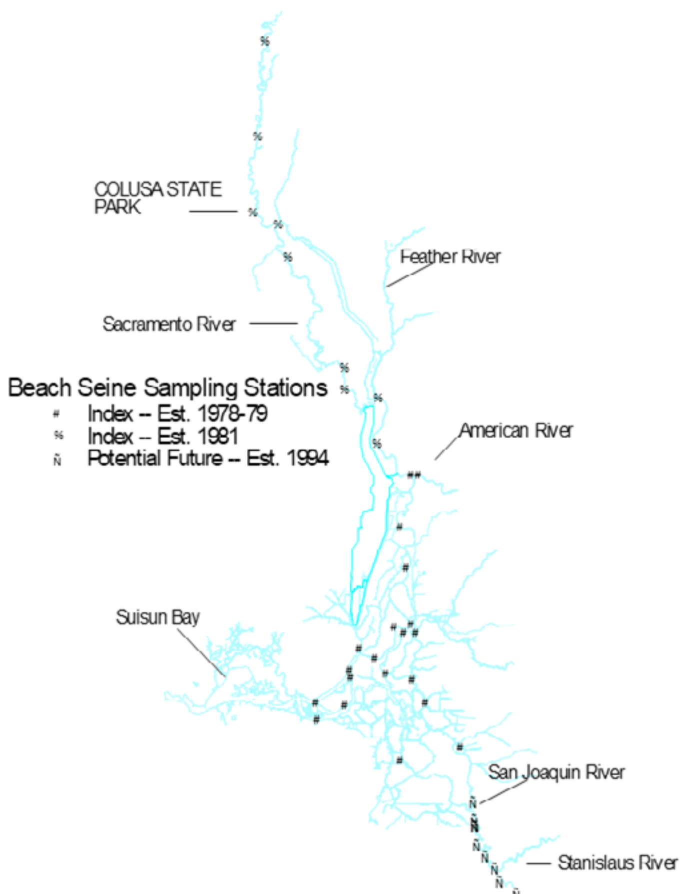
Since 1994, USFWS has conducted beach seine sampling weekly year-round at approximately 40 stations in the Delta and in the lower Sacramento and San Joaquin rivers (Brandes and McLain 2000). Data from 33 stations are used to calculate the annual age-0 Splittail abundance index (Fig. 4). These stations range from Sherman Lake to Ord Bend on the Sacramento River, and to just downstream of the Tuolumne River confluence with the San Joaquin River (Fig. 5). Hereafter, we refer to the confluence of the Sacramento and San Joaquin Rivers at Sherman Lake as the Confluence, and the Tuolumne River confluence with the San Joaquin River as the Tuolumne confluence. To calculate a juvenile splittail index, all Splittail <25 mm FL (measured individuals and proportions resulting from plus counts) and ≥85 mm in May and ≥105 mm in June (cutoffs for age-1) are removed from calculations, leaving only age-0 individuals. The 33 index stations are grouped into 10 regions. The annual index is calculated as the mean catch per m^3 for seine hauls conducted first at each station and month for the months May and June, and then across months for each sub-region. Finally, the mean catch per m^3 for each year and sub-region was summed across regions to produce the annual age-0 Splittail index.

Figure 3. Map of the Fall Midwater Trawl Survey stations. Index stations have been sampled since survey inception in 1967 and their data are used for calculating survey and annual abundance indices. Non-index stations were added as indicated in the legend to better assess the distribution of Delta Smelt and other pelagic fishes.



FMWT data were used to describe abundance trends and distribution patterns of all six fish species listed in the introduction. In normal years, SFBS data were used to describe trends for age-0 American Shad, age-0 Delta Smelt, age-0 Longfin Smelt, age-0 Splittail, and age-0 Striped Bass; however due to repeated boat breakdowns in 2016-2017, no SFBS data are reported here. STN described trends for Delta Smelt and Striped Bass. Two studies only provided single species information: the 20-mm Survey for the abundance and distribution of larval and juvenile Delta Smelt, and USFWS beach seine data for age-0 Splittail abundance and distribution. Because recent abundance indices are much lower than earlier years, inset graphs of the most recent 5 years were added to abundance graphics for greater clarity.

Figure 4. Map of USFWS beach seine survey stations. Data from 1994 through present and from the Sacramento River, the San Joaquin River and the Delta are used for age-0 Splittail annual abundance indices.



Results

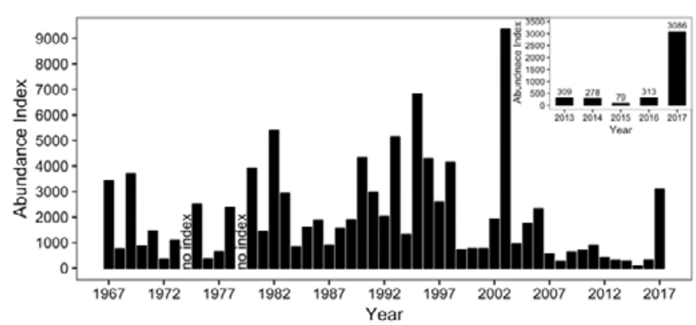
American Shad

The American Shad was introduced into the Sacramento River in 1871 (Dill and Cordone 1997). This anadromous species spawns in the Sacramento, Feather, Yuba and American rivers from April through June. Juveniles can be found in freshwater areas within the Delta from late May through summer and into fall. From summer through fall, juveniles migrate to the ocean where they mature. Males reach maturity at 3 to 4 years whereas females mature slightly later at 4 to 6 years (Able and Fahay 1998). A large proportion of the spawning population in the Delta succumbs to natural mortality shortly after spawning; however, spent females have been observed downstream of spawning sites indicating some survival (Stevens 1966). Surveys conducted in the Susquehanna River, in the Northeastern United States, suggest that post-spawning mortality is higher among females than males (Walburg and Nichols 1967).

The 2017 FMWT index for American Shad was 3086, the highest index since 2003 and an 886% increase from the 2016 FMWT index value (Fig. 5). American Shad FMWT index value peaked at 9360 in 2003. 2017 was the first index after 2003 to exceed 25% of the 2003 index and the majority of years since have failed to exceed 10% of the record high.

Throughout the 2017 FMWT sampling season, 2357 American Shad were collected at index stations throughout the upper estuary and Delta. In September, American Shad were collected at index stations in San Pablo Bay (n=47), Carquinez Strait (n=7), Suisun Bay (n=260), the lower Sacramento River (n=5), the lower San Joaquin River (n=2), and the southern Delta (n=1).

Figure 5. Annual abundance indices of American Shad from the Fall Midwater Trawl Survey, 1967-2017 (all sizes). Inset graphics show most recent 5 years in more detail.



American Shad were collected at non-index stations in Cache Slough (n=4), the SRDWSC (n=36), the Mokelumne River (n=1), Steamboat Slough (n=1), and the Sacramento River north of Isleton (n=2). In October, they were collected at index stations in San Pablo Bay (n=34), Carquinez Strait (n=17), Suisun Bay (n=174), the lower Sacramento River (n=96), the lower San Joaquin River (n=23), and the southern Delta (n=3). American Shad were collected at non-index stations in the Napa River (n=1), Cache Slough (n=4), Mokelumne River (n=9), and the SRDWSC (n=11). November catches were from index stations in San Pablo Bay (n=23), Carquinez Strait (n=131), Suisun Bay (n=890), the lower Sacramento River (n=327), and the lower San Joaquin River (n=109). American Shad were collected at nonindex stations in the Napa River (n=3), Steamboat Slough (n=5), Sacramento River north of Isleton (n=3), and the SRDWSC (n=48). In December, American Shad were collected at index stations in San Pablo Bay (n=10), Carquinez Strait (n=38), Suisun Bay (n=121), the eastern Delta (n=4), the lower Sacramento River (n=17), and the lower San Joaquin River (n=18). American Shad were collected at non-index stations in the SRDWSC (n=11).

Threadfin Shad

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

The FMWT Threadfin Shad index for 2017 was 291, making it the 7th lowest index on record (Fig. 6). Abundance was highest during the late 1990s and early 2000s, with the two highest indices occurring in 1997 (15,267) and 2001 (14,401).

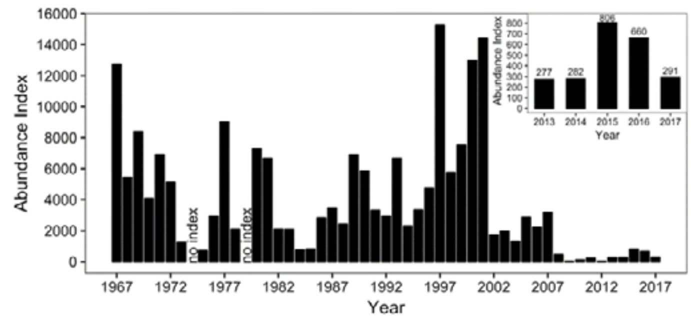
During FMWT, 262 Threadfin Shad were collected at index stations across the entire sampling region from San Pablo Bay to the Sacramento and San Joaquin rivers and the south Delta. In September, Threadfin Shad were collected at index stations in Suisun Bay (n=9) and the lower Sacramento River (n=3). Threadfin Shad were collected at non-index stations in the SRDWSC (n=433). In October, fish were collected at index stations in Carquinez Strait (n=1), Suisun Bay (n=19), the lower Sacramento River (n=36), and the lower San Joaquin River (n=4). Threadfin Shad were collected at non-index stations in Cache Slough (n=1) and the SRDWSC (n=490). Catches in November were found at index stations in Carquinez Strait (n=3), Suisun Bay (n=66), the lower Sacramento River (n=13), and the lower San Joaquin River (n=1). Threadfin Shad were collected at non-index stations in the Napa River (n=1) and the SRDWSC (n=366). In December, Threadfin Shad were collected at index stations in Carquinez Strait (n=8), Suisun Bay (n=42), the lower Sacramento River (n=22), and the lower San Joaquin River (n=35). Threadfin Shad were collected at non-index stations in the SRDWSC (n=835).

Delta Smelt

The Delta Smelt is a small (<90 mm FL) osmerid endemic to the San Francisco Estuary. In the 1980s, Delta Smelt underwent a severe population decline (Figs. 7 B-C) and in 1993 was listed as a threatened species by state and federal agencies. It is considered environmentally sensitive due to an annual life cycle, dependence on a spatially-limited oligohaline to freshwater habitat, and low fecundity (1,200 to 2,600 eggs per female on average; (Moyle et al. 1992)). Low fecundity appears to be offset by the ability of females to produce multiple clutches in a single spawning season (Bennett 2005; Damon et al. 2017).

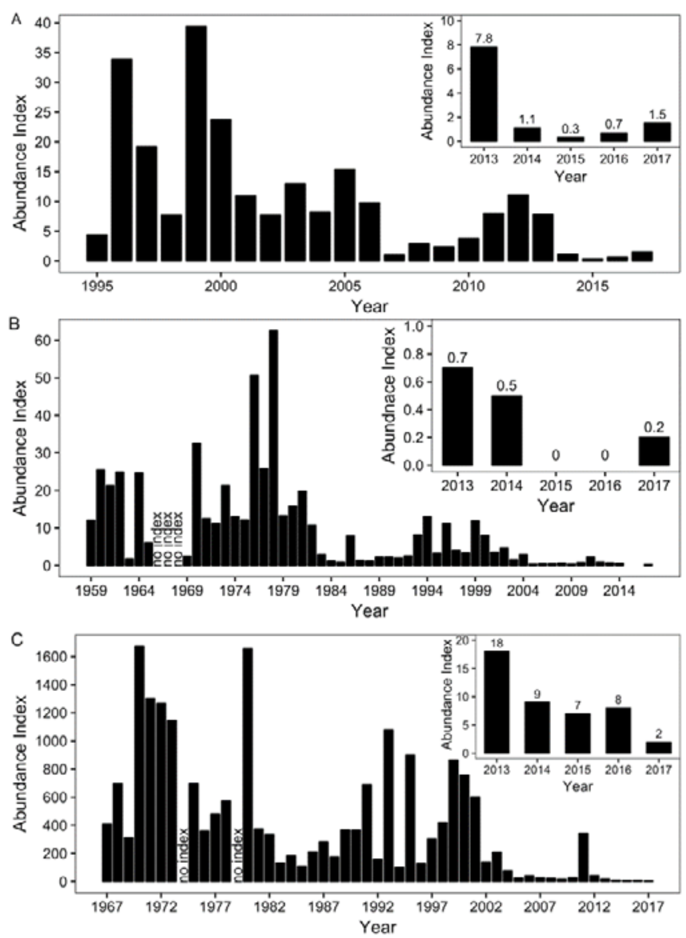
The 20-mm Delta Smelt index for 2017 was 1.5, the highest on record since 2013 (Fig. 7A). The 2017 index was calculated from surveys 3 – 6, during which time

Figure 6. Annual abundance indices of Threadfin Shad from the Fall Midwater Trawl Survey, 1967-2017 (all sizes). Inset graphics show most recent 5 years in more detail.



79 Delta Smelt were collected from index stations. Over the course of the 2017 20-mm surveys, a total of 184 Delta Smelt were collected, with the majority collected at single stations in the lower SRDWSC (n=80) and the Napa river (n=80). Catches during mid March (survey 1) were low (n=9), Delta Smelt were collected from the Lower Sacramento River (n=1), SRDWSC (n=6), and Montezuma Slough (n=2). During late March (survey 2), seven Delta Smelt were caught. Catches were from index stations in Napa river (n=5) and non-index stations in Cache Slough (n=1) and the SRDWSC (n=1). In mid April (survey 3), Delta Smelt were collected from index stations in Napa river (n=6), and non-index stations in the SRDWSC (n=4). Late April (survey 4) Delta Smelt were found in index stations in Montezuma Slough (n=1), Napa river (n=29), and Suisun Bay (n=1). They were also collected from non-index stations in the SRDWSC (n=13). In early May (survey 5) Delta Smelt were collected from index stations in Montezuma Slough (n=1), Napa river (n=33), and Suisun Bay (n=1). Fish from non-index stations were collected from the SRDWSC (n=9). The late May survey (survey 6) found Delta Smelt at index stations in Napa River (n=6) and Suisun Bay (n=1); while non-index catch was solely from the SRDWSC (n=35). Survey 7 in early June showed signs of tapering off, with only seven Delta Smelt caught. There fish were from index stations in Napa river (n=1) and Suisun Bay (n=2), as well as non-index stations in SRDWSC (n=4). Catch in late June (survey 8) was only from index stations in Suisun Bay (n=4) and a single non-index station in the SRDWSC (n=8). The last survey in early July (survey 9) caught only a single Delta Smelt at a station near Chipps Island.

Figure 7. Annual abundance indices of Delta Smelt from: A) 20-mm Survey (larvae and juveniles; 1995-2017); B) Summer Townet Survey (juveniles; 1959-2017); C) Fall Midwater Trawl Survey (sub-adults; 1967-2017). Inset graphics show most recent 5 years in more detail.



The STN Delta Smelt index for 2017 was 0.2. It is the third-lowest index on record and follows two years in which the index was zero (Fig. 7B). Catch during the two June surveys used to calculate the index consisted of 6 fish. During the first survey, a single Delta Smelt was collected in Grizzly Bay (n=1). During the second survey, Delta Smelt were collected in Grizzly Bay (n=3) and two were collected in Suisun Bay (n=2). An additional Delta Smelt was collected at a supplemental station in the SRDWSC during the second survey (n=1).

The FMWT Delta Smelt index for 2017 was 2, the lowest in FMWT history (Fig. 7C). In 2017, two Delta Smelt were collected at index stations in October. One was from Suisun Bay and the other from the confluence of Sacramento and San Joaquin Rivers. No Delta Smelt were collected in September, November, or December. This year's catch is consistent with the low catches and limited geographic distribution seen in recent years.

Longfin Smelt

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

The 2017 FMWT Longfin Smelt index was 141, the highest value since 2013 (Fig. 8). Longfin Smelt abundance was highest in the late 1960s and peaked again in the early 1980s. After a brief increase in the late 1990s, abundance dropped again and has remained relatively low for most recent years.

Seventy Longfin Smelt were caught in total during the 2017 FMWT survey. None were caught at non-index stations throughout the survey. In September, one Longfin Smelt was collected at index stations in San Pablo Bay. For October, Longfin Smelt were collected at index stations in San Pablo Bay (n=3), Carquinez Strait (n=4), Suisun Bay (n=5), and the lower San Joaquin River (n=1). During November, Longfin Smelt were collected at index stations in San Pablo Bay (n=3), Carquinez Strait (n=3), Suisun Bay (n=3), and the lower Sacramento River (n=1). In December, Longfin Smelt were collected at index stations in San Pablo Bay (n=7), Carquinez Strait (n=9), Suisun Bay (n=26), the lower Sacramento River (n=1), and lower San Joaquin River (n=3).

Splittail

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

The 2017 USFWS Beach Seine index for age-0 Splittail was 13, a three-fold increase over the previous year (Fig. 9A). Regional abundance was highest in the Delta and San Joaquin River regions, and low in the Sacramento River region.

The 2017 FMWT Splittail index for all ages was 1, continuing a trend of very little to no catch of Splittail in FMWT (Fig. 9B). The Splittail FMWT index tends to be low or zero except in relatively wet years, such as 2011, when age-0 fish tend to be abundant. However, this was not the case for 2017, which was a very wet year. FMWT operates in water >2 m deep, whereas Splittail, particularly age-0 fish, appear to primarily inhabit water <2 m deep. Thus, during most years, FMWT data probably does not accurately reflect trends in age-0 Splittail abundance. However, FMWT does effectively detect strong year classes, such as the one in 1998 and the most recent one in 2011.

Figure 8. Annual abundance indices of Longfin Smelt from Fall Midwater Trawl Survey (all sizes; 1967-2017). Inset graphics show most recent 5 years in more detail.

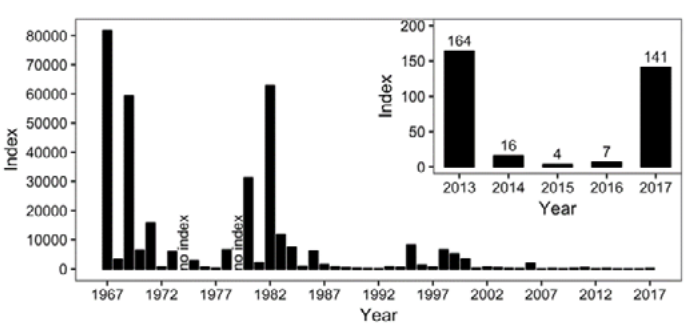
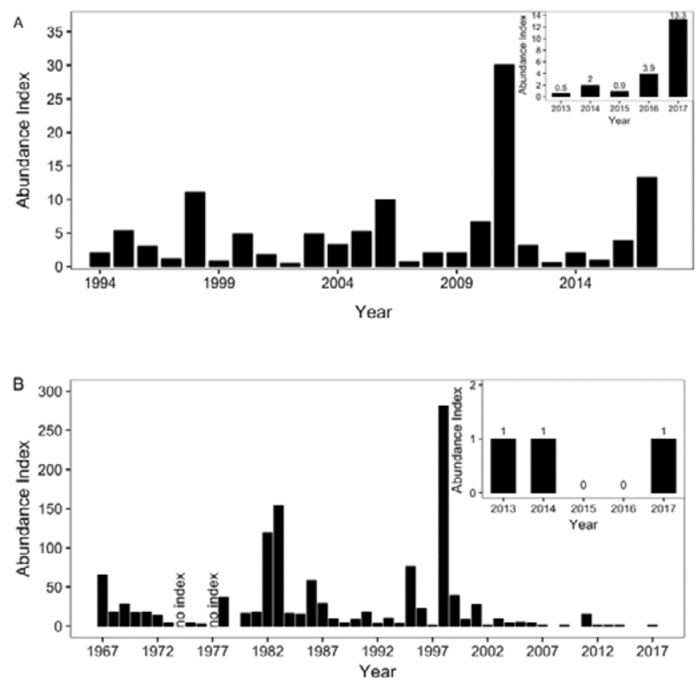


Figure 9. Annual abundance indices of Splittail from: A) USFWS Beach Seine Survey (juveniles ≥ 25mm), 1994-2017; B) Fall Midwater Trawl Survey (all sizes), 1967-2017. Inset graphics show most recent 5 years in more detail.



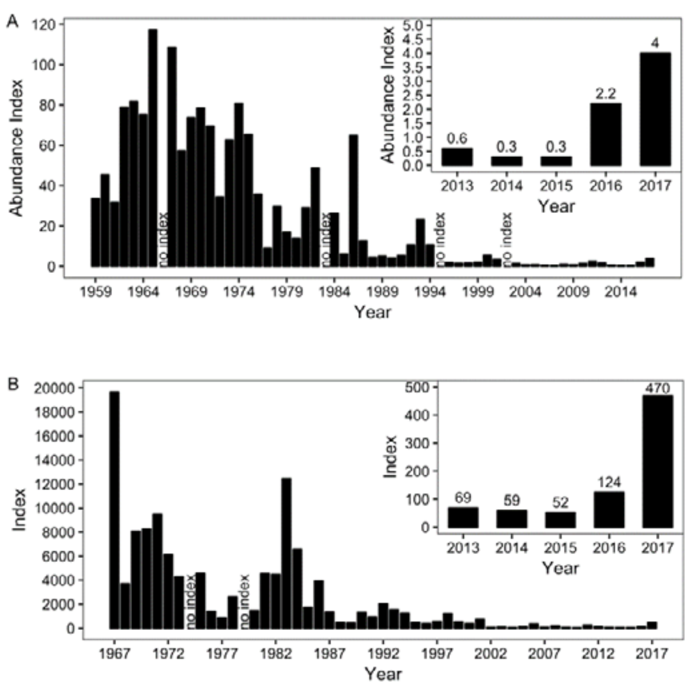
One Splittail was collected at an index station in December from Suisun Bay. No other Splittail were collected in September, October, or November from index or non-index stations.

Age-0 Striped Bass

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

Both STN and FMWT indices showed declines in age-0 Striped Bass abundance in the mid-1970s (Figs. 10A & 10B). Abundance dropped further in the late 1980s and again in the 1990s, and has not approached historic numbers over the last 15 years. Stevens et al. (1985) hypothesized that four factors were responsible for the low abundance: 1) the adult population was too low to maintain adequate egg production; 2) planktonic food production has decreased to a point that is too low to sustain historic population levels; 3) loss to entrainment in water diversions; and 4) pollution in the form of pesticides, petrochemicals, and other toxic substances. More recently, Sommer et al. (2011) argued that age-0 Striped Bass distribution had shifted almost exclusively to shoal and shoreline areas, which are under-sampled by CDFW trawl surveys. While a shift of this nature would reduce catch and thus reduce abundance indices, Sommer et al. (2011) cautioned against attributing low values solely to a change in habitat use.

Figure 10. Annual abundance indices of age-0 Striped Bass from: A) Summer Townet, 1959-2017 (all sizes); B) Fall Midwater Trawl Survey (all sizes), 1967-2017. Inset graphics show most recent 5 years in more detail.



The 2017 STN index for age-0 Striped Bass was 4, an 81% increase over the previous year and its highest value since 2000 (Fig. 10A). In 2017, age-0 Striped Bass reached an average fork length of 38.1 mm on August 6th, between survey 4 (July 24-26) and survey 5 (August 7-9). In survey 4, 212 age-0 Striped Bass were collected from index stations, which include Suisun Bay (n=86), at the confluence of the Sacramento and San Joaquin Rivers (n=17), in the lower Sacramento River (106), in the lower San Joaquin River (n=2) and in the South Delta (n=1). One additional fish was collected at a non-index station in Cache Slough. In survey 5, 167 age-0 Striped Bass were collected from index stations from Suisun Bay (n=62), at the confluence of the Sacramento and San Joaquin Rivers (n=15), and in the lower Sacramento River (n=90).

During the entire 2017 STN season, a total of 1890 age-0 Striped Bass were collected from locations ranging from the Suisun Bay to the lower Sacramento and San Joaquin rivers, as well as in the SRDWSC and the south Delta. Catches were consistently concentrated in Montezuma Slough (n=997), and to a lesser extent the Suisun Bay (n=416). Age-0 Striped Bass were also collected from non-index stations in Cache Slough (n=4) and the SRDWSC (n=10) as well as index stations in the Confluence (n=73), South Delta (n=15), San Joaquin river (n=20), and the Sacramento River (n=355). Catch declined gradually over time from 512 in survey 1 to 86 in survey 6.

The 2017 FMWT index for age-0 Striped Bass was 470, the highest value since 2001 (Fig. 10B). The index was highest at the inception of the survey in 1967, peaked again in 1971, and a third time in 1983. In the later 1980s, age-0 Striped bass abundance declined and in the early 2000s it dropped and has remained low since then.

Three hundred ninety-nine age-0 Striped Bass were collected at FMWT index stations spanning from the Carquinez Strait to the lower Sacramento and San Joaquin rivers and the south Delta. In September, age-0 Striped Bass were collected from Suisun Bay (n=44) and the lower Sacramento River (n=7). Two Striped Bass were collected at non-index stations in the SRDWSC. In October, they were collected in Carquinez Strait (n=5), Suisun Bay (n=89), and the lower Sacramento River (n=15). No Striped Bass were collected at non-index stations. In November, age-0 Striped Bass were collected from San Pablo Bay (n=1), Carquinez Strait (n=25), Suisun Bay (n=64), the lower Sacramento River (n=9), and the lower San Joaquin River (n=1). At non-index stations, Striped Bass were collected in the SRDWSC (n=1) and the Napa River (n=1). In December, fish were caught in San Pablo Bay (n=1), Carquinez Straight (n=6), Suisun Bay (n=104), the eastern Delta (n=1), the lower Sacramento River (n=8), and the lower San Joaquin River (n=19). At non-index stations, Striped Bass were collected in Napa River (n=1) and the SRDWSC (n=4). Age-0 Striped Bass were conspicuously absent from Cache Slough, given the high catch there in 2014 (n=44).

Wakasagi

The Wakasagi (*Hypomesus nipponensis*) is native to Japan and was purposely introduced as a forage fish in lakes and reservoirs in 1959 (Dill and Cordone 1997, Moyle 2002). Wakasagi were first detected in the San Francisco Estuary in 1990, and are closely related to the native Delta Smelt (*H. transpacificus*) (Moyle 2002). Similar to Delta Smelt, Wakasagi are also planktivorous, reach maturity by one year, and spawn in late winter to spring (Moyle et al 1992, Moyle 2002). Wakasagi have been shown to have higher salinity, higher high temperature, and lower low temperature tolerances than Delta Smelt (Swanson et al 2000). Despite having a higher salinity tolerance than Delta Smelt, Wakasagi are typically found in freshwater areas in the SFE, with the potential to move downstream during wet years.

In 2017, Wakasagi (N=76) were caught by all CDFW long-term monitoring projects reported here (20MM Survey, STN, FMWT) (Table 1, 2, and 3), as well as by surveys conducted by the Hobbs Lab at UC Davis. The majority of the Wakasagi caught were in the upper Sacramento River or the Deep Water Ship Channel (SDWSC) (n=64), and ranged in fork length from 10-102 millimeters. Wakasagi were also found in areas further downstream such as the Napa River (n=4, FL ranged 9-50mm), Sonoma Creek (n=1, FL= 75mm), Suisun Bay (n=6, FL= 6-19mm), and the west delta (n=1, FL= 60mm). This trend is similar to previous wet years, such as 2011, when Wakasagi were caught in Suisun Bay by 20 MM (n=5, Table 1), FMWT (n=4, Table 2), and STN surveys (n=2, Table 3). Periods with high rain flow during years that are not classified overall as “wet” could also

Table 1. Wakasagi regional catch in the 20-mm Survey from 1995-2017. Stations in the upper Sacramento River region were added to the survey in 2008. Regions with no Wakasagi catch during the 1995 to 2017 period are not shown.

Year	*San Pablo Bay*	*Napa River*	*Suisun Bay*	*Confluence*	*Lower Sac River*	*Cache Slough*	*SDWSC*	*Upper Sac River*	*South Delta*	*Lower San Joaquin River*
1995	1	0	0	0	1	0	0	no sample	0	0
1996	1	2	6	1	3	0	0	no sample	1	1
1997	0	0	2	1	0	1	0	no sample	0	0
1998	0	0	0	0	0	2	0	no sample	0	0
1999	0	0	1	4	8	0	5	no sample	0	5
2000	0	0	23	5	22	7	4	no sample	2	3
2001	0	0	0	0	0	2	0	no sample	0	0
2002	0	0	0	0	2	0	0	no sample	3	0
2003	0	0	2	0	0	0	1	no sample	0	0
2004	0	0	1	0	4	0	0	no sample	1	0
2005	0	0	2	0	1	0	3	no sample	0	0
2006	1	2	2	1	0	0	0	no sample	0	1
2007	0	0	0	1	0	0	1	no sample	0	0
2008	0	0	0	0	0	0	3	3	0	0
2009	0	0	8	0	14	2	24	45	0	3
2010	0	0	0	0	0	0	2	2	0	1
2011	0	0	5	1	7	1	6	17	0	1
2012	0	0	0	1	4	0	2	14	0	1
2013	0	0	3	5	5	1	12	13	3	0
2014	0	0	0	0	0	0	0	1	0	0
2015	0	0	0	0	0	0	5	0	0	0
2016	0	0	2	1	1	7	5	18	0	0
2017	0	3	6	1	0	0	55	3	0	0

result in Wakasagi being pushed downstream, however, it was not examined further here.

With higher salinity and temperature tolerances than Delta Smelt, it is unknown why Wakasagi is not found in greater abundance throughout the estuary (Swanson et al 2000). Wakasagi are generally found downstream in years with high flow, which could indicate that individuals are being pushed into those areas, as opposed to there being established populations. Wakasagi are capable of hybridizing with Delta Smelt and hybrids of the species have been found in the Yolo Bypass and lower Sacramento River, where both species are found (Benjamin et al 2018). During wet years, the areas where Wakasagi and Delta Smelt co-occur, and therefore, the chance of hybridization is increased. This could have implications for accurate species identification and management of Delta Smelt.

Conclusion

With the record wet-year in 2017, annual abundance indices in showed a mixed level of improvement from the low values observed for these seven fish species over the past several years. For FMWT, age-0 Striped Bass, Longfin Smelt, and American Shad had the highest index in the past 16, 4, and 14 years, respectively. Unfortunately, Delta Smelt did not show any signs of recovery like the previous wet water year (2011). Overall, while some species exhibited an increase in recent years, their current levels are only a fraction of the abundance exhibited

Table 2. Wakasagi regional catch from the Summer Townet Survey from 1995-2017. Stations in the Sacramento Deep Water Ship Channel (SDWSC) region were added in 2009. Regions with no Wakasagi catch during the 1995 to 2017 are not shown.

Year	Suisun Bay	Lower Sac River	Cache Slough	SDWSC	South Delta	Lower San Joaquin River
1995	0	1	no sample	no sample	0	0
1996	0	1	no sample	no sample	1	0
1997	0	0	no sample	no sample	0	0
1998	2	0	no sample	no sample	0	0
1999	0	0	no sample	no sample	0	0
2000	0	1	no sample	no sample	1	0
2001	0	0	no sample	no sample	0	0
2002	0	0	no sample	no sample	0	0
2003	0	0	no sample	no sample	0	0
2004	0	0	no sample	no sample	0	0
2005	0	0	no sample	no sample	0	0
2006	0	0	no sample	no sample	0	0
2007	0	0	no sample	no sample	0	0
2008	0	0	no sample	no sample	0	0
2009	4	1	no sample	no sample	0	0
2010	0	0	no sample	no sample	0	0
2011	2	0	4	9	0	0
2012	0	0	0	4	0	1
2013	0	2	0	8	0	0
2014	0	0	0	1	0	0
2015	0	0	0	0	0	0
2016	0	0	0	0	0	0
2017	0	0	0	1	0	0

Table 3. Wakasagi regional catch from the Fall Midwater Trawl Survey from 1995-2017. Stations in the Sacramento Deep Water Ship Channel (SDWSC) region were added in 2009. Regions with no Wakasagi catch during the 1995 to 2017 period are not shown.

Year	Suisun Bay	Lower Sac River	Cache Slough	SDWSC
1995	0	3	0	no sample
1996	1	0	0	no sample
1997	1	0	0	no sample
1998	0	0	0	no sample
1999	0	0	0	no sample
2000	0	0	3	no sample
2001	0	1	0	no sample
2002	0	0	0	no sample
2003	0	0	0	no sample
2004	0	0	0	no sample
2005	0	0	0	no sample
2006	0	0	0	no sample
2007	0	0	0	no sample
2008	0	0	0	no sample
2009	1	0	0	8
2010	0	0	1	8
2011	4	0	3	9
2012	0	0	0	1
2013	0	0	0	2
2014	0	0	0	2
2015	0	0	0	5
2016	0	1	0	6
2017	0	0	0	5

through the 1990s and into the early 2000s. The low catches of Delta Smelt indicate that population size may be near the threshold of detection for most life stages. Given that abundance indices from these studies have specific management implications, index values of "0" have been and will continue to be problematic. Catches in the south Delta also continue to decline. For example, during the entire 2017 FMWT season, only 11 tows at 8 stations yielded fish of any species in the south Delta (3 Striped Bass, 18 American Shad, and 1 Redear Sunfish). Future reviews should look at changes in regional abundance in more detail.

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Christina Burdi, California Department of Fish and Wildlife, Lead Editor
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State Water Resources Control Board
U.S. Bureau of Reclamation
U.S. Army Corps of Engineers

California Department of Fish and Wildlife
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