State of the Estuary Report 2015

Summary

PROCESSES – Zooplankton as Food

Prepared by
April Hennessy, California Department of Fish and Wildlife

State of the Estuary Report 2015- Zooplankton Indicator

1. Brief description of indicator and benchmark

Table 1.1

Attribute	Indicator	Benchmarks
Zooplankton	• Mysid and calanoid copepod biomass in Delta and Suisun regions	• Benchmark was the historical average 1974-1986 biomass for each region. At or above benchmark was considered "Good", below benchmark to 25% of benchmark was "fair", and below 25% of benchmark was "poor". Current status determined by 2010-2014 average biomass.

2. Indicator status and trend measurements

Table 1.2

Attribute	Status	Trend	Details
Mysid biomass- Suisun & Delta	Poor	Declined from historic, stable since 2000	Mysid biomass has shown a significant decline since the historical benchmark period and the current status is "poor", due in part to competition with the non-native invasive clam *Potamorcorbula amurensis.*
Calanoid copepod biomass- Suisun	Fair	Declined from historic, stable since 2000	Calanoid copepod biomass has shown a significant decline since the historical benchmark period and the current status is "fair", due in part to competition with and predation from the non-native invasive clam *Potamocorbula amurensis.*
Calanoid copepod biomass- Delta	Good	Increased from historic, stable since 2000	Calanoid copepod biomass has shown a significant increase since the historical benchmark period and the current status is "good".
Zooplankton	Mixed	Declined from historic, stable since 2000	Mysid biomass declined in both the Suisun and Delta regions and the current status is "poor", due in part to competition with the non-native invasive clam *Potamorcorbula amurensis.* In Suisun, calanoid copepod biomass declined and the current status is "fair", due in part to competition with and predation from the non-native invasive clam *Potamocorbula amurensis.* In the Delta, calanoid copepod biomass has significantly increased and the current status is "good".

3. Brief write-up of scientific interpretation

Provide 2-3 sentences to answer the question: What is this indicator?

Provide 2−3 sentences to answer the question: Why is it important?

Zooplankton are small aquatic invertebrates that provide an important trophic link between primary producers and fish. Most larval and juvenile fish eat zooplankton, and some small fish such as Delta Smelt and Longfin Smelt rely on zooplankton for food throughout their lives. To assess trends in fish food resources in the upper San Francisco Estuary (SFE), the Interagency Ecological Program's Zooplankton Study has provided annual zooplankton abundance estimates since 1972. Calanoid copepods and mysids are crustaceans that were chosen for the zooplankton indicator because they are important food items for Delta Smelt and Longfin Smelt, two listed fish species in the upper SFE.

Zooplankton samples were collected by the California Department of Water Resources during their monthly water quality monitoring cruise at 16 to 22 stations using plankton nets. The samples were preserved and returned to the California Department of Fish and Wildlife's Laboratory in Stockton, CA for processing. Average annual biomass, which is a measure of available carbon, of calanoid copepods and mysids was calculated using March through November data from 14 stations (6 in Suisun region and 8 in Delta region, see map) that have been consistently sampled since 1974.

Provide 2−3 sentences to answer the questions: What is the benchmark? How was it selected?

Provide 2−3 sentences to answer the question: What is the status and trend for this indicator?

Since the late 1980s, zooplankton biomass has decreased in most areas of the upper SFE, particularly in the low salinity zone. This decrease has been attributed in large part to the introduction of *Potamocorbula amurensis* in 1986, an invasive clam found in the low salinity zone (see benthic indicator for more about this clam). Competition with *P. amurensis* for phytoplankton, a shared food resource, as well as clam consumption of copepod nauplii (babies) has reduced zooplankton. The historical reference period 1974-1986 was selected as the benchmark, as it is the earliest data available before the disturbance caused by *P. amurensis.* At or above the 1974-1986 average biomass was considered "good", below to 25% of this benchmark was considered "fair", and below 25% of this benchmark was considered "poor". The current status was considered the average 2010-2014 biomass. The trend was determined by a linear slope of the annual data, and the significance of this slope was determined by a Mann-Kendall test ($p<0.005$ was considered significant).

Mysid biomass has declined in both the Suisun and Delta regions of the upper SFE since monitoring began. Since 2001, mysid biomass in both regions has been "poor". The 2010-2014 average biomass was 1.6 milligrams of carbon per cubic meter of water sampled for the Suisun region and 0.4 milligrams of carbon per cubic meter of water sampled for the Delta region, placing the current status of both regions as "poor". There was a significant downward trend in annual mysid biomass for both regions from 1974-2014 ($p<0.001$). However, since 2000 there was no significant trend, indicating that although mysid biomass is lower than it was historically, it does not appear to be declining further.

Calanoid copepod biomass has declined in the Suisun region of the upper SFE since monitoring began. Since 1988, calanoid copepod biomass in the Suisun region has fluctuated between "fair" and "poor", with small peaks occurring during higher flow years such as 2006 and 2011. The current status of calanoid copepods in the Suisun region is "fair". Like the mysids, there was a significant downward trend from 1974-2014 in the Suisun region ($p<0.001$). However, from 2000 through 2014 there was no significant trend, indicating that although calanoid copepod biomass is lower than it was historically, it does not appear to be declining further in the Suisun region.

Calanoid copepod biomass has increased in the Delta region of the upper SFE since monitoring began. In the Delta region calanoid copepod biomass has fluctuated between "good" and "fair" for the entire monitoring period, however biomass during the historical reference period used to establish the benchmark was low. The current status of calanoid copepods in the Delta region is "good". There was a significant upward trend in biomass from 1974-2014 in the Delta region ($p=0.0047$); however from 2000-2014, there was no trend.

Provide 4–6 sentences to answer the questions: What does it mean? Why do we care?

Zooplankton plays a key role in the food web by providing the means for energy to move up the food chain from phytoplankton to fish. The food web of the upper SFE has been highly altered by the introduction of non-native invasive species, particularly the clam *P. amurensis*. The resultant zooplankton decline in the low salinity zone has been implicated as one of the many causes of the pelagic organism decline (POD) which described the dramatic decline of several pelagic fish species. Recovery of listed fish species such as the Delta Smelt and Longfin Smelt relies in part on food availability.

State of the Estuary Report 2015

Technical Appendix

PROCESSES – Zooplankton as Food

Prepared by
April Hennessy, California Department of Fish and Wildlife

5. Technical appendix- Zooplankton Indicator

- **Background and Rationale**
    - **Discuss how the indicator relates to the ecological health of the estuary.**
    - **Include historical information about the indicator and any current programs to evaluate it.**
    - **Explain why this indicator and this calculation approach were chosen**.

Zooplankton is an important component of the pelagic food web, providing a key trophic link between fish and phytoplankton. Most larval and juvenile fish in the upper San Francisco Estuary (SFE) feed on zooplankton, and some smaller fish like Delta Smelt and Longfin Smelt feed on zooplankton throughout their lives. Summer to fall survival of Delta Smelt has been positively linked with zooplankton biomass (Kimmerer 2008).

Monitoring of zooplankton in the upper SFE is conducted by the California Department of Fish and Wildlife's Zooplankton Study as part of the Interagency Ecological Program for the San Francisco Estuary (IEP). Since the late 1980s, zooplankton has decreased in most areas of the upper SFE, particularly in the low salinity zone. This decrease has been attributed in large part to the introduction of *Potamocorbula amurensis* in 1986, an invasive clam found in the low salinity zone (see benthic indicator for more about this clam). Competition with *P. amurensis* for phytoplankton, a shared food resource, as well as predation on copepod nauplii (babies) by *P. amurensis* has reduced zooplankton (Kimmerer and Orsi 1996, Orsi and Mecum 1996, Kimmerer et al. 1994). The decline is particularly evident in Suisun Bay, a region heavily impacted by *P. amurensis.*

Zooplankton biomass, as calculated for this indicator, is an estimate of the relative amount of carbon available in calanoid copepods and mysids for comparison between years, and is not meant to estimate the total carbon available from the entire zooplankton population. Calanoid copepods and mysids were chosen as the representative zooplankton taxa for the indicator because these are important food items for Delta Smelt and Longfin Smelt, 2 listed fish species in the upper SFE (Chigbu and Sibley 1998, Nobriga 2002, Hobbs et al. 2006, Slater and Baxter 2014).

- **Benchmark**
    - **Describe the benchmark and why it was chosen.**

The average biomass during the historical reference period 1974-1986 was chosen as the benchmark, because there is no established standard threshold for "healthy" zooplankton biomass in the upper SFE. Therefore, the earliest available data prior to the disturbance caused by the introduction and spread of *Potamocorbula amurensis* around 1987 was used as the benchmark. The benchmark was established as the 1974-1986 average and was considered "good", less than the benchmark down to 25% of the benchmark was considered "fair", and less than 25% of the benchmark was considered "poor". The current status was reported as the average 2010-2014 biomass. The trend was determined by a linear slope of the annual data and the significance of this slope was determined by a Mann-Kendall test where $p<0.005$ was considered significant.

- **Discuss any limitations of the benchmark and how it might be improved in the future.**

The historical reference period (1974-1986) used to set the benchmark for "good" zooplankton biomass is biologically relevant, since most zooplankton declined after the introduction of *P. amurensis*. However, many human-induced changes occurred in the upper SFE before this period, therefore it probably does not truly reflect a pristine state of zooplankton biomass. The benchmark was based on the average biomass in each region during the historical reference period, therefore in areas like the Delta where the historical biomass was lower the benchmark was lower. Zooplankton data is highly variable, both in time and space, so one way to improve the benchmark in the future may be to take a station by station approach and look at how many stations in each region or season reached a specific threshold rather than taking the average of all stations in the region from March through November.

The indicator could be improved in the future by limiting analysis to the most utilized copepod species. Some fish like Delta Smelt tend to utilize certain calanoid copepod species more than others and also utilize some species of cyclopoid copepods (Slater and Baxter 2014).

- **Data Sources**

  - **Describe the data used and where they came from.**

The data used for this indicator was from the IEP's Zooplankton Study, a long-term monitoring survey which has been monitoring zooplankton in the upper SFE since 1972. Zooplankton samples were collected by the California Department of Water Resources during their monthly water quality monitoring cruise at approximately 16 to 22 stations using plankton nets. The number of stations sampled varied depending on the location of the floating entrapment zone stations (where sampling location is determined by a bottom specific conductivity of 2 and 6 mS/cm, approximately 1 and 3 ‰), and specific conductance (3 stations in San Pablo Bay and Carquinez Strait were only sampled when surface specific conductance was less than 20 mS/cm). The study area extends from eastern San Pablo Bay through the Delta (see complete station map at www.dfg.ca.gov/delta/data/zooplankton/stations.asp). Only a subset of selected stations in the Delta and Suisun regions were used for this indicator. Data is available through a password protected ftp site; access information can be obtained by contacting April Hennessy of the California Department of Fish and Wildlife (April.Hennessy@wildlife.ca.gov).

At each station, plankton nets were towed obliquely for 10 minutes, to get samples that were representative of zooplankton in the entire water column from the bottom to the surface. Two conical nets arranged next to each other on a sled were used to target zooplankton of different sizes. A meso-zooplankton net was used to target adult and juvenile calanoid copepods (160 micron mesh) and a macro-zooplankton net was used to target mysids (500 micron mesh). A General Oceanics flowmeter was mounted in the mouth of each net to measure the volume of water sampled during the tow. Pump samples were also collected to target smaller zooplankton like rotifers and smaller cyclopoid copepods, however this data was not used to develop the zooplankton indicator presented here. Samples were preserved in 10% formalin and returned to the California Department of Fish & Wildlife's Laboratory in Stockton, CA for processing. Organisms in samples were identified and enumerated using a dissecting microscope.

Meso-zooplankton samples were rinsed and then diluted in a beaker of water to an approximate organism concentration of 200-400 organisms per milliliter of water (called dilution volume). Subsamples were taken 1 milliliter at a time with an auto pipette, and placed on a Sedgewick-Rafter slide for identification and enumeration. Between 5 and 20 slides were examined for each sample, this number varied depending on the dilution volume with a target of 6% of the sample examined. For example if the sample volume was 100 ml, then 6 slides were examined. Catch-per-unit-effort (CPUE) was then calculated for each sample as:

CPUE = ((C/S)L)/V

Where:
CPUE = the number of a taxon per cubic meter of water filtered
C = the cumulative number of a taxon counted for the sample
L = the reconstituted sample volume (dilution volume) in milliliters
S = the number of Sedgewick-Rafter cells examined (1 ml ea)
V = the volume of water filtered through the net (m^3) (where volume filtered is estimated by:
VolFiltered = (end meter – start meter) * calibration factor * mouth area)

Biomass-per-unit-effort (or BPUE, also referred to simply as "biomass" for this indicator) was then calculated by multiplying CPUE by a carbon weight for each taxon in micrograms, using some literature based values and some provided by Dr. Wim Kimmerer of Romberg-Tiburon Center for Environmental Studies (Kimmerer 2006, Uye et al. 1983, Culver et al. 1985, Hoof and Bollens 2004). BPUE was then converted from micrograms to milligrams per cubic meter of water sampled, as reported here, by dividing by 1000.

Macro-zooplankton samples were rinsed with water to remove excess formalin, and then placed in a sorting tray for processing. Samples that appeared to have more than 400 mysids were subsampled by placing a quadrant splitter into the tray. If the first quadrant appeared to have more than 400 mysids, then this quadrant was split again into 4 more quadrants. This process was repeated until the subsample appeared to have no more than 400 mysids in it. Each quadrant was processed until a minimum of 400 mysids were processed and the number of quadrants processed determined the subsample. The first 100 non-gravid females (those not carrying eggs), males, and juveniles, as well as the first 30 gravid females (those carrying eggs) of each species were measured from the tip of the eye to the base of the telson. Measurements were rounded up to the nearest millimeter and recorded. All remaining mysids of each species in the subsample were counted and the total was recorded as the plus count. The total number of each mysid species was determined by the equation:

$N = C/S$
N = total number of each mysid species in the sample
C = total of mysids in the sub-sample (number measured + plus count)
S = sub-sample or fraction of the sample examined.

Biomass was calculated from length-frequency using length-weight regression equations for *Neomysis mercedis* and *Hyperacanthomysis longirostris* (J. Orsi CDFW, unpublished). The length weight equation for *N. mercedis* was used for all other species besides *H. longirostris.* Weight was then summed by species for each sample date and station, and biomass estimated using a carbon to dry weight ratio of 40% (Uye 1982).

- **Methods**
  - **Describe the calculation methods.**

The sum of total calanoid copepods BPUE and total mysid BPUE was calculated for each sample date and station. Annual averages for each region were then calculated using March-November data for all stations in each region. The benchmark was calculated as the average of the 1974-1986 annual averages, and the "fair-poor" scoring break as 25% of the benchmark. The current status was calculated as the average of the 2000-2014 annual averages. The trend was calculated by a linear slope of the annual averages for each region, and the significance of the slope tested using a Mann-Kendall test where $p<0.005$ was considered significant.

  - **Include a description of the assumptions and uncertainties.**

Zooplankton are sampled monthly at fixed stations, therefore data are limited temporally and spatially. It is assumed that BPUE at these stations is representative of zooplankton BPUE throughout the upper SFE, however zooplankton is highly variable temporally and spatially.

- **Peer Review**
  - **Describe how the indicator was vetted with other experts in the community as per the SOTER Peer Input Guidelines.**

Several venues were used for peer review of the zooplankton indicator. Consultation with fellow State of the Estuary contributors Elizabeth Wells (California Department of Water Resources) and Hildegarde Spautz (California Department of Fish and Wildlife), as well as Dr. Wim Kimmerer from the Romberg Tiburon Center for Environmental Studies, and Kathryn Hieb (DFW) led to several revisions of the indicator. Drafts of the indicator ideas, calculations, and results were presented at State of the Estuary meetings as well as at several California Estuary Monitoring Workgroup meetings, and were discussed in meetings of the Living Resources subgroup of the California Estuary Monitoring Workgroup. Further discussion of indicator benchmarks and scoring was conducted with Letitia Grenier and Amy Richey (both of the San Francisco Estuary Institute), as well as with Elizabeth Wells and Hildegarde Spautz.

- **Results**
  - **In addition to summarizing the status and trend, this is a place to provide greater detail on the results that may not be possible in the limited space of the main report.**

Mysids have declined in both the Suisun and Delta regions of the upper SFE since monitoring began. The historical reference period from 1974-1986 established the benchmarks of 17.3 milligrams of carbon per cubic meter of water (a measure of biomass) sampled for the Suisun region and 7.7 milligrams of carbon per cubic meter of water sampled for the Delta region. After a slight upturn in 2000, biomass in both regions has been below the "fair" threshold of 4.3 milligrams of carbon per cubic meter of water sampled for the Suisun region and 1.9 milligrams of carbon per cubic meter of water sampled for the Delta region. The 2010-2014 average biomass was 1.6 milligrams of carbon per cubic meter of water sampled for the Suisun region and 0.4 milligrams of carbon per cubic meter of water sampled for the Delta region, placing the current status of both regions as "poor". The annual data had a significant downward trend for both regions from 1974-2014 ($p<0.001$). However, from 2000 through 2014 there was no significant trend, indicating that although mysid biomass is lower than it was historically, it does not appear to be declining further.

Calanoid copepods have declined in the Suisun region of the upper SFE since monitoring began. The 1974-1986 average of 15.3 milligrams of carbon per cubic meter of water sampled was the historical reference period used to establish the benchmark for the Suisun region. At or above this benchmark was considered "good", below this benchmark down to 25% of this benchmark was considered "fair", and less than 25% was considered "poor". In the Suisun region calanoid copepod biomass fluctuated between "good" and "fair", until 1988 when it fell below the threshold of 3.8 milligrams of carbon per cubic meter of water sampled to "poor". Since 1988, calanoid copepod biomass in the Suisun region fluctuated between “fair” and “poor”, with small peaks occurring during higher flow years like 2006 and 2011. The current status of calanoid copepods in the Suisun region is “fair” with the 2010-2014 average of 4.7 milligrams of carbon per cubic meter of water sampled. Similar to the mysids, there was a significant downward trend from 1974-2014 in the Suisun region ($p<0.001$). However, in recent years from 2000 through 2014 there was no significant trend, indicating that although calanoid copepod biomass is lower than it was historically, it does not appear to be declining further in the Suisun region.

Calanoid copepod biomass has increased in the Delta region of the upper SFE since monitoring began. The 1974-1986 average of 5.6 milligrams of carbon per cubic meter of water sampled was the historical reference period used to establish the benchmark for the Delta region. At or above this benchmark was considered “good”, below this benchmark down to 25% of this benchmark was considered “fair”, and less than 25% was considered “poor”. In the Delta region calanoid copepod biomass has fluctuated between “good” and “fair” for the entire monitoring period, however biomass during the historical reference period used to establish the benchmark was low. The current status of calanoid copepods in the Delta region is “good” with the 2010-2014 average of 7.9 milligrams of Carbon per cubic meter of water sampled. From 1974 through 2014 there was a significant upward trend in calanoid copepod biomass in the Delta region ($p=0.0047$), however from 2000-2014 there was no trend.

- **Literature Cited**

Chigbu, P. and T. H. Sibley. 1998. Predation by longfin smelt (*Spirinchus thaleichthys)* on the mysid *Neomysis mercedis* in Lake Washington. Freshwater Biology 40(2):295-304.

Culver, D. A., M. M. Boucherle, D. J. Bean, and J. W. Fletcher. 1985. Biomass of freshwater crustacean zooplankton from length-weight regressions. Canadian Journal of Fisheries and Aquatic Sciences **42**: 1380-1390.

Hobbs, J. A., W. A. Bennett, and J. E. Burton. 2006. Assessing nursery habitat quality for native smelts (*Osmeridae*) in the low-salinity zone of the San Francisco estuary. Journal of Fish Biology 69: 907-922.

Hooff, R. C. and S. M. Bollens. 2004. Functional response and potential predatory impact of *Tortanus dextrilobatus*, a carnivorous copepod recently introduced to the San Francisco Estuary. Marine Ecology Progress Series **277**: 167-179.

Kimmerer, W. J. 2006. Response of anchovies dampens effects of the invasive bivalve *Corbula amurensis* on the San Francisco Estuary foodweb. Marine Ecology Progress Series 324: 207-218.

Kimmerer, W. J. 2008. Losses of Sacramento River Chinook Salmon and Delta Smelt *(Hypomesus transpacificus)* to Entrainment in Water Diversions in the Sacramento-San Joaquin Delta. San Francisco Estuary and Watershed Science Vol. 6, Issue 2 (June), Article 2.

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.

Nobriga, M. L. 2002. Larval delta smelt diet composition and feeding incidence: environmental and ontogenetic influences. California Fish and Game 88(4):149-164.

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.

Slater, S. B. and R. D. Baxter. 2014. Diet, Prey Selection, and Body Condition of Age-0 Delta Smelt, *Hypomesus transpacificus*, in the Upper San Francisco Estuary. *San Francisco Estuary and Watershed Science* **12**(3).

Uye, S. 1982. Length-weight relationships of important zooplankton from the Inland Sea of Japan. *Journal of the Oceanographical Society of Japan* **38**: 149-158.

Uye, S., Y. Iwai, S. Kasahara.1983. Growth and production of the inshore marine copepod *Pseudodiaptomus marinus* in the central part of the Inland Sea of Japan. Marine Biology **73**(1): 91-98.

- **Acknowledgements-**

I would like to acknowledge and thank the field crew who collected the samples and the laboratory staff who processed the samples:
Eric Santos, Scott Waller, Nicholas VanArk, and Gregg Schmidt (retired) from the Department of Water Resources; Sally Skelton, Tina Enderlein, and Danae Jordan from California Department of Fish and Wildlife; as well as The Interagency Ecological Program for the San Francisco Estuary for funding and facilitating the Zooplankton Study.

I would also like to thank Elizabeth Wells (DWR), Hildegarde Spautz (DFW), Kathryn Hieb (DFW), Steven Slater (DFW), Karen Kayfetz (Delta Science Program) and Dr. Wim Kimmerer (RTC) for their input and review.