Zooplankton Monitoring 2013-2015 Summary

Zooplankton were sampled monthly from 1974 through 2015 at 22 stations in the upper SFE, extending from eastern San Pablo Bay through the Delta (www.dfg.ca.gov/delta/data/zooplankton/stations.asp). At each station, 3 gear types were used to collect zooplankton of various sizes: 1) a pump for sampling smaller zooplankton, including rotifers and copepods of the genus *Limnoithona*; 2) a modified Clarke-Bumpus (CB) net for sampling mid-sized zooplankton, including cladocerans and most copepods (net mesh 160 micron openings); and 3) a mysid net for sampling mysid shrimp (net mesh 505 micron openings). Abundance indices were calculated using data from the gear type that most effectively captures each organism and are reported as the mean number of each organism per cubic meter of water sampled (catch-per-unit effort, CPUE). Here, annual abundance indices are presented from 1974 through 2015 for the most common copepods, cladocerans, rotifers, and mysids. Annual mean abundance was calculated for selected taxa as the mean March through November CPUE, as these were the only months consistently sampled throughout the entire study period. Sixteen stations were used to calculate abundance indices, including 14 fixed stations sampled consistently since 1974 and 2 non-fixed stations sampled where bottom specific conductance was 2 and 6 mS/cm (approximate salinity of 1 and 3 psu).

Copepods

When monitoring began in the 1970s, *Eurytemora affinis* and *Acartia* spp. were the most abundant copepods in the upper San Francisco Estuary (Figure 1). *E. affinis* is a calanoid copepod introduced to the SFE long before monitoring started. It was a major food source for larval and juvenile fishes of many species and also adult planktivores, such as Delta Smelt and Threadfin Shad. However, *E. affinis* annual abundance has since declined (Figure 1), as new species have been introduced and become established in the estuary. One of the first introductions 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* became the most abundant calanoid copepod in the upper estuary in most years from 1979 through 1984 (Figure 1).

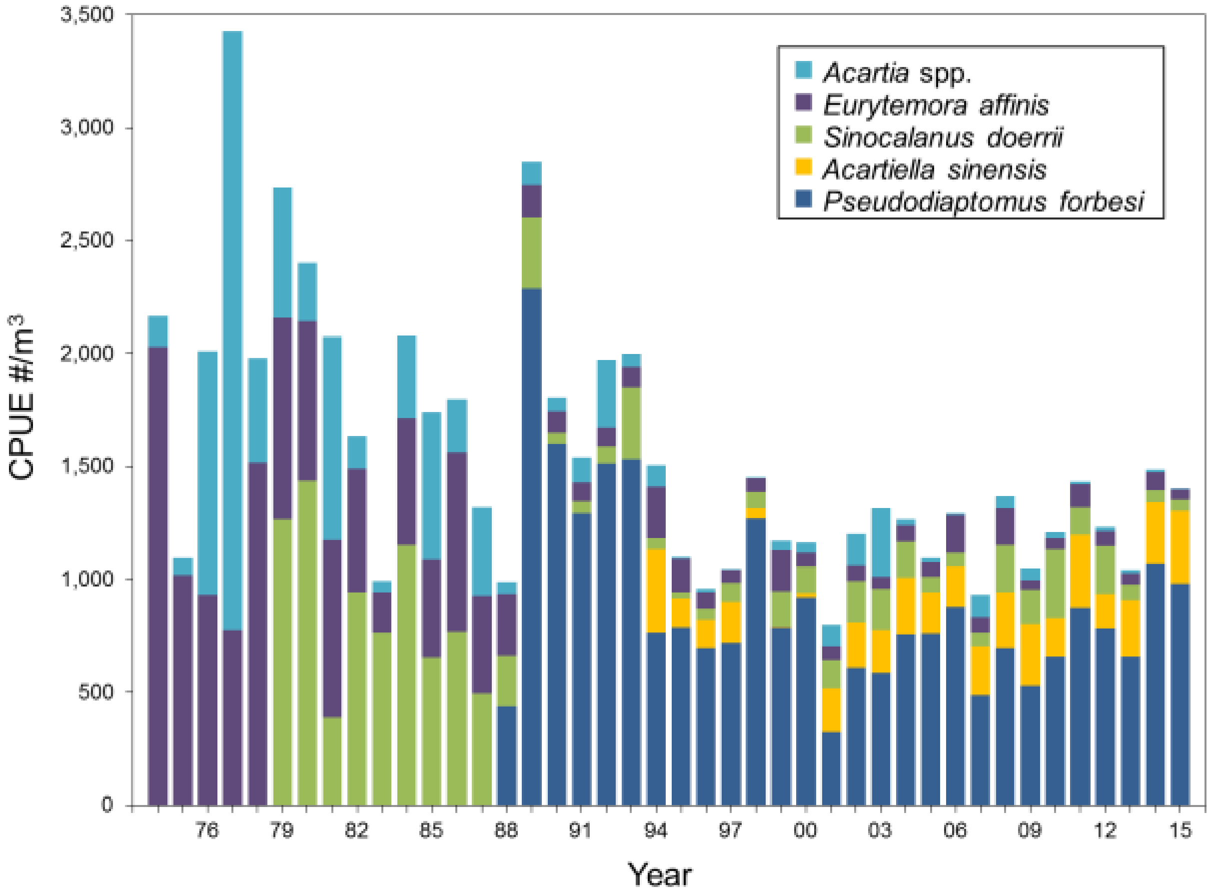

Figure 1

In 1979, the cyclopoid copepod *Limnoithona sinensis* was introduced (Ferrari and Orsi 1984). Smaller than the calanoid copepods that inhabited the estuary, *L. sinensis* (originally recorded as *Limnoithona* spp.) wasn't retained well by the CB net, but abundance estimates from the pump samples quickly became comparable to *E. affinis* and *S. doerrii* abundance estimates from the CB samples (Figure 2).

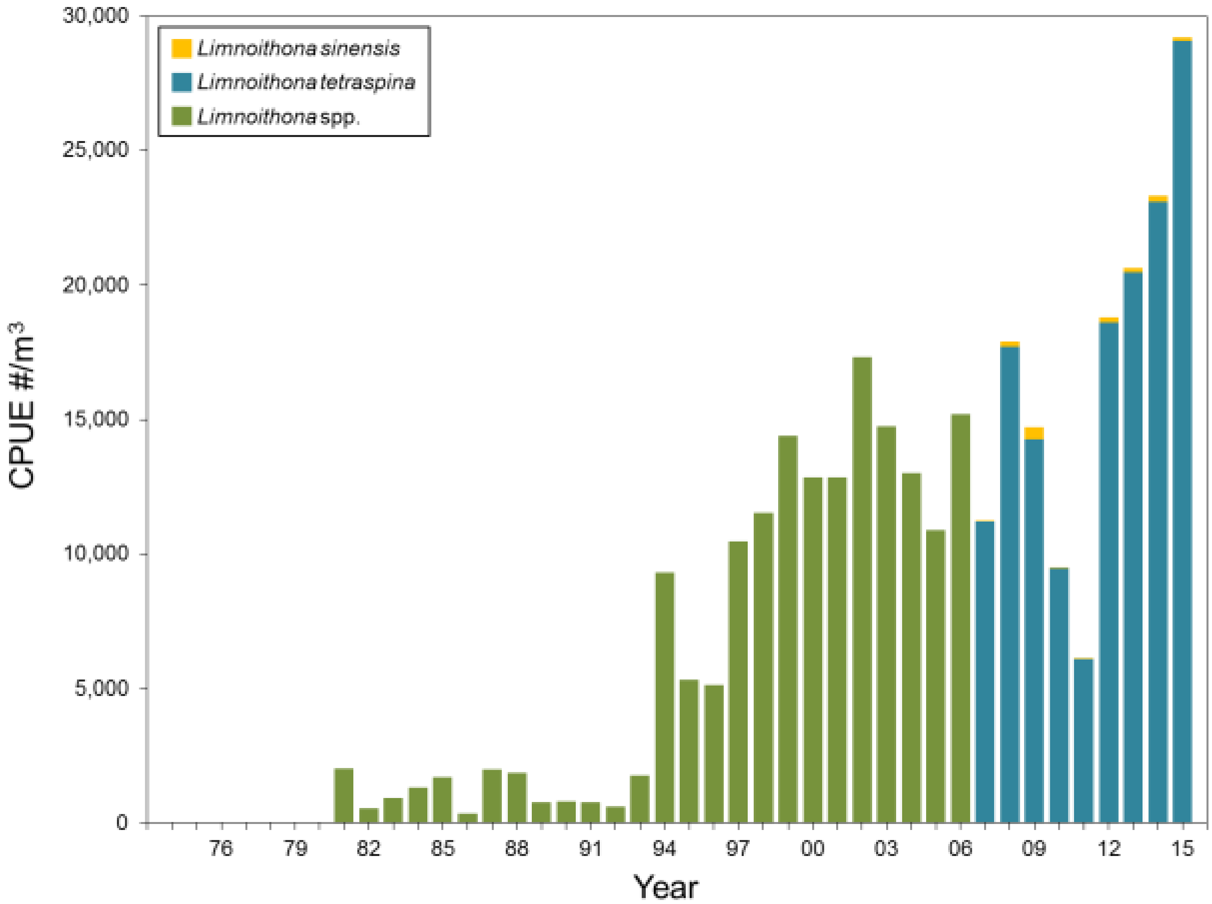

Figure 2

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. Then in 1987 another calanoid copepod, *Pseudodiaptomus forbesi*, was also introduced (Orsi and Walter 1991). Both *P. amurensis* and *P. forbesi* grazed on phytoplankton and thus competed with *E. affinis* for food (Kimmerer and Orsi 1996). Additionally *P. amurensis* also grazed on copepod nauplii in the water column, thereby further reducing *E. affinis* abundance through predation (Kimmerer et al. 1994). Since its introduction, *P. forbesi* has remained the most abundant calanoid copepod in the estuary during most years (Figure 1). Several more copepods were introduced in 1993. In 1993, the calanoid copepod *Acartiella sinensis* was first recorded (Orsi and Ohtsuka 1999). By 1994, *A. sinensis* was the second most abundant calanoid copepod in the upper estuary (Figure 1).

Limnoithona tetraspina, a cyclopoid copepod, was also first recorded by this study in 1993 (Orsi and Ohtsuka 1999). It mostly supplanted the historically common and slightly larger *L. sinensis* and became the numerically dominant copepod in the upper estuary by 1994 (Figure 2). *L. tetraspina* is now more abundant than any other copepod has been in the upper estuary since monitoring began, with record high annual abundances in 2013 through 2015. 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). Annual abundance of *L. sinensis* was much lower than *L. tetraspina* from 2013 through 2015, but *L. sinensis* was relatively abundant compared to other copepods in the upper estuary (Figures 1 and 2).

The most abundant calanoid copepod in the upper estuary from 2013 through 2015 was *P. forbesi*, and the second most abundant was *A. sinensis* (Figure 1). Annual abundance of *P. forbesi* and *A. sinensis* was higher during 2014 and 2015, than most previous years (Figure 1). The third and fourth most abundant calanoid copepods from 2013 through 2015 alternated between *S. doerrii* and *E. affinis,* followed by the native *Acartia* spp. which were the fifth most abundant (Figure 1). Annual abundance of *S. doerrii, E. affinis,* and *Acartia* spp. were lower from 2013 through 2015 than in most previous years (Figure 1).

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 (Figure 3).

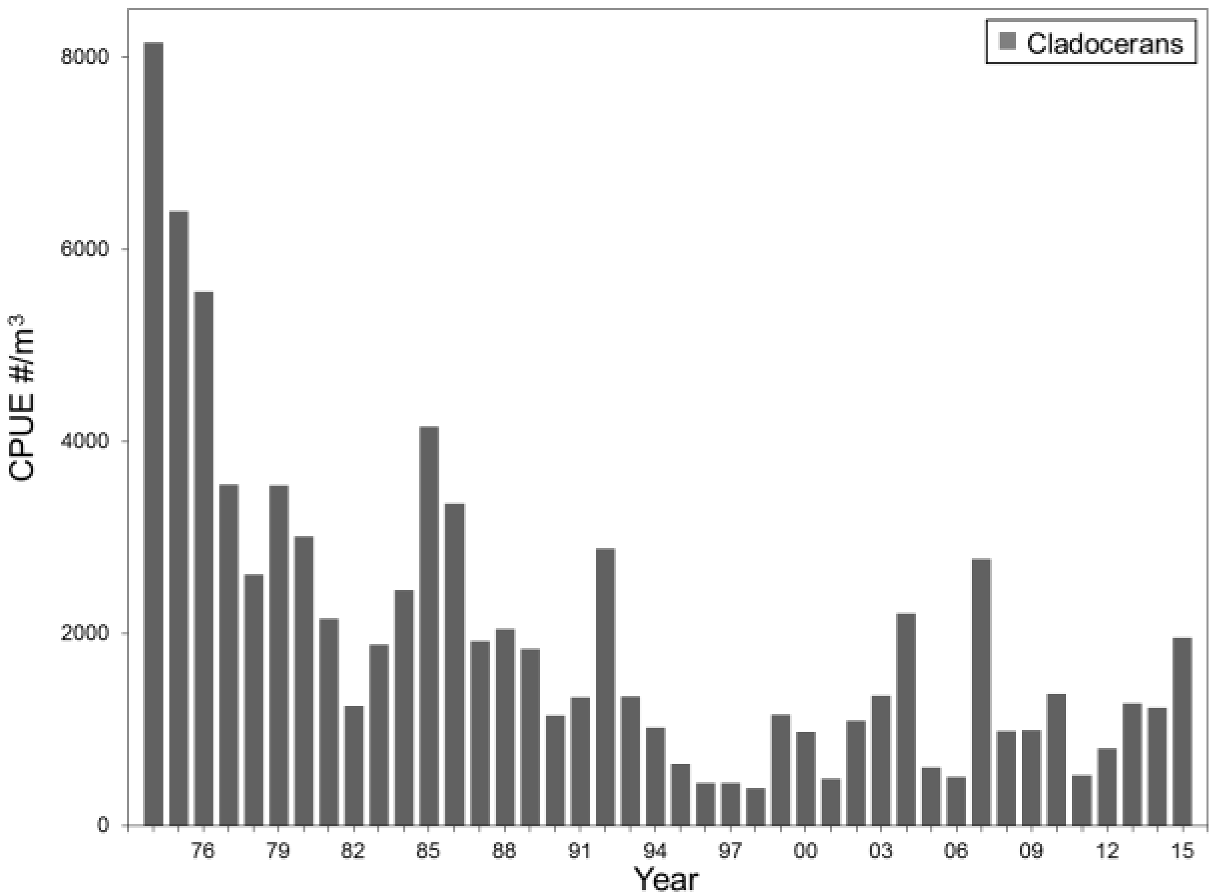

Figure 3

Rotifers

Synchaeta bicornis is a native brackish-water rotifer that has declined since the 1970s (Figure 4). In 2011 annual abundance was higher than it had been since 1985, but from 2012 through 2015 annual abundance was below average (Figure 4). Abundance of all other rotifers, without *S. bicornis*, declined from the early 1970s through the 1980s, but stabilized since the early 1990s (Figure 4). In 2011, annual abundance was higher than it had been since 1989, but declined in 2012 and despite slight increases remained below average through 2015 (Figure 4).

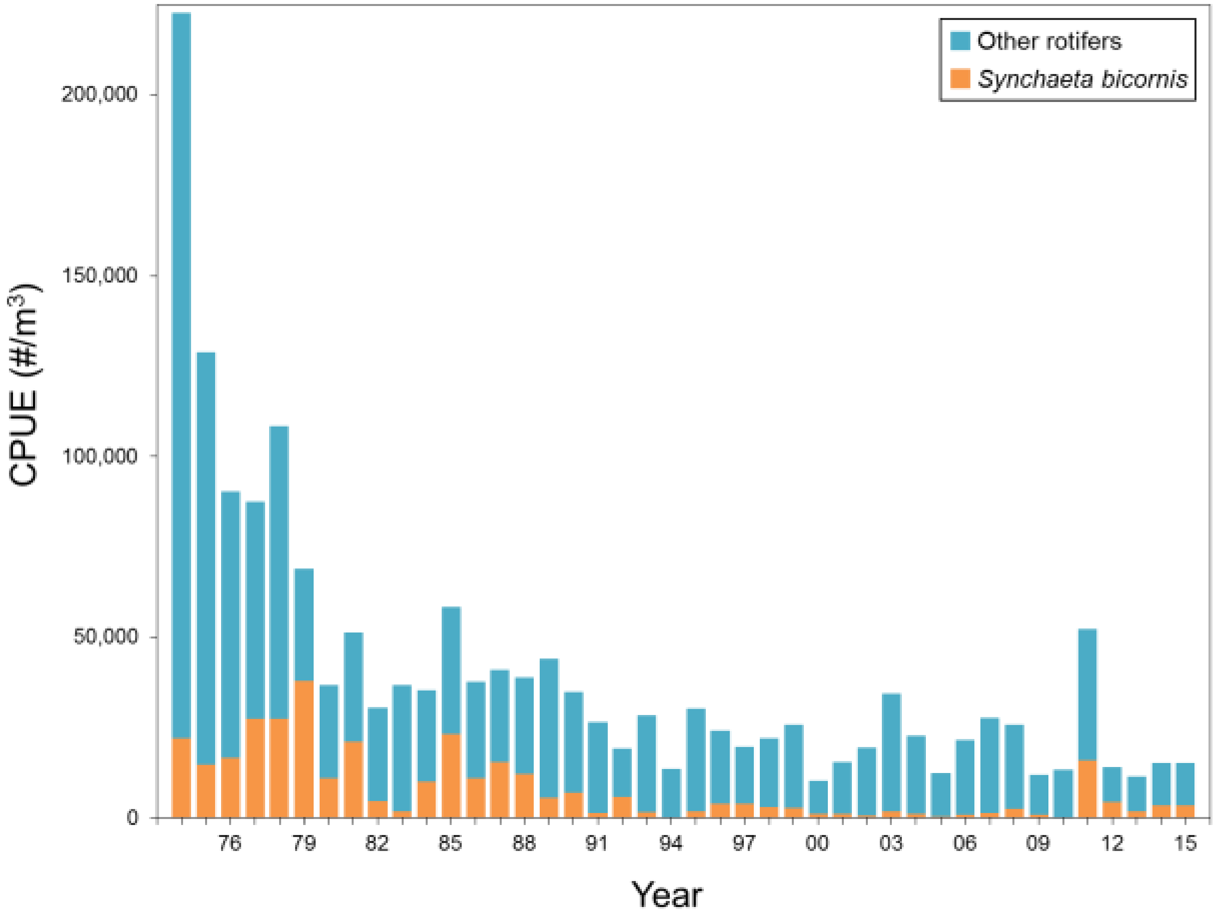

Figure 4

Mysids
Neomysis mercedis was the only mysid commonly found in the upper estuary when monitoring began in the 1970s. Similar to *E. affinis*, *N. mercedis* abundance also dropped in the early 1990s after the introduction of the overbite clam, *P. amurensis* (Table 1). This decline was caused by competition with *P. amurensis* for phytoplankton, a shared food resource (Orsi and Mecum 1996). Shortly after *N. mercedis* abundance began declining, two newly introduced mysids were first collected by this study: *Acanthomysis aspera* was first collected in 1992, and *Hyperacanthomysis longirostris* (formerly *Acanthomysis bowmani*) was first collected in 1993 (Modlin and Orsi 1997). After its introduction, *H. longirostris* abundance increased rapidly, and by 1994 it was the most abundant mysid in the upper estuary (Table 1). In 2015, *H. longirostris* annual abundance was higher than it had been since 2002 (Table 1). *Neomysis kadiakensis* is a native brackish-water mysid that regularly appeared in mysid samples beginning in 1995, but was not abundant until recently (Table 1). *N. kadiakensis* had the second highest mean annual mysid abundance from 2013 through 2015 (Table 1). *Acanthomysis aspera, a* brackish-water mysid with historically low abundance compared to other mysids in the upper estuary, recently increased in abundance (Table 1) and from 2013 through 2015, *A. aspera* had the third highest mean annual mysid abundance (Table 1). In 2014, mean annual abundance was the highest ever recorded for *A. aspera* (Table 1). *Alienacanthomysis macropsis* is a native brackish-water mysid usually found in San Pablo Bay and Carquinez Strait that began to be consistently enumerated by this study in 1995. In 2013 through 2015, *A.*

macropsis had the fourth highest mean annual abundance (Table 1). *N. mercedis,* although historically abundant before 1994, was one of the least abundant mysids in 2013 through 2015 (Table 1).

Year	*Neomysis mercedis*	*Hyperacanthomysis longirostris*	*Neomysis kadiakensis*	*Acanthomysis aspera*	*Alienacanthomysis macropsis*
1974	99.377				
1975	76.791				
1976	92.323				
1977	5.420				
1978	42.275				
1979	35.113				
1980	70.998				
1981	41.946				
1982	91.716				
1983	17.195				
1984	63.419				
1985	71.184				
1986	109.769				
1987	26.993				
1988	22.718				
1989	17.448				
1990	10.346				
1991	16.209				
1992	2.080				
1993	10.254			<0.001	
1994	0.393	8.100	<0.001	0.108	0.016
1995	0.308	4.046	0.053	0.001	0.001
1996	0.652	5.879	0.017	<0.001	0.001
1997	0.202	14.007	0.142	0	0.003
1998	0.149	14.249	0.052	0.001	0.004
1999	0.182	17.713	0.040	0.006	0.005
2000	0.339	23.997	0.235	0.005	0.001
2001	0.159	8.990	0.257	0.017	0.005
2002	0.030	12.933	0.404	0.012	0.003
2003	0.022	9.786	0.230	0.001	0.014
2004	0.056	9.500	0.135	0.016	0.001
2005	0.077	7.870	0.118	0.003	0.002
2006	0.154	7.761	0.281	<0.001	0.001
2007	0.009	3.453	0.200	0.007	0.010
2008	0.057	11.041	0.787	0.001	0.061
2009	0.009	2.597	0.260	0.001	0.054

Year	***Neomysis mercedis***	***Hyperacanthomysis longirostris***	***Neomysis kadiakensis***	***Acanthomysis aspera***	***Alienacanthomysis macropsis***
2010	0.060	9.952	0.176	0.003	0.095
2011	0.163	2.606	0.235	0.002	0.039
2012	0.052	7.939	0.266	0.019	0.061
2013	0.006	9.034	0.439	0.032	0.021
2014	0.003	5.311	0.655	0.139	0.010
2015	0.002	12.176	0.886	0.038	0.004

Table 1

References

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.

Ferrari, F.D. and J. Orsi. 1984. *Oithona davisae,* new species, and *Limnoithona sinensis* (Burckhardt, 1912) (Copepoda: Oithonidae) from the Sacramento-San Joaquin Estuary, California. Journal of Crustacean Biology 4(1):106-126.

Kimmerer, W.J., E. Gartside, and J.J. Orsi. 1994. Predation by an introduced clam as the likely cause of substantial declines in zooplankton of San Francisco Bay. Marine Ecology Progress Series 113:81-93.

Kimmerer, W.J., and J.J. Orsi. 1996. Changes in the zooplankton of the San Francisco Bay Estuary since the introduction of the clam *Potamocorbula amurensis*. In *San Francisco Bay: The ecosystem*, ed. J.T. Hollibaugh, 403-424. San Francisco: Pacific Division of the American Association for the Advancement of Science.

Modlin, R.F. and J.J. Orsi. 1997. *Acanthomysis bowmani*, a new species, and *A. aspera* Ii, Mysidacea newly reported from the Sacramento-San Joaquin Estuary, California (Crustacea: Mysidae). Proceedings of the Biological Society of Washington 110(3):439-446.

Orsi, J J. and W.L. Mecum. 1996. Food limitation as the probable cause of a long-term decline in the abundance of *Neomysis mercedis* the opossum shrimp in the Sacramento-San Joaquin Estuary. In *San Francisco Bay: The ecosystem*, ed. J.T. Hollibaugh, 375-401. San Francisco: Pacific Division of the American Association for the Advancement of Science.

Orsi, J.J., T. E. Bowman, D.C. Marelli, and A. Hutchison. 1983. Recent introduction of the planktonic calanoid copepod *Sinocalanus doerrii* (Centropagidae) from mainland China to the Sacramento-San Joaquin Estuary of California. Journal of Plankton Research 5(3):357-375.

Orsi, J.J. and S. Ohtsuka. 1999. Introduction of the Asian copepods *Acartiella sinensis*, *Tortanus dextrilobatus* (Copepoda: Calanoida), and *Limnoithona tetraspina* (Copepoda: Cyclopoida) to the San Francisco Estuary, California, USA. Plankton Biology and Ecology 46(2):128-131.

Orsi, J.J. and T.C. Walter. 1991. *Pseudodiaptomus forbesi* and *P. marinus* (Copepoda: Calanoida), the latest copepod immigrants to California's Sacramento-San Joaquin Estuary. Bulletin of the Plankton Society of Japan Special Volume on Proceedings of the Fourth International Conference on Copepoda: 553-562.