

# Current Report

## Introduction

This report presents zooplankton annual and seasonal abundance indices and distribution trends from 1974 through 2021 for the most common copepods, cladocera, rotifers, and mysids of the upper estuary.

## Trends

Since the implementation of the Zooplankton Study in 1974, a significant decrease in the overall abundance of zooplankton has been detected in the estuary (Figure 68). Only the abundance of cyclopoid copepods increased in the region during this period, driven by the invasion and spread of *Limnoithona tetraspina*. The overall decrease in zooplankton abundance in the estuary can be attributed to a series of invasions into the estuary, most notably that of the Asian clam *Potamocorbula amurensis* in the mid-1980s (Kimmerer, Gartside, and Orsi 1994; Carlton et al. 1990). The spread of *P. amurensis* throughout SFE has had significant impacts on planktonic abundance in the upper estuary due to its high filtration feeding rates on phytoplankton and copepod nauplii. Not only has abundance decreased for most of the zooplankton groups, but dramatic shifts in the composition of these communities have been detected during the study period. These changes have been driven by the introduction and spread of non-native zooplankton species throughout the estuary, compounded with changes to the abiotic and biotic environments.

## Calanoid copepods

While overall calanoid copepod abundance has declined slightly over the study period, community composition has shifted dramatically (Figure 68A). When the study began in the early 1970s the copepods *Eurytemora affinis* and *Acartia* spp. dominated the calanoid community. The

non-native *E. affinis* was once the primary prey item of the endangered Delta Smelt, but its abundance has declined to a fraction of what it once was, forcing fish to prey switch to more recently introduced calanoids like *Pseudodiaptomus forbesi* (Moyle et al. 1992; Slater and Baxter 2014). One of the first recorded introduced calanoid copepods was *Sinocalanus doerrii*, a freshwater species native to China that invaded the estuary in 1978 and became the most dominant calanoid species in the estuary for a decade (Orsi et al. 1983). Then in 1987, after the invasion of *P. amurensis*, the calanoid *Pseudodiaptomus forbesi* was introduced and first detected in the region, competing with the abundant *E. affinis* (Orsi and Walter 1991). *P. forbesi* quickly became the numerically dominant calanoid in the upper estuary and remains the most abundant to this day. Another introduction occurred in 1993, when the predatory calanoid copepod *Acartiella sinensis* quickly became the second most abundant calanoid in the upper estuary, dominating the low-salinity zone in Suisun and the West Delta (Orsi and Ohtsuka 1999). This invasion was hypothesized to have narrowed the range of *P. forbesi* and calanoid copepods towards the freshwater zone of the estuary (Figure 69A), as predation on *P. forbesi* nauplii by *A. sinensis* has been recorded (Kayfetz and Kimmerer 2017).

In general, calanoid copepod abundance is highest in the estuary during the summer and fall months, with lowest abundances during the winter (Figure 70A). While calanoid copepod abundance peaked in the summer of 2017 at a 20 year high, 2018 through 2021 abundance returned to levels comparable to the previous two decades. In 2021 the distribution of calanoids throughout the estuary was similar to the last two years, with *P. forbesi* the most abundant in summer and fall in most of the upper estuary (Figure 70A). The predatory *Acartiella sinensis* was seen in highest densities in the summer and fall mostly in the West Delta, with lower abundances in the Suisun Bay and Suisun Marsh regions compared to 2020. In the summer and fall of 2021, *A. sinensis* was the most abundant calanoid in Suisun and the West Delta, where it co-occurred with high densities of one of its primary prey item *Limnoithona tetraspina* (Figure 70B), while *P. forbesi* was most abundant in the Central and East Delta. The shift of density for *P. forbesi* upstream out of Suisun Marsh could be due to the ongoing drought conditions in the estuary. *Acartia* spp. was the only native calanoid copepod commonly found in 2021, but it was restricted to Suisun Bay and San Pablo Bay in the lower reaches of the estuary. *Eurytemora affinis* was most dominant calanoid in the estuary in the spring of 2021, similar to seasonal distribution patterns of the last two decades.

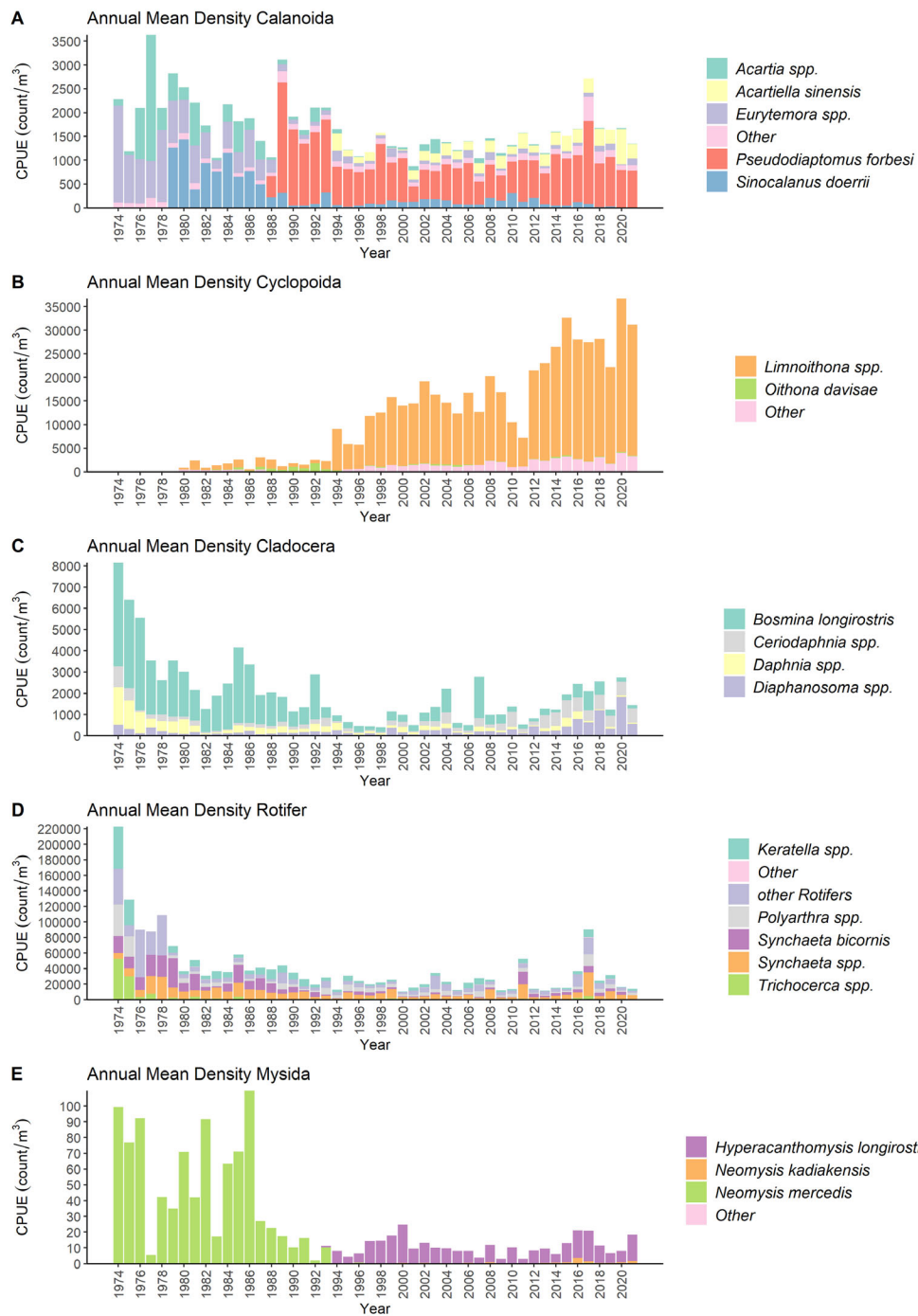


Figure 68: Annual (Mar-Nov) mean zooplankton CPUE for A) Calanoid CPUE in the CB net, B) Cyclopoida CPUE in pump samples, C) Cladocera CPUE in the CB net, D) Rotifer CPUE in pump samples, and E) Mysid CPUE in the mysid net.

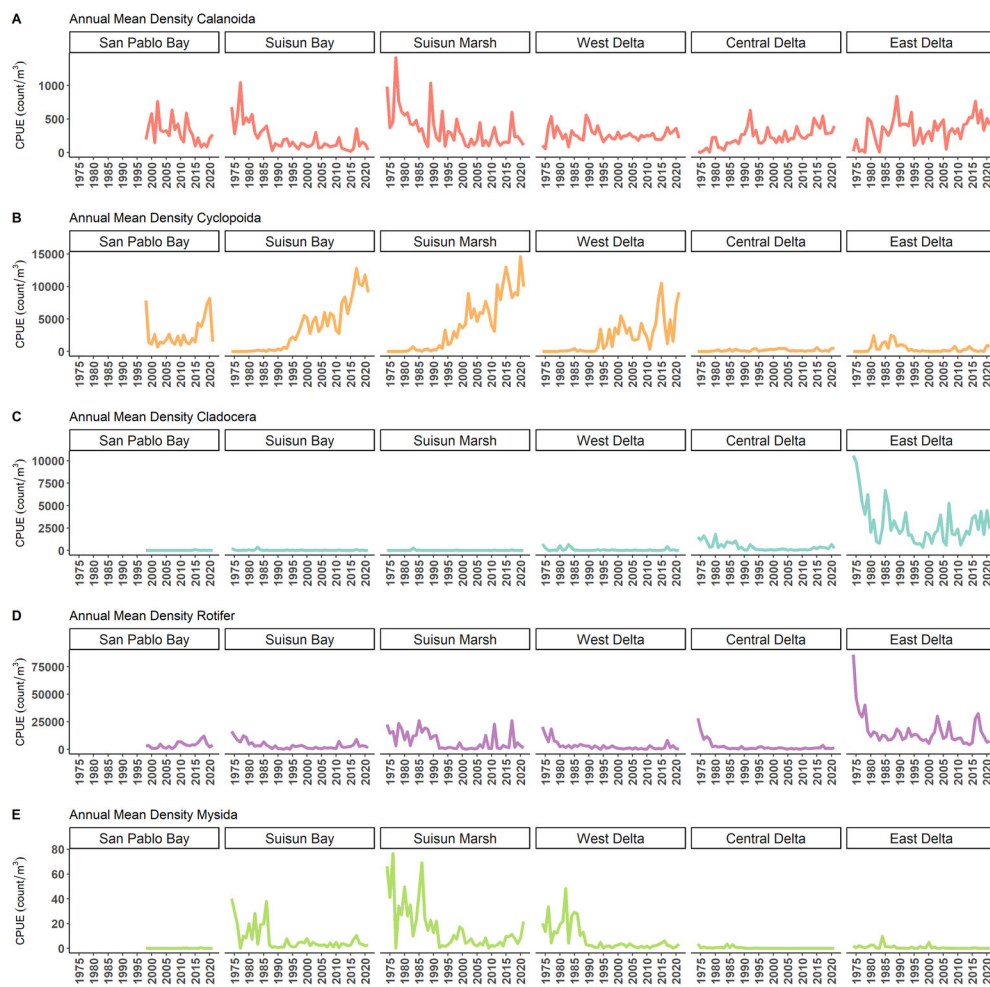


Figure 69: Annual (Mar-Nov) mean zooplankton CPUE by region and order for A) Calanoida CPUE in the CB net, B) Cyclopoida CPUE in pump samples, C) Cladocera CPUE in the CB net, and D) Mysid CPUE in the mysid net, from the EMP survey.

## Cyclopoid copepods

While overall zooplankton abundance has declined over the study period, the abundance of cyclopoid copepods has exploded (Figure 68B). The native *Oithona* spp. and *Acanthocyclops* copepods were at low abundances when the study began, but with the introduction of *Limnoithona sinensis* in the early 1980s, and the later identification of the invasive *Limnoithona tetraspina* in 1993, cyclopoid indices have increased dramatically (Ferrari and Orsi 1984; Orsi and Ohtsuka 1999). Abundance indices for the two species of *Limnoithona* were reported together from 1980 through 2006 as *Limnoithona* spp., then separately since 2007 when they were identified and enumerated as *L. sinensis* and *L. tetraspina*. For the sake of consistency, both have been summed as *Limnoithona* spp. in figures for this report. In 2021, *Limnoithona* spp. abundance was the highest observed for all zooplankton (Figure 68B).

Much smaller than calanoid copepods collected in the CB net, the *Limnoithona* cyclopoids are best retained in pump samples, which use a smaller mesh. Since the early 1990s, *Limnoithona* spp. abundance has been higher than calanoid copepod abundance, and the small *L. tetraspina* has become the most common zooplankton in the upper estuary. This increase in *L. tetraspina* abundance is likely due to a decline of Northern Anchovy in the upper SFE and subsequent decreased predation (Kimmerer 2006), as well as the cyclopoid's small size, high growth rate, and motionless behavior, making it very difficult for visual feeders to capture (Bouley and Kimmerer 2006; Greene et al. 2011). These characteristics may increase its ability to escape predation in a region where visual predation is most dominant among fish (Kimmerer 2006). The introduction of *L. tetraspina* is also linked to the reduction of the range of *P. forbesi* out of the low-salinity zone of the estuary, as high *L. tetraspina* densities may have fed and sustained larger populations of the predatory *A. sinensis*, which also feed on *P. forbesi* nauplii (Kayfetz and Kimmerer 2017).

Seasonally, *Limnoithona tetraspina* peaks in summer and fall (Figure 69B), with lower abundance in winter and spring. As in prior years, these cyclopoids were most abundant in the low-salinity zone of the estuary in Suisun Bay and the West Delta (Figure 70B). *Oithona davisae*, a native cyclopoid, was the most abundant cyclopoid in the higher-salinity San Pablo Bay in summer and fall (Figure 70B).

## Cladocera

The cladoceran community of the upper estuary is composed of *Bosmina*, *Daphnia*, *Ceriodaphnia*, and *Diaphanosoma* species, whose populations have also substantially declined since the onset of the study (Figure 68C). These cladocera tend to be herbivorous, feeding primarily on phytoplankton, and were likely hard hit by the invasion of *P. amurensis* (Baxter et al. 2008; Kratina and Winder 2015). Cladocerans make up a significant portion in the diets of Delta Smelt, juvenile Chinook Salmon, and young-of-the-year Striped Bass throughout the upper estuary (Heubach et al. 1963; Slater and Baxter 2014; Goertler et al. 2018). The invasion and increase of available copepod prey such as *P. forbesi* and the decline in cladocera has created a shift in the nutritional content of the plankton community available for fish, with yet to be determined consequences (Kratina and Winder 2015).

While Cladocera abundance has declined overall since the study began, recent years abundance has been increasing above the lowest levels found in the 1990s (Figure 69C). In the high outflow year of 2017 some cladocera, namely *Bosmina*, were found downstream in Suisun and the West

Delta, but in 2021 the highest densities of cladocera were found in the East Delta, with trace concentrations found in other regions of the estuary (Figure 70C).

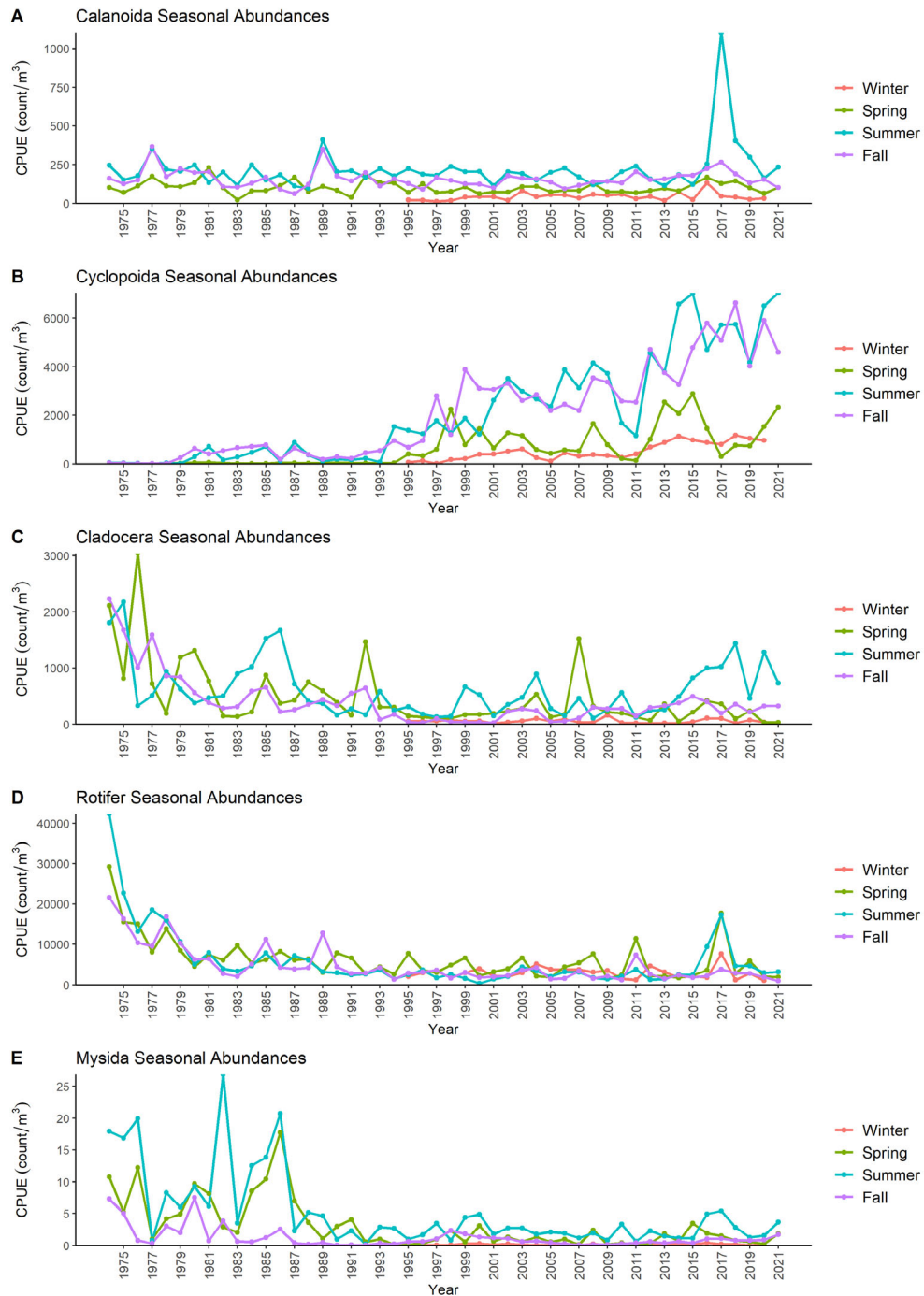


Figure 70: Seasonal mean zooplankton CPUE. Spring, summer, and fall are reported for 1974-2018, winter is reported for 1995-2019. A) Calanoid CPUE in the CB net. B) Cyclopoida CPUE in pump samples. C) Cladocera CPUE in the CB net. D) Rotifer CPUE in pump samples. E) Mysid CPUE in the mysid net



## Rotifer

While they are the most abundant zooplankton in the estuary, long-term sampling of rotifers shows a dramatic decrease in their annual abundance in the estuary since the beginning of this study (Figure 68D). Several species of rotifers make up the community: most abundant being the *Polyarthra*, *Synchaeta*, and *Keratella* genera. Interestingly, the decline of rotifer abundance beginning in the late 1970s preceded the invasion of *P. amurensis* in the estuary (Cloern and Jassby 2012).

The distribution and abundance of rotifers were similar in 2021 to previous years, with abundances similar to those found since the invasion of *P. amurensis*. Overall rotifer abundance peaked in the summer and spring (Figure 69D). *Keratella* and *Polyarthra* tend to be most abundant in the freshwater and low-salinity zone of the estuary, while *Synchaeta* species are most abundant in the higher-salinity areas of San Pablo Bay and Suisun (Winder and Jassby 2011). A spatial and temporal split was discernible between *Synchaeta* and other rotifers, with *Synchaeta* having highest densities in the low-salinity zone Bay during the spring, and other rotifers being most abundant in the East Delta in summer.

## Mysida

Not only have mysid abundances declined significantly since the 1970s, but the community has also shifted from being composed almost entirely by the native *Neomysis mercedis*, to being dominated by the non-native *Hyperacanthomysis longirostris* (formerly *Acanthomysis bowmani*) (Figure 68E). The first significant decline in *N. mercedis* occurred during the 1976-1977 drought, likely caused by food limitation from an absence of diatoms due to very low river discharges (Siegfried et al. 1979; Cloern et al. 1983). The populations of *N. mercedis* were able to rebound after the years of drought and stayed at high densities in the Suisun Bay region of the upper estuary until the introduction of *P. amurensis* in the mid-1980s, after which their numbers crashed.

In 1993 the introduced *H. longirostris* was first detected by this study, shortly after the decline of *N. mercedis*, and it quickly became the most common mysid in the system. However, overall mysid abundances have not returned to their pre-clam invasion levels (Modlin and Orsi 1997, Figure 68E). Mysids have always peaked in the spring and summer months, fluctuating with the higher productivity in the estuary during those seasons (Figure 69E). Historically mysids have been of critical importance in the diets of many fish species in the SFE including Delta Smelt, Longfin Smelt, Striped Bass, and Chinook Salmon (Moyle et al. 1992; Feyrer et al. 2003; CDFG

2009; Goertler et al. 2018). However, the decline of mysids in the upper estuary has resulted in a significant decrease in their presence in the diets of fishes of the region (Feyrer et al. 2003). These low abundances have continued, even though 2021 saw a slight increase in overall mysid abundance compared to the previous few years (Figure 68E), and the distribution and timing of peaks stayed similar over the last two decades (Hennessy 2018). *Hyperacanthomysis longirostris* was again the most common mysid in the estuary during all seasons, while the once common and native *Neomysis mercedis* continued to be almost imperceptible in the region. This has been the overall trend in the estuary's mysid communities since 1994. As in prior years, mysids in 2021 were most abundant during the summer and fall (Figure 69E), and highest concentrations occurred in the low-salinity zone of Suisun and the West Delta (Figure 70E).



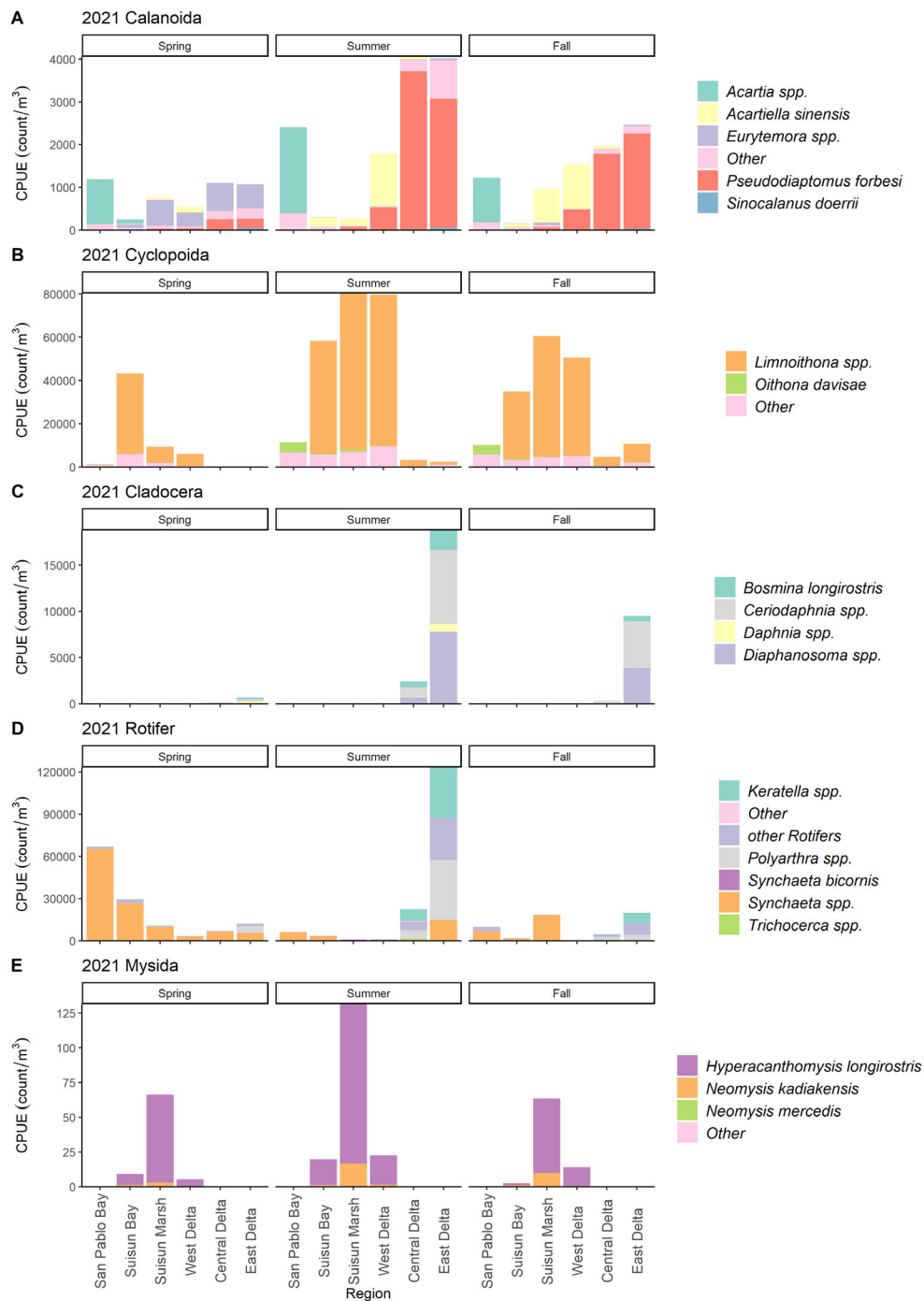


Figure 71: Seasonal mean zooplankton CPUE for reporting year by region for A) Calanoid CPUE in the CB net, B) Cyclopoida CPUE in pump samples, C) Cladocera CPUE in the CB net, D) Rotifer CPUE in pump samples, and E) Mysid CPUE in the mysid net.

## Conclusion

In 2021 the Zooplankton Study recorded the abundances of calanoids, cladocera, rotifers, and mysids at lower densities comparable to other recent years and consistent with the downward historic trends in the estuary. Abundances for all zooplankton peaked in summer for 2021. The small, abundant *Limnoithona tetraspina* was again the most abundant copepod in the upper estuary, and has also become the most abundance zooplankton in the upper estuary. This multi-decade zooplankton study has enabled researchers and managers to track the shifts in zooplankton abundances and community composition across the estuary for nearly 5 decades. The Zooplankton Study has documented the introduction and dominance of *Pseudodiaptomus forbesi*, *Limnoithona tetraspina*, and *Hypercanthomysis longirostris*, as well as the community's response to the invasive clam *Potamocorbula amurensis*. Understanding these dynamics and how they have fundamentally changed trophic interactions is critical to assessing food resources for fish and conservation strategies in the San Francisco Estuary.

## References

- Baxter R, Feyrer F, Nobriga M, Sommer T. 2008. Pelagic Organism Decline Progress Report: 2007 Synthesis of Results. Bouley P, Kimmerer WJ. 2006. Ecology of a highly abundant, introduced cyclopoid copepod in a temperate estuary. Mar Ecol Prog Ser. 324(October):219–228.
- Carlton JT, Thompson JK, Schemel LE, Nichols FH. 1990. Remarkable invasion of San Francisco Bay (California, USA) by the Asian clam *Potamocorbula amurensis*. I. Introduction and dispersal. Mar Ecol Prog Ser. 66:81–94.
- CDFG. 2009. A Status Review of the Longfin Smelt (*Spirinchus thaleichthys*) in California. Sacramento.
- Cloern JE, Alpine AE, Cole BE, Wong RLJ, Arthur JF, Ball MD. 1983. River discharge controls phytoplankton dynamics in the northern San Francisco Bay estuary. Estuar Coast Shelf Sci. 16(4):415–429.
- Cloern JE, Jassby AD. 2012. Drivers of change in estuarine-coastal ecosystems: Discoveries from four decades of study in San Francisco Bay. Rev Geophys. 50:4001.

Ferrari FD, Orsi J. 1984. *Oithona davisae*, new species, and *Limnoithona sinensis* (Burckhardt, 1912) (Copepoda: Oithonidae) from the Sacramento-San Joaquin Estuary, California. J Crustac Biol. 4(1):106–126.

Feyrer F, Herbold B, Matern SA, Moyle PB. 2003. Dietary shifts in a stressed fish assemblage: Consequences of a bivalve invasion in the San Francisco Estuary. Goertler P, Jones K, Cordell J, Schreier B, Sommer T. 2018. Effects of extreme hydrologic regimes on juvenile Chinook Salmon prey resources and diet composition in a large river floodplain. Trans Am Fish Soc. 147:287–299.

Greene VE, Sullivan LJ, Thompson JK, Kimmerer WJ. 2011. Grazing impact of the invasive clam *Corbula amurensis* on the microplankton assemblage of the northern San Francisco estuary. Mar Ecol Prog Ser. 431(February):183–193.

Hennessy A. 2018. Zooplankton Monitoring 2017. Interag Ecol Progr Newsl. 32(1):21–32.

Heubach W, Toth RJ, Mccready AM. 1963. Food of Young-of-the-year Striped Bass (*Roccus Saxatilis*) in the Sacramento-San Joaquin River. Calif Fish Game. 49(4):224–239.

Hobbs JA, Bennett WA, Burton JE. 2006. Assessing nursery habitat quality for native smelts (Osmeridae) in the low-salinity zone of the San Francisco estuary. J Fish Biol. 69(3):907–922.

Kayfetz K, Kimmerer W. 2017. Abiotic and biotic controls on the copepod *Pseudodiaptomus forbesi* in the upper San Francisco Estuary. Mar Ecol Prog Ser. 581(Runge 1988):85–101.

Kimmerer W, Ignoffo TR, Bemowski B, Modéran J, Holmes A, Bergamaschi B. 2018. Zooplankton dynamics in the Cache Slough Complex of the upper San Francisco estuary. San Fr Estuary Watershed Sci. 16(3).

Kimmerer WJ. 2006. Response of anchovies dampens effects of the invasive bivalve *Corbula amurensis* on the San Francisco Estuary foodweb. Mar Ecol Prog Ser. 324(Cloern 1982):207–218.

Kimmerer WJ, Gartside E, Orsi JJ. 1994. Predation by an introduced clam as the likely cause of substantial declines in zooplankton of San Francisco Bay. Mar Ecol Prog Ser. 113(1–2):81–94.

Kratina P, Winder M. 2015. Biotic invasions can alter nutritional composition of zooplankton communities. Oikos. 124:1337–1345.

Modlin RF, Orsi JJ. 1997. *Acanthomysis bowmani*, a new species, and *A. aspera* li, Mysidacea newly reported from the Sacramento-San Joaquin Estuary, California (Crustacea: Mysidae). Proc Biol Soc Washingt. 110(3):439–446.

Moyle PB, Herbold B, Stevens DE, Miller LW. 1992. Life history and status of Delta Smelt in the Sacramento-San Joaquin estuary, California. *Trans Am Fish Soc.* 121(1):67–77.

Orsi J, Walter TC. 1991. *Pseudodiaptomus forbesi* and *P. marinus* (Copepoda: Calanoida), the latest copepod immigrants to California's Sacramento-San Joaquin Estuary. *Bull Plankt Soc Japan.*:553–562.

Orsi JJ, Bowman TE, Marelli DC, Hutchinson A. 1983. Recent introduction of the planktonic calanoid copepod *Sinocalanus doerrii* (Centropagidae) from mainland China to the Sacramento-San Joaquin Estuary of California. *J Plankton Res.* 5(3):357–375.

Orsi JJ, Ohtsuka S. 1999. Introduction of the Asian copepods *Acartiella sinensis*, *Tortanus dextrilobatus* (Copepoda: Calanoida), and *Limnoithona tetraspina* (Copepoda: Cyclopoida) to the San Francisco Estuary, California, USA. *Plankt Biol Ecol.* 46(2):128–131.

Schroeter RE, O'Rear TA, Young MJ, Moyle PB. 2015. The aquatic trophic ecology of Suisun Marsh, San Francisco Estuary, California, during autumn in a wet year. *San Fr Estuary Watershed Sci.* 13(3).

Siegfried CA, Kopache ME, Knight AW. 1979. The Distribution and Abundance of *Neomysis mercedis* in Relation to the Entrapment Zone in the Western Sacramento-San Joaquin Delta. *Trans Am Fish Soc.* 108(3):262–270.

Slater SB, Baxter R. 2014. Diet, Prey Selection, and Body Condition of Age-0 Delta Smelt, *Hypomesus transpacificus*, in the Upper San Francisco Estuary. *San Fr Estuary Watershed Sci.* 12(3):1–24.

Sommer T, Armor C, Baxter R, Breuer R, Brown L, Chotkowski M, Culberson S, Feyerer F, Gingras M, Herbold B, et al. 2007. The collapse of pelagic fishes in the upper San Francisco Estuary. *Fisheries.* 32(6):270–277.

Winder M, Jassby AD. 2011. Shifts in Zooplankton Community Structure: Implications for Food Web Processes in the Upper San Francisco Estuary. *Estuaries and Coasts.* 34:675–690.

## Data and Contact Info

Data available on the [Environmental Data Initiative portal](#) or the [CDFW FTP site](#).

For questions related to EMP's zooplankton data sets, please contact Arthur Barros at [arthur.barros@wildlife.ca.gov](mailto:arthur.barros@wildlife.ca.gov).