State of California
Department of Fish and Wildlife

M e m o r a n d u m

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To: Stephen Louie
Senior Environmental Scientist
Department of Fish and Wildlife
Water Branch

From: April Hennessy
Environmental Scientist

Zair Burris
Environmental Scientist

Bay-Delta Region
Stockton, CA

Subject: Preliminary analysis of current relationships between zooplankton abundance and freshwater outflow in the upper San Francisco Estuary

This memo documents new California Department of Fish and Wildlife (CDFW) information regarding zooplankton abundance trends in the low salinity zone of the upper San Francisco Estuary in response to freshwater outflow.

Zooplankton are an important food resource for juvenile fish and small pelagic fish (e.g., Delta Smelt and Longfin Smelt) in the upper San Francisco Estuary. The CDFW Zooplankton Study has provided indices of annual zooplankton abundance in the upper San Francisco Estuary (SFE) from 1972-2016, based on monthly sampling from January through December at 19 stations (www.wildlife.ca.gov/Conservation/Delta/Zooplankton-Study). The calanoid copepod *Eurytemora affinis* and the mysid shrimp *Neomysis mercedis* are zooplankton species that have exhibited relationships between abundance and freshwater outflow. The abundance of *E. affinis* was not correlated with flow until the invasion of an invasive clam in 1986, after which spring abundance has been positively related to Delta outflow (Kimmerer 2002). The flow-abundance relationship of N*. mercedis* also changed after the clam invasion, such that summer abundance now increases with low outflows (Kimmerer 2002). *Pseudodiaptomus* *forbesi* is a calanoid copepod that comprises over half of the summer and fall diets of Delta Smelt, Longfin Smelt, and some other planktivorous fishes (Hobbs et al. 2006, Bryant and Arnold 2007, Slater and Baxter 2014), and now freshwater outflow influences its abundance in the western portion of its range. Because these relationships may have changed over time, our goal was to update the flow-abundance relationships through 2015. Abundance of all three species was found to have a positive relationship with freshwater outflow using simple linear regression.

We describe trends in abundance for the three species using catch per unit effort (CPUE as the number per cubic meter of water sampled) data from the CDFW Zooplankton Study (ftp://ftp.dfg.ca.gov/IEP_Zooplankton/). For the two copepod species, we used data collected by a modified Clarke-Bumpus (CB) net (160-micron mesh). For *Neomysis mercedis*, we used data collected by the mysid shrimp net (505-micron mesh).

We examined *Eurytemora affinis* and *Neomysis mercedis* abundance using data from the 'floating entrapment zone stations', which are stations that move up and down the estuary with less or more outflow (Table 1). These stations were sampled where bottom specific conductance was approximately 2 milliSiemens per centimeter and 6 milliSiemens per centimeter (i.e., 1 ppt and 3 ppt). Monthly sampling at these stations began in 1994 in order to characterize zooplankton abundance in the low salinity zone (ca. 1-6 ppt), and our analysis includes 1994-2015 data. For *Pseudodiaptomus forbesi*, we used 1989-2015 data from all stations in the Suisun Bay region (Table 1). For both copepod species, naupliar abundance was excluded from the analysis since the CB net does not sample these small organisms well. Instead, the sum of the CPUE values for adults and juveniles were calculated for each station. Because these species are seasonal, we focused on the months during which they are most abundant (Table 1). For each month and year of interest, we averaged CPUE values from the specific stations by month, and then these monthly means were averaged for each year to get an annual abundance value. In all cases, abundance data were transformed to normalize residuals (see Table 1).

Daily Delta outflow (cubic feet per second) was obtained from the Department of Water Resources (http://www.water.ca.gov/dayflow/output/). Mean outflows were calculated for each month then averaged over the specific month period for each species (Table 1) and for each year. Non-transformed species abundance data (y-values) were plotted on mean outflow data to establish and visualize the relationships (Figures 1-3). Finally, we transformed mean outflows (Table 1) and performed least squares linear regressions (with R 3.3) with transformed outflow as the explanatory variable for transformed species abundance.

Abundance for each of the three species increases significantly with increasing outflow (For all: R^2>0.3, P<0.001; Table 1). Even with the selected transformation for *Pseudodiaptomus forbesi*, the residuals were not normally distributed such that a simple linear regression was not the best fit. Nonetheless, there was a significant positive correlation between abundance and outflow (Table 1).

We found that, outflow- or another factor correlated with outflow- is an important determinant of:

1. ***Eurytemora affinis* spring abundance in the low salinity zone and its persistence into early summer**
2. ***Pseudodiaptomus forbesi* summer and early fall transport to and abundance in Suisun Bay**
3. ***Neomysis mercedis* spring abundance in the entrapment zone**

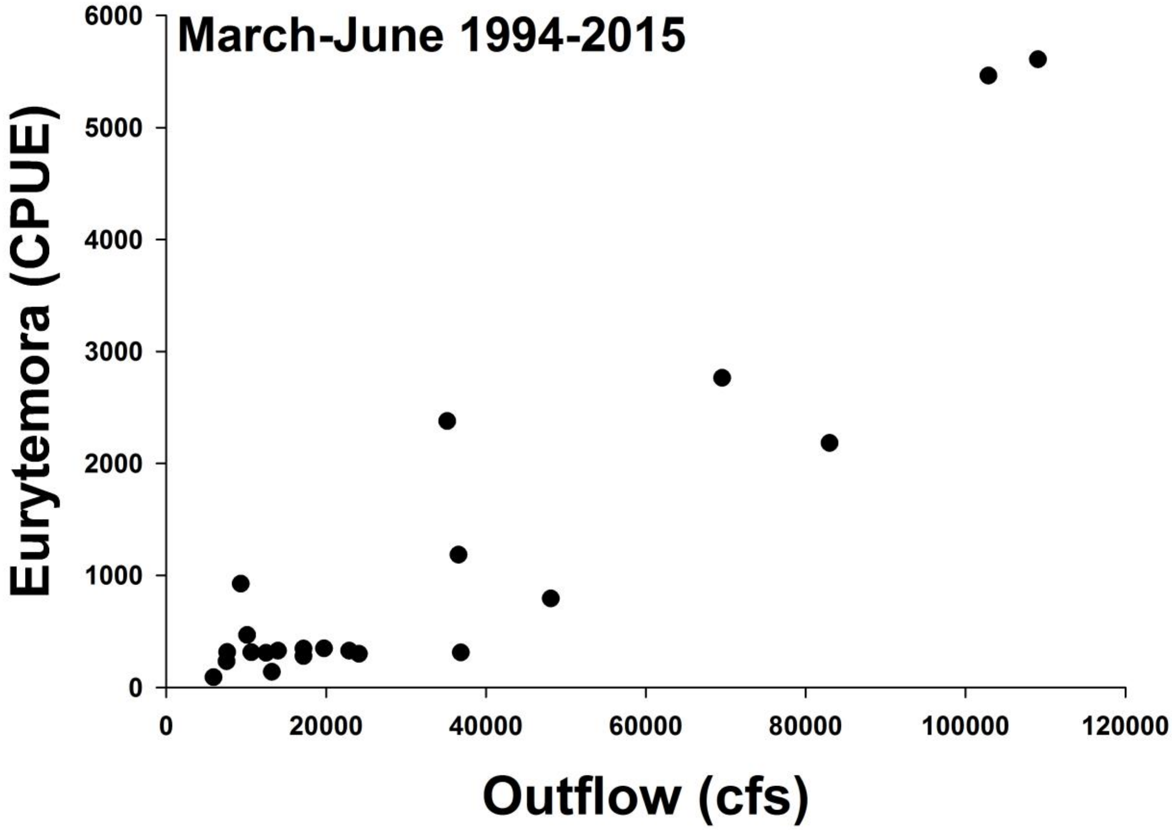

Figure 1: Mean abundance (CPUE) in the entrapment zone by mean Delta outflow (cfs) for *Eurytemora affinis* adults and *Eurytemora* spp. juveniles from March through June each year from 1994 to 2015. CPUE data from CDFW Zooplankton Study CB net and outflow data from DWR DAYFLOW.

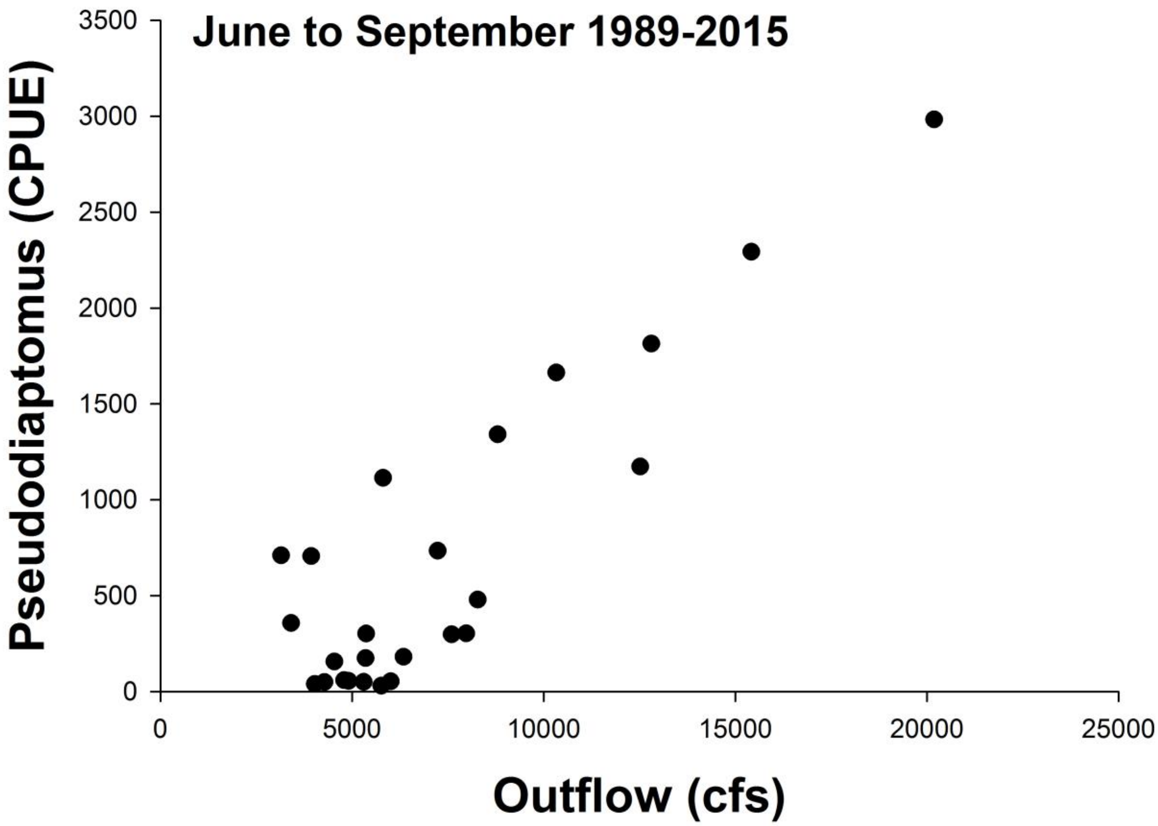

Figure 2: Mean Suisun Bay abundance (CPUE) by mean Delta outflow (cfs) for adult *Pseudodiaptomus forbesi* and juvenile *Pseudodiaptomus* spp. from June to September each year from 1989 to 2015. CPUE data from CDFW Zooplankton Study CB net and outflow data from DWR DAYFLOW.

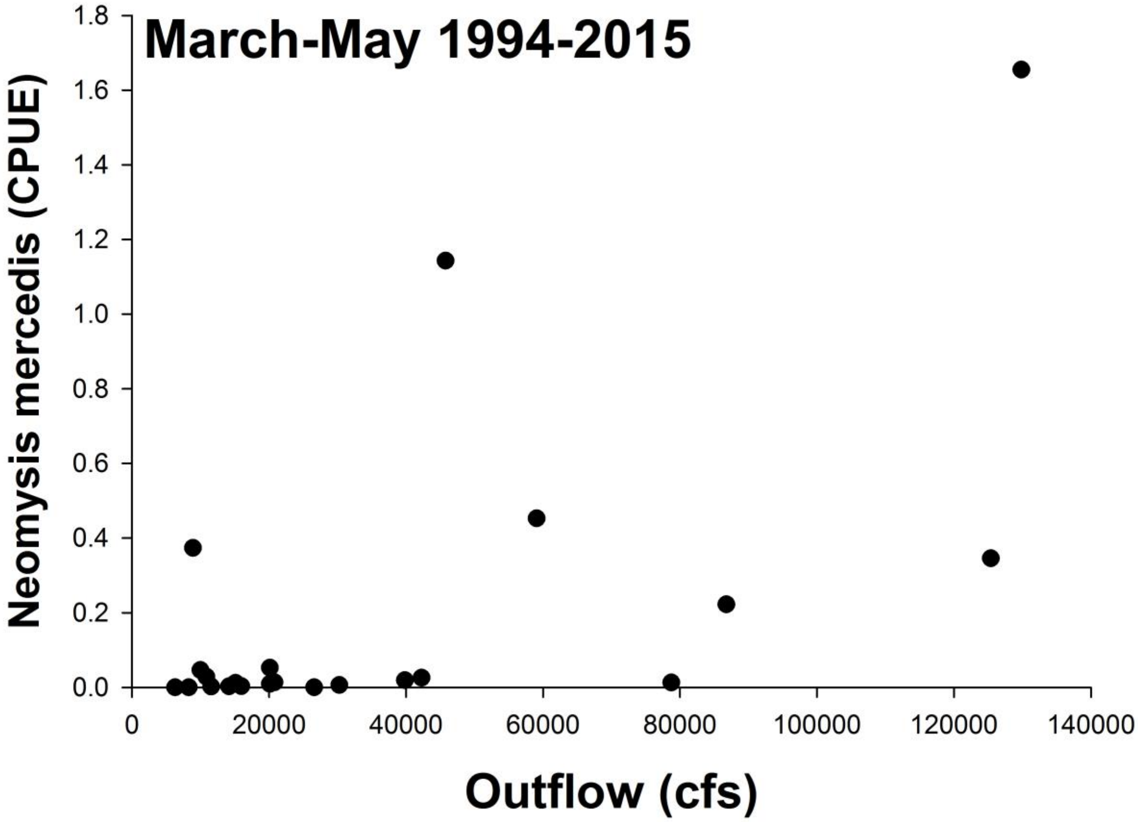

Figure 3: Mean abundance (CPUE) in the entrapment zone by mean Delta outflow (cfs) for *Neomysis mercedis* from March through May each year from 1994 through 2015. CPUE data from CDFW Zooplankton Study mysid net and outflow data from DWR DAYFLOW.

Species	Timeframe	Species stations	Outflow transformations	Species transformations	Rationale	Regression
E. affinis	March-June; 1994-2015	Entrapment zone: NZEZ2 and NZEZ6	1/sqrt(outflow)	1/sqrt(CPUE)	Peak abundance during spring; entrapment zone corresponds to areas of high larval fish abundance	Y=0.00381 +(5.995X); R^2=0.58; P<0.001
P. forbesi	June-September; 1989-2015	Suisun Bay (NZ020, 022, 024, 028, 030, 036, 038, 040, 042, 044, 046, 048, 050, 052, 054)	1/(outflow)	Natural log (CPUE)	Peak abundance during summer and early fall; Suisun Bay overlaps with range of its fish predators; high flows seed the population from upstream	Y=7.896-(12550X); R^2=0.39; Pearson's R=-0.63; Spearman's Rho=-0.71; Kendall's Tau=-0.57 P<0.001 for all
N. mercedis	March-May; 1994-2015	Entrapment zone: NZEZ2 and NZEZ6	1/sqrt(outflow)	Natural log (CPUE+ 0.001). Addition of 0.001 to CPUE because of some zero CPUE values.	Peak abundance during spring; entrapment zone corresponds to areas of high larval fish abundance	Y=-0.602-(447.59X) R^2=0.32; P<0.001

Table 1: Time frame and stations used in analysis, transformations performed on outflow and abundance data, rationale, and linear regression statistics for *E. affinis*, *P. forbesi*, and *N. mercedis.* Abundance data obtained from the CDFW Zooplankton Study and delta outflow data obtained from the Department of Water Resources (see text for links).

References

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CC:
Kathryn Hieb
Marty Gingras
Randall Baxter
Steven Slater