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Zooplankton Monitoring 2010

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Introduction

The Zooplankton Study has estimated the abundance of zooplankton taxa in the upper San Francisco Estuary, since 1972 as a means of assessing trends in fish food resources. The study also detects and monitors zooplankton recently introduced to the estuary and determines their effects on native species. Three gear types are used: 1) a pump for sampling microzooplankton <1.0 mm long, including rotifers, copepod nauplii, and adult copepods of the genus *Limnoithona*; 2) a modified Clarke-Bumpus (CB) net for sampling mesozooplankton 0.5-3.0 mm long, including cladocerans, copepodids (immature copepods), and adult copepods; and 3) a macrozooplankton net for sampling zooplankton 1-20 mm long, including mysid shrimp. Here seasonal abundance indices are presented from 1974 through 2010 for a select group of the most common copepods, cladocerans, rotifers, and mysids.

Methods

During 2010, sampling occurred monthly from January through December at 22 stations, including 12 core stations (i.e., stations sampled consistently since study inception in 1972) and 2 floating entrapment zone (EZ) stations located at bottom electrical conductivity of 2 and 6 mS/cm (about 1 and 3 ‰). The study area extends from eastern San Pablo Bay through the Delta and the station map can be viewed at http://www.dfg.ca.gov/delta/data/zooplankton/stations.asp. Indices presented here were calculated using 16 stations: the 12 core stations, the 2 EZ stations, and 2 additional stations sampled consistently since 1974 (Suisun Slough station S42 and Disappointment Slough station MD10). Reports published prior to 2007 used data from 1972 forward that included only the 12 core stations and 2 EZ stations. Since this report utilizes data from 2 additional stations, indices start in 1974 and may be slightly different than those reported prior to 2007. Overall trends remain the same.

Data were grouped into 3 seasons: 1) spring, March through May, 2) summer, June through August, and 3) fall, September through November. January, February, and December were not always sampled historically and therefore were not used for long-term trend analyses. Abundance indices were calculated as the mean number of each taxon per cubic meter of water (reported as catch-per-unit effort, CPUE) by gear, season, and year for the 16 stations. Relative calanoid copepod abundance for each season of 2010, including winter, which was December 2009 through February 2010, used data from all 22 stations sampled. Similar to the 2004 through 2009 Status and Trends reports, indices reported below were separated by gear type and taxon, whereas pre-2004 reports combined the CB and pump data for each taxon into a single index.

Copepods

Both congeners of the cyclopoid copepod genus *Limnoithona* inhabit the upper estuary: *L. sinensis,* first recorded in 1979, and *L. tetraspina*, first recorded in 1993. In 1993, *L. tetraspina* mostly supplanted the historically common and slightly larger *L. sinensis,* and numerically became the dominant copepod species in the upper estuary. *L. tetraspina* is common in both brackish and freshwater. As an ambush predator that feeds on motile prey (Bouley and Kimmerer 2006), *L. tetraspina* may have benefited from the phytoplankton species composition change described by Brown 2009 from non-motile diatoms to motile flagellates. Despite high densities of *L. tetraspina* 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). Both pump and CB net indices are presented here because *L. tetraspina* is not completely retained by the CB net, especially in summer and fall when adults are smaller than in winter and spring. Pump *L. tetraspina* abundance decreased in 2010 from 2009 in all seasons (Figure 1), whereas CB abundance decreased in spring and summer, but increased in fall. In 2010, spring pump abundance was the lowest since 1994, while summer pump abundance was the lowest since 2000 (Figures 1A and 1B). Fall 2010 pump abundance decreased from 2009 and was slightly lower than the fall average from 1999 through 2009 (Figure 1C). *L. tetraspina* was most abundant during late summer and early fall 2010 in the lower Sacramento River, Suisun Marsh, and Suisun Bay. In 2010, peak densities of *L. tetraspina* occurred in July and August in eastern Suisun Bay (52,236 m^{-3}). *L. sinensis* continued to be collected in very low numbers in 2010.

Eurytemora affinis, a calanoid copepod introduced to the estuary before monitoring began, was once a major food for larval and juvenile fishes of many species and adults of planktivores, such as delta smelt and threadfin shad. It is found throughout the upper estuary in every season and is most abundant in salinities less than 6 ‰. *E. affinis* abundance declined in all seasons since monitoring began, with the sharpest downturns during summer and fall of the late-1980s (Figure 2), subsequent to the introductions of the overbite clam, *Corbula amurensis*, and the calanoid copepod *Pseudodiaptomus forbesi*. Prior to these introductions, *E. affinis* abundance was usually highest during summer; however, since 1987 abundance has been highest in spring and dropped abruptly in summer, when both *P. forbesi* abundance and *C. amurensis* grazing rates increase. In 2010, *E. affinis* was the fifth most abundant calanoid copepod in the study area across all months. Abundance was highest in spring, when it accounted for 9% of the total calanoid copepod CPUE (Figure 3). *E. affinis* abundance decreased in spring 2010 from 2009, but increased in summer and fall. In 2008, spring abundance was the highest since 1994, but declined in both 2009 and 2010, with 2010 abundance the lowest since monitoring began (Figure 2A). Summer and fall *E. affinis* abundance increased in 2010 and both were among the highest abundances in recent years (Figures 2B and 2C). *E. affinis* was common in Suisun Marsh from January through June, and in the eastern Delta January through May. After a summer decline, densities increased in the eastern Delta from September through November. In Suisun Marsh, densities did not increase from their seasonal low until November and December. In 2010, *E. affinis* abundance peaked in May in eastern Suisun Bay (536 m^{-3}) and Suisun Marsh (371 m^{-3}), and also in the eastern Delta in January (378 m^{-3}) and November (358 m^{-3}).

Pseudodiaptomus forbesi is an introduced freshwater calanoid copepod first detected in the upper estuary in 1988. By 1989, *P. forbesi* summer and fall abundance was comparable to *E. affinis* before its decline (Figure 2). Although *P. forbesi* abundance has declined slightly since its introduction, it remained relatively abundant in summer and fall compared to other copepods. In 2010, *P. forbesi* was the most abundant calanoid copepod in the study area across all months. Relative abundance peaked in summer, when it accounted for 63% of the total calanoid copepod CPUE (Figure 3). Spring abundance has always been highly variable and decreased slightly in 2010 from 2009 (Figure 2A). Summer and fall abundance increased slightly in 2010 from 2009 (Figures 2B and 2C). During summer and fall 2009, *P. forbesi* was common in all regions upstream of Suisun Bay and most abundant in the San Joaquin River and the eastern Delta. The highest density was in July in Frank's Tract in the South Delta, where the CPUE was 5,822 m^{-3}.

Several species of the native calanoid copepod genus *Acartia* are abundant in San Pablo Bay and expand their range into Suisun Bay and the western Delta as salinity increases seasonally and annually. Conversely, their affinity for higher salinities is sufficiently strong that their distribution shifts seaward of the sampling area during high-outflow events, resulting in low seasonal and annual abundance. In 2010, *Acartia* was the second most abundant calanoid copepod in the study area based on mean CPUE across all months. Relative abundance peaked in winter, when *Acartia* accounted for 80% of the total calanoid copepod CPUE (Figure 3). *Acartia* abundance declined in spring and summer 2010 from 2009, for the third year in a row, but increased slightly in fall (Figure 4). The higher spring outflow in 2010 resulted in lower *Acartia* abundance, similar to that seen in the higher outflow springs of 2004 through 2006 (Figure 4A). The lowest summer abundances corresponded with the highest outflow years, and 2010 summer abundance was similar to the most recent higher outflow summers (Figure 4B). By fall 2010, outflow was much lower than during spring and summer, which allowed abundance to increase slightly in 2010 from 2009 (Figure 4C). *Acartia* densities were high throughout the year in San Pablo Bay with a peak in January (4,877 m^{-3}). *Acartia* was also found in Carquinez Strait throughout the year with a peak in January (6,349 m^{-3}).

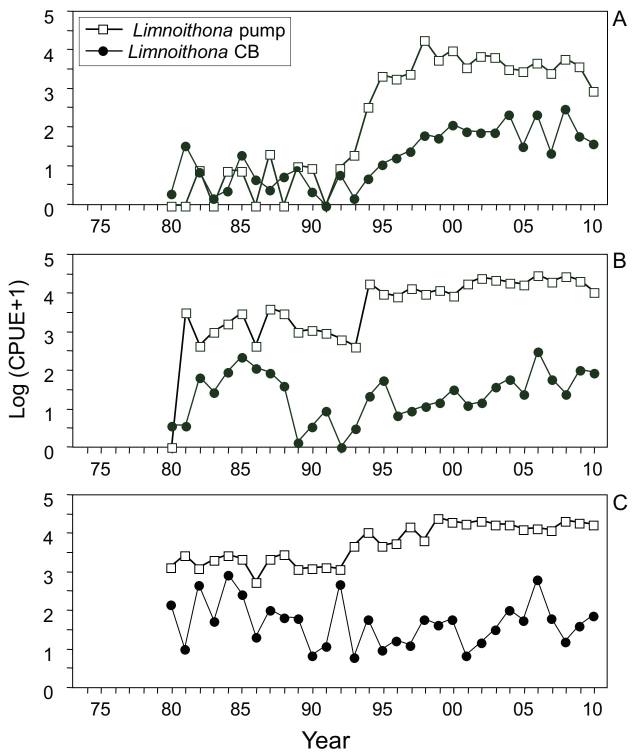

Figure 1 Abundance of Limnoithona tetraspina and L. sinensis combined (Log of mean catch*m^{-3}+1) from the pump and CB net in spring (A), summer (B), and fall (C), 1974 - 2010.

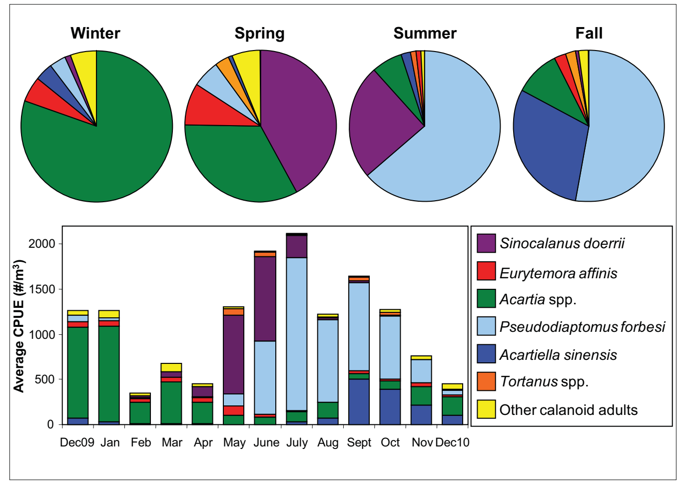

Figure 3 Relative abundance of the most common calanoid copepods (percent mean catch*m^{-3}) from the CB net from all stations by seasons and by months in 2010. Seasonal pie charts include winter (December 2009-February 2010), spring (March-May 2010), summer (June-August 2010), and fall (September-November 2010). Bar graph shows average monthly CPUE of the most common calanoid copepods.

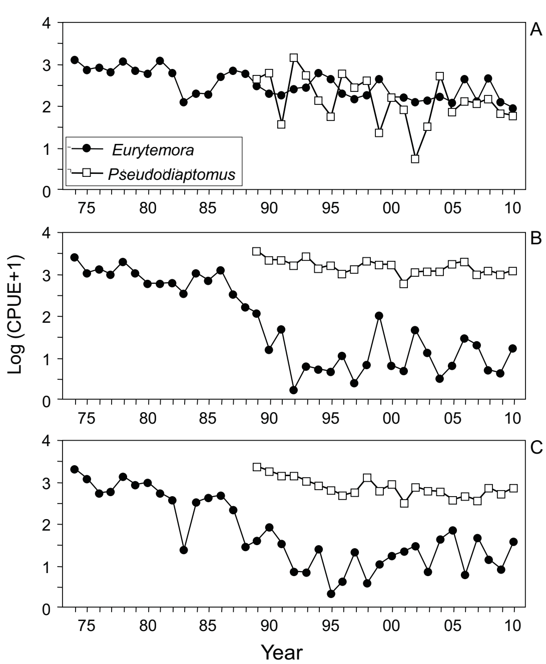

Figure 2 Abundance of Eurytemora affinis and Pseudodiaptomus forbesi (Log of mean catch*m^{-3}+1) from the CB net in spring (A), summer (B), and fall (C), 1974 - 2010.

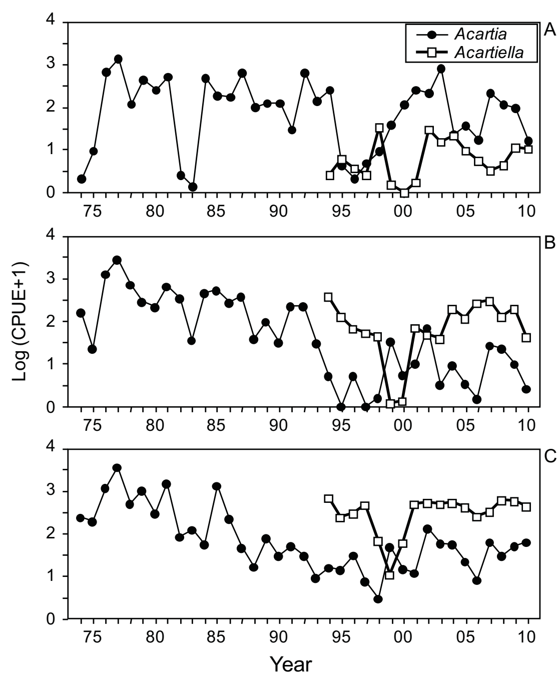

Figure 4 Abundance of Acartia spp. and Acartiella sinensis (Log of mean catch*m^{-3}+1) from the CB net in spring (A), summer (B), and fall (C), 1974 - 2010.

Acartiella sinensis is an introduced calanoid copepod first recorded in spring 1994 that is most abundant in the entrapment zone during summer and fall. In 2010, *A. sinensis* was the fourth most abundant calanoid copepod in the study area across all months. Relative abundance was highest in fall, when it accounted for 30% of the total calanoid copepod CPUE (Figure 3). In 2010, *A. sinensis* abundance decreased in spring, summer, and fall from 2009 (Figure 4). Spring abundance has always been highly variable, but declined steadily from 2004 through 2007, followed by slight increases in 2008 and 2009, before decreasing slightly in 2010 (Figure 4A). Since 2001, summer abundance rebounded from the record lows of 1999 and 2000, and in 2007, reached the second highest summer abundance since its introduction (Figure 4B). After declining in 2008, summer abundance again increased in 2009 before declining sharply in 2010. Fall abundance has been relatively stable since 2001 and after reaching the third highest in 2009, decreased slightly in 2010 (Figure 4C). In 2010, *A. sinensis* abundance peaked in September in the lower Sacramento River, just downstream of the entrapment zone (2,010 m^{-3}).

The introduced freshwater calanoid copepod *Sinocalanus doerrii* was first recorded in spring 1979. Initially most abundant in summer, *S. doerrii* abundance began to decline during summer and fall in the mid-1980s (Figures 5B and 5C). This downward trend continued through the mid-1990s, followed by modest increases recently. In 2010, *S. doerrii* was the third most abundant calanoid copepod in the study area across all months. Relative abundance peaked in spring, when it accounted for 42% of the total calanoid copepod CPUE (Figure 3). *S. doerrii* abundance increased in 2010 from 2009 in all seasons (Figure 5). Spring abundance, historically more variable than summer or fall abundance, was lowest in 1995 and steadily increased through 2004 before declining again in 2005 and 2006 (Figure 5A). Subsequently, spring abundance increased in 2008, but decreased in 2009 before slightly increasing again in 2010. Summer and fall abundance declined sharply in 2004 and remained low through 2007 (Figures 5B and 5C). In 2010, summer abundance increased sharply from 2009 to the highest level since 1987, while fall abundance increased only slightly from 2009. In 2010, *S. doerrii* was most abundant in May and June in Montezuma Slough in Suisun Marsh (3,147 m^{-3}), and in the lower Sacramento and San Joaquin rivers (1,785 m^{-3}).

Tortanus dextrilobatus is an introduced brackish-water calanoid copepod first recorded in spring 1994. *T. dextrilobatus* is a large carnivorous copepod whose abundance increases in the sampling area as flows decrease and salinities increase during summer and fall. In 2010, *T. dextrilobatus* was the least abundant common calanoid copepod in the study area; relative abundance peaked in summer when it accounted for only 3% of the total calanoid copepod CPUE (Figure 3). *T. dextrilobatus* abundance decreased in spring and summer of 2010 from 2009, but increased in fall (Figure 5). Spring abundance rose steadily from the low in 2006, caused by the extremely high flows, and in 2009 reached the fifth highest spring abundance before dropping sharply in 2010 (Figure 5A). In 2008 and 2009, summer abundance was the highest since *T. dextrilobatus* was introduced, before declining in 2010 (Figure 5B). Fall abundance increased slightly from 2009, and 2010 abundance the highest since 2000 (Figure 5C). In 2010, *T. dextrilobatus* was most abundant in Carquinez Strait, where abundance peaked in June (325 m^{-3}).

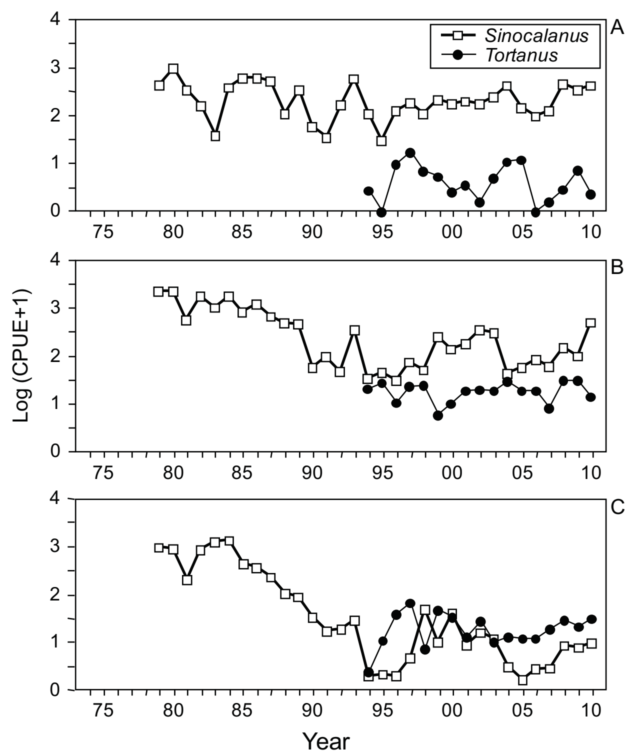

Figure 5 Abundance of Sinocalanus doerrii and Tortanus dextrilobatus (Log of mean catch*m^{-3}+1) from the CB net in spring (A), summer (B), and fall (C), 1974 - 2010.

Cladocerans

Bosmina, *Daphnia*, and *Diaphanosoma* are the most abundant cladoceran genera in the upper estuary. Combined, these native freshwater cladocerans had an overall downward trend since the early 1970s, especially in fall (Figure 6). From 2009 to 2010, abundance remained steady in spring and fall, but increased in summer. In 2010, cladocerans were common throughout the upper estuary upstream of the entrapment zone and were most abundant in the eastern Delta from April through October. Peak densities occurred in the eastern Delta in Disappointment Slough in July (50,335 m^{-3}) and September (40,964 m^{-3}).

Rotifers

Synchaeta bicornis is a native brackish-water rotifer that is usually most abundant in the upper estuary in summer and fall, when salinity increases. However, abundance, especially in summer and fall, has experienced long-term declines since the 1970s (Figure 7). Spring abundance, although erratic, has also shown an overall downward trend (Figure 7A). After a peak in spring 2000, abundance declined sharply in 2001, and from 2002 through 2007 there was no catch during spring at any core stations. Low flows in spring 2008 and 2009 resulted in the highest spring abundance since 2000. In 2010, higher outflows resulted in no catch during spring or summer at any stations sampled (Figures 7A and 7B). Summer 2008 abundance was the highest level in 10 years, before decreasing in 2009 and dropping to 0 in 2010 for the first time since monitoring began. Fall 2010 abundance increased slightly from 2009, but was the fourth lowest since monitoring began (Figure 7C). In 2010 *S. bicornis* was only found at 1 station in January in the entrapment zone, and then from Carquinez Strait to the lower Sacramento and San Joaquin rivers from September through November. Peak densities occurred in Montezuma Slough in Suisun Marsh in October (5,070 m^{-3}).

Abundance of all other rotifers, without *S. bicornis*, declined in all seasons from the early 1970s through the 1980s, but stabilized since the early 1990s (Figure 7). In 2010, rotifer abundance increased slightly from 2009 in spring and summer, but decreased in fall. After decreasing to the lowest spring abundance for the study period in 2009, spring abundance increased slightly in 2010 (Figure 7A). Summer abundance increased in 2010 from 2009 for the second year in a row (Figure 7B). Fall abundance decreased in 2010 and was the lowest fall abundance since monitoring began (Figure 7C). Rotifers were common throughout the study area in 2010, with the highest abundance near Stockton in the lower San Joaquin River, where mean CPUE for the year was 67,641 m^{-3} and abundance peaked at 335,352 m^{-3} in August.

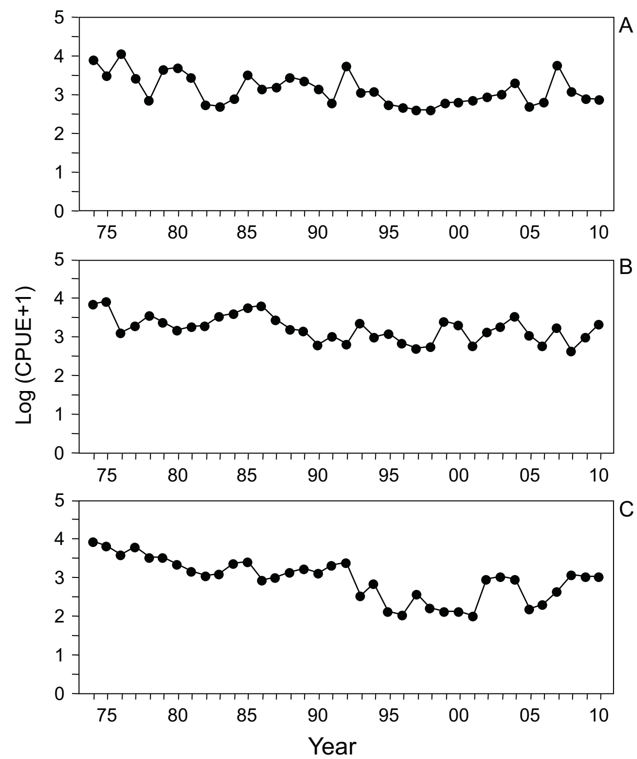

Figure 6 Abundance of Cladocera (Log of mean catch*m^{-3}+1) from the CB net in spring (A), summer (B), and fall (C), 1974 - 2010.

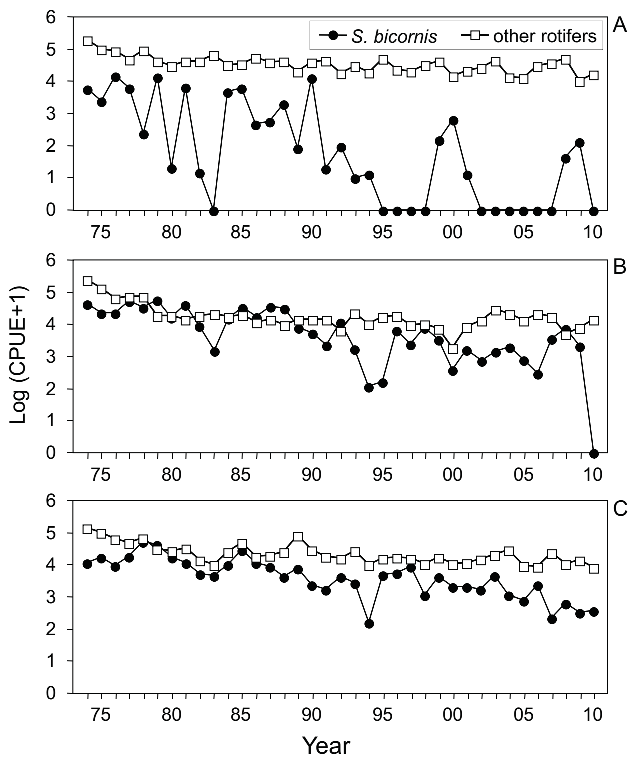

Figure 7 Abundance of Synchaeta bicornis and rotifers excluding *S. bicornis* (Log of mean catch*m^{-3}+1) from the pump in spring (A), summer (B), and fall (C), 1974 - 2010.

Mysids

Hyperacanthomysis longirostris (formerly *Acanthomysis bowmani*), an introduced mysid first collected by the study in summer 1993, has been the most abundant mysid in the upper estuary every season since summer 1995 (Table 1). *H. longirostris* is commonly found in densities of more than 10 m$^{-3,}$ and occasionally in densities of more than 100 m^{-3}. Spring *H. longirostris* abundance increased from 1995 to 1998, and fluctuated annually thereafter. Although spring abundance increased in 2010 from the second lowest on record in 2009, it remained below average. Summer abundance had a downward trend since 2003, but in 2010 summer abundance increased sharply and was the highest since 2000. *H. longirostris* fall abundance declined consistently since a local peak in 2004, resulting in record low fall abundances from 2007 through 2009 of less than 1 m^{-3}. In fall, 2010 *H. longirostris* abundance increased from the record lows of the last 3 years, but remained below average. In 2010, *H. longirostris* was most abundant in June and July in the entrapment zone, which included the lower Sacramento River and eastern Suisun Bay, near the confluence of the Sacramento and San Joaquin rivers. The highest 2010 density occurred in the entrapment zone in June (245 m^{-3}).

Neomysis mercedis, historically the only common mysid in the upper estuary, suffered a severe population crash in the early 1990s. In 2010, it was the fourth most abundant mysid in the sampling area across all months for the fourth year in a row. *N. mercedis* is most abundant in spring and summer, and prior to the population crash spring and summer densities averaged more than 50 m^{-3} (Table 1). Since 1994, mean spring abundance has been less than 1 m^{-3}, rendering *N. mercedis* inconsequential as a food source in most open-water areas of the upper estuary. After a record low in 2007, spring 2008 abundance increased slightly, but decreased in 2009 and again in 2010 to the second lowest since monitoring began. Summer abundance has been extremely low since 1997. After decreasing to the lowest summer abundance on record in 2009, summer abundance increased slightly in 2010 to the highest since 1999. No *N. mercedis* were caught during fall at any of the stations sampled from 2005 through 2008. In both fall 2009 and 2010 only 1 *N. mercedis* was caught. Since June 2006, *N. mercedis* has been uncommon throughout the study area with densities less than 1 m^{-3} at most stations. In 2010, *N. mercedis* densities exceeded 1 m^{-3} in June in Suisun Marsh (1.4 m^{-3}) and at 1 station in the lower Sacramento River (1.4 m^{-3}), and in July in the lower San Joaquin River (1.6 m^{-3}).

Table 1 Seasonal abundance of the most common mysid species (mean catch*m^{-3}) from the macrozooplankton net.

Year	*Hyperacanthomysis longirostris*			*Neomysis mercedis*			*Neomysis kadiakensis*			*Alienacanthomysis macropsis*		
	Spring	Summer	Fall	Spring	Summer	Fall	Spring	Summer	Fall	Spring	Summer	Fall
1974-1989				54.506	87.293	18.154						
1990				23.458	7.612	0.436						
1991				32.058	18.331	0.489						
1992				4.223	1.989	0.076						
1993			2.470	7.850	22.503	0.008						
1994	0.932	21.604	2.063	0.449	0.733	0.004						
1995	0.437	7.180	4.407	0.590	0.370	0.000				0.000	0.000	0.004
1996	1.636	11.693	4.432	0.541	1.432	0.001	0.032	0.001	0.017	< 0.001	0.000	0.003
1997	6.939	27.630	7.714	0.565	0.063	0.000	0.011	0.011	0.385	0.006	0.000	0.004
1998	18.136	6.015	18.691	0.181	0.238	0.025	0.108	0.041	0.006	0.005	0.000	0.008
1999	3.888	34.697	14.329	0.264	0.288	0.001	0.037	0.007	0.075	0.014	0.000	0.001
2000	23.580	38.453	9.958	0.880	0.136	0.001	0.074	0.165	0.465	0.003	0.000	0.001
2001	4.767	13.441	8.956	0.422	0.052	0.001	0.285	0.351	0.143	0.013	0.001	0.001
2002	10.121	21.224	7.516	0.022	0.069	0.001	0.209	0.254	0.753	0.005	0.000	0.002
2003	4.342	21.307	4.555	0.022	0.046	< 0.001	0.314	0.209	0.166	0.038	0.000	0.003
2004	9.915	13.725	5.044	0.150	0.016	0.002	0.129	0.106	0.170	0.001	0.000	0.001
2005	4.010	16.281	3.265	0.092	0.141	0.000	0.173	0.104	0.077	0.003	0.000	0.004
2006	7.186	14.143	1.967	0.321	0.137	0.000	0.071	0.727	0.051	0.001	0.000	0.001
2007	0.969	8.997	0.575	0.005	0.023	0.000	0.176	0.306	0.122	0.004	< 0.001	0.025
2008	17.696	14.574	0.715	0.063	0.108	0.000	1.359	0.820	0.154	0.027	< 0.001	0.155
2009	0.729	6.303	0.681	0.016	0.013	< 0.001	0.418	0.240	0.128	0.064	0.003	0.096
2010	2.887	25.975	2.045	0.013	0.174	< 0.001	0.177	0.280	0.081	0.090	0.002	0.183
Average:	6.951	17.838	5.521	25.521	39.220	7.879	0.238	0.241	0.186	0.017	< 0.001	0.031

Neomysis kadiakensis is a native brackish-water mysid that regularly appeared in mysid samples beginning in 1996, but was not common until recently (Table 1). From 2001 through 2008, *N. kadiakensis* was the second most abundant mysid in the study area, but in 2009 and 2010 fell to the third most abundant mysid in the study area. In 2010, *N. kadiakensis* abundance decreased in spring and fall, but increased slightly in summer. After reaching a record high in spring 2008, abundance decreased in spring 2009 and again in 2010. In 2010 summer, abundance increased slightly from 2009 and was just above the summer average across years. Fall abundance decreased in 2010 for the second year in a row, and again was below the fall average. In 2010, peak densities occurred in May and June in Suisun Bay (2.3 m^{-3}). Since the late 1990s, *N. kadiakensis* has extended its range into lower salinity water at the confluence of the Sacramento and San Joaquin rivers, leading to the hypothesis that some of the upper-estuary specimens may be a second species, *N. japonica*. To date, no physical characteristics have been published to separate these 2 species.

Alienacanthomysis macropsis is a native brackish-water mysid found most often in San Pablo Bay and Carquinez Strait that was first consistently enumerated by the study in 1995. *A. macropsis* has never been common in the sampling area and therefore indices were not reported until 2007. In 2009 and 2010, *A. macropsis* abundance surpassed *N. kadiakensis* and *A. macropsis* became the second most abundant mysid in the upper estuary across all stations and surveys, although it remained a minor component of the mysid community due to high *H. longirostris* abundance. Spring abundance increased in 2010 for the fourth year in a row and was the highest spring abundance recorded (Table 1). After reaching the highest summer abundance on record in 2009, summer abundance decreased slightly in 2010. Fall 2010 abundance increased from 2009, and was the highest fall abundance recorded. In 2010, *A. macropsis* was most abundant from January through April and again in December in San Pablo Bay and Carquinez Strait; by November and December *A. macropsis* distribution shifted upstream and was most abundant in eastern Suisun Bay. The highest CPUE of 2010 occurred in February in eastern San Pablo Bay and Carquinez Strait where the average abundance was 18 m^{-3}.

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Bouley, P. and W.J. Kimmerer. 2006. Ecology of a highly abundant, introduced cyclopoid copepod in a temperate estuary. Marine Ecology Progress Series. 324: 219-228.

Brown,T. 2009. Phytoplankton Community Composition: The Rise of the Flagellates. IEP Newsletter 22(3):20-28.

2010 Status and Trends Report for Pelagic Fishes of the Upper San Francisco Estuary

Dave Contreras, Virginia Afentoulis, Kathryn Hieb, Randy Baxter, and Steven Slater (CDFG)[1]

Introduction

The 2010 Status and Trends report includes pelagic fish data from 4 of the Interagency Ecological Program's long-term monitoring surveys in the upper San Francisco Estuary: 1) the Summer Townet Survey (TNS), 2) the Fall Midwater Trawl Survey (FMWT), 3) the Delta Smelt 20mm Survey (20mm Survey), and 4) the U.S. Fish and Wildlife Service (USFWS) Beach Seine Survey (see Honey et al. 2004 for additional information). The most recent abundance indices, long-term abundance trends, and distributional information are presented by species phylogenetically in following sections for American shad (*Alosa sapidissima)*, threadfin shad (*Dorosoma petenense*), delta smelt (*Hypomesus transpacificus*), longfin smelt (*Spirinchus thaleichthys*), wakasagi (*H. nipponensis*), splittail (*Pogonichthys macrolepidotus*) and striped bass (*Morone saxatilis*). Several of these pelagic species that spawn and rear in the upper estuary have undergone severe declines in recent years (Sommer et al. 2007). To date, the abundances of POD fishes persist at very low levels.

Abundance indices and distribution of upper estuary demersal fishes and marine demersal and pelagic fishes will be reported in an upcoming IEP Newsletter.

Methods

Freshwater flow through the estuary positively affects the abundance of many upper estuary fish species (Stevens and Miller 1983, Jassby et al. 1995, Kimmerer 2002). We examined outflow effects by regressing species annual abundance indices on a mean outflow measure derived by grouping flow data from a critical seasonal period in each species' life. Though the actual mechanism(s) for these relationships remain unknown, it is believed that increased outflow enhances abundance by one or more of several mechanisms: 1) increasing low salinity habitat; 2) by dispersing and transporting larvae or juveniles to favorable habitat; 3) by stimulating the food web and increasing food supply; or 4) by reducing predation or other top down effects. Delta outflow data, as daily outflow in cubic feet per second (cfs) at Chipps Island, were acquired from the Department of Water Resources Dayflow database available online at: http://www.water.ca.gov/dayflow/. Daily outflow values were averaged by month, then averaged again for a series of months specific to each fish species representing an important period. In most cases, these outflow means were $\log_{10}$ transformed, and then $\log_{10}$ transformed abundance indices were regressed on the transformed outflow means and plotted. These abundance vs. outflow plots distinguish years leading up to the establishment of *Corbula amurensis* in the estuary (i.e., through 1987), years after establishment (1988 and later) and years after the start of the pelagic organism decline (i.e., POD, i.e., after 2000) to depict how the relationships have changed.

The 20mm Survey monitors larval and juvenile delta smelt distribution and relative abundance throughout its historical spring range, which includes the entire Delta downstream to eastern San Pablo Bay and the Napa River. Surveys have been conducted every other week from early March through early July since 1995, with 9 surveys com-

1. Authorship: Introduction and methods, K. Hieb, S. Slater and Randy Baxter; American and threadfin shad, longfin smelt, and wakasagi, D. Contreras; delta smelt, splittail, and striped bass, V. Afentoulis; and splittail introduction, R. Baxter.