# AQUATIC RESOURCE PROGRAM REPORT

## 4. Flood plain management to enhance primarily productivity and native invertebrates

This section consists of a single report on the lower trophic levels on the Cosumnes River floodplain.

# 4. Floodplain Management to Enhance Primary Productivity and Native Invertebrates

## Edwin Grosholz and Erika Gallo

**Abstract**

Production of native invertebrates, particularly zooplankton, which provides the majority of the food base for larval and juvenile fish, showed strong temporal and spatial patterns that is influenced largely by patterns of phytoplankton production that is driven by residence time, water temperature and nutrient abundance. We see repeated cycles of increases in phytoplankton abundance followed by increases in zooplankton abundance following flooding events. After the initial period of dilution as new flood waters fill the floodplain, we increases in nutrients (nitrate, phosphate) and new growth of phytoplankton. Water quality data indicates that nitrate and phosphate levels as well as N:P ratios are indicative of periodic nitrogen as well as phosphorous limitation. Repeated spillover events apparently result in increased availability of nutrients, thus recharging the system after a period of nutrient limitation after extended periods of ponding up. Laboratory studies of zooplankton growth and reproduction confirm that phytoplankton abundance is an important food source relative to detrital sources. Further, increased abundance of phytoplankton at sites with higher temperatures and presumably higher residence times are also sites with rates of growth and reproduction indicating better food quality. Drift net sampling demonstrated that detrital inputs to the floodplain from the river are significant. The biomass of detrital inputs to the floodplain do not show a seasonal trend but the magnitude of these inputs are positively associated with the

magnitude of the flood event. Control of secondary production of zooplankton shifts from being largely bottom up (driven by food) early in the season to increasingly influenced by top down limitation (driven by predation) as increased size and abundance of larval fishes increases. Light trap data and experimental exclosures of fishes indicate that zooplankton abundances decline rapidly in April due to fish predation but also that the size structure of the zooplankton changes as cladocerans and other larger zooplankton become depleted faster than copepods and other smaller zooplankton. These results are mirrored in experimental exclusions of fish predators where fishes decrease the numbers of zooplankton, but have the greatest impact on larger cladocerans relative to smaller copepods.

## Introduction

One of the key goals of floodplain management must be ways to enhance primary production (plants including phytoplankton and benthic periphyton) and secondary production (zooplankton and benthic invertebrates) in floodplain habitats (Radar et al. 2001). However, little known about the controls of primary production (Muller-Solger et al. 2002) or of the role of fish predators (Batzer et al. 2000, Moyle et al. *in review*) in the freshwater, seasonal wetlands of central California. If increased productivity through the entire food web is an important goal, then boosting the primary production must be a prerequisite for higher overall production of the floodplain relative to traditionally leveed river channels. The immediate goal of the work covered in this section to understand what forces were controlling primary production in order to really understand what was driving secondary production of crustacean zooplankton and benthic insects.

In order to address these forces, we bring together several different kinds of data to understand what drives and limits primary production, how this influences patterns of secondary production of crustacean zooplankton and aquatic invertebrates, and how, in turn, secondary production may contribute to and be limited by predation by fishes. In developing these lines of inquiry, we present data on physical parameter, phytoplankton and periphyton abundance, zooplankton diversity and abundance, and experimental investigations of fish abundance and predation. In this mix, we also present some water quality to the degree that it is important for interpreting limitations to phytoplankton and to a lesser extent periphyton growth. The complete presentation of water quality data are given in a separate section by R. Dahlgren.

## Methods

***Planktonic and Benthic Primary Production.*** In order to estimate the relative abundance of planktonic primary production, we collected water samples to estimate the relative abundance of phytoplankton using chlorophyll a (Chl a) as a surrogate. At weekly intervals throughout all years, we collected replicate 500 ml water samples in 500 ml Nalgene bottles, which were kept cool and dark until return to the lab. Samples were then filtered onto 1 um GF/C preweighed glass filters and then extracted in methanol using standard methods.

In order to estimate the availability of benthic primary production, in 2003, we deployed collectors to estimate the weekly production and standing biomass of periphyton. At one of the few sites (Pond 1) that was continuously inundated during the winter of 2003, we established ten mesh collectors (10 cm x 10 cm) constructed of 1 mm

plastic mosquito screen fastened to pairs of wooden dowels that held the collectors either vertically or horizontally above the substratum. Individual collectors were retrieved by surrounding them with Ziploc plastic bags and then closing the bag before moving the collector to minimize disturbance of the periphyton. Additional samples were made on adjacent vegetation for analysis of species composition. All collectors were replaced with fresh collectors for the next week.

Once in the lab, all periphyton was removed from the collectors, invertebrates were removed, and the material was gently dissociated and agitated in a small volume of water to remove sediments. All samples were then dried to calculate total biomass and then ashed at 300 deg C for 24 hrs to determine ash-free dry weight.

***Detrital Inputs.*** To develop an estimate of the biomass of detrital inputs from the river into the floodplain during spillover events and to determine whether there were strong seasonal differences in the quantity of these inputs, where used drift nets (30 cm x 30 cm, 250 um mesh) to sample to abundance of detrital material coming into the floodplain on several discrete flood events. Drift nets had a propeller flow meter (Ocean Dynamics, San Diego, CA) fastened at the mouth of the net to record the flow of water moving into the net. In both 2001 and 2002, we deployed drift nets at one of the primary inflow sites, Corp Breach, where the river flows directly onto the upper floodplain and at Site 11 where the upper floodplain flows into the lower floodplain.

At each site, we deployed a drift net for a five-minute period with the net directly into the flow with the mouth of the net positioned to capture material in the water column from the surface down to 30 cm (the height of net opening). In some cases under very high flow, for safety reasons, we were not in the portion of the incoming water with the

highest velocity. At the end of the 5 minute sampling period, all material was rinsed into a Ziploc bag and returned to the lab for fixing and counting. Zooplankton and insects were removed and treated separately, while other detrital material was dried (60 deg C for 24 hrs) and weighed.

***Controls of Primary Production.*** Primary production in seasonally flooded areas in this region may be limited by the availability of both N and P. During all three years 2001-2003, water quality variable including nitrate, phosphate, sulfate, TN, TP, TSS, VSS, ammonium, carbonate, Na, K, Mg, Ca, Cl, Si, Chl a, Pheo a, DOC. Additional variables including DO, EC, temperature, salinity, depth, and flow were also made simultaneously as well as at all sampling sites.

Water samples were collected in one of two ways. Weekly water samples were made by collecting surface water in paired acid washed 500 ml Nalgene bottles and kept cool until return to the lab. One sample was prepared for Chl a and Pheo a and the other for anions, cations, nutrients, etc. See complete methods in separate report on Water Quality by R. Dahlgren and Clesceseri et al. 1998.

***Food Quality for Zooplankton.*** We conducted laboratory assays to address spatial variation across floodplain sites in food quality for zooplankton. These assays involved using water collected from four sites, which were then fed to standard cultures of *Daphnia,* a common cladoceran, that were examined for differences in growth rate and reproduction.

In order to examine spatial difference spatial differences in growth and reproduction, laboratory-reared *Daphnia magna* juveniles were fed seston collected daily from several flood plain sites in four-day flow-through incubations. Each day, seston variables (POC,

PON, TP, chlorophyll a, poly-unsaturated fatty acids (PUFAs), C&N stable isotopes) were measured to explore if they could explain variability in potential *Daphnia* growth and egg production between different flood plain and river sites and flow conditions. Statistical procedures used were mostly nonlinear regressions and partial residual plots using a general additive model procedure.

***Larval Fish Predation.*** To simultaneous measure the abundance of larval fishes and crustacean zooplankton, in collaboration with fish investigators (see parallel section on Fishes by P. Moyle), we deployed light traps in the evening hours at several sites in both pond, floodplain, river, and slough sites. This method involves passive sampling of of both groups of organisms by attracting them with a light source and permitting passage into a central collection area.

On several dates in 2000 and 2001, we deployed light traps at river sites (Corp Breach, RRB), slough sites (WDS), and floodplain sites (Pond 1 and Pond 2). At each site, 3 replicate collectors 2 were deployed with a waterproof flashlight as a light source. Collectors were deployed at each site in sequence, so from deployment to collection, each collector was in place actively "fishing" for approximately two hours. Samples were immediately fixed in formalin after removal from the collector and prior to return to the lab, because of the delicate condition of larval fish. Once in the lab, zooplankton were separated from larval fish, transferred to Lugol's and late enumerated with the same methods as other zooplankton.

***Juvenile Fish Predation.*** In April 2002, we conducted an experiment to directly measure the impacts of juvenile fishes on zooplankton density and community structure. In Pond 1, we deployed eight square cages (1 m x 1 m x 1 m) made of 105 um mesh

supported by PVC pipe. The 105 um mesh is porous to phytoplankton but can exclude or retain virtually all zooplankton and all fishes. The cages were deployed so that they were initially filled with water without fish and zooplankton, but with ambient phytoplankton densities. Zooplankton were gathered with a plankton net adjacent to the cages and distributed evenly to all eight cages so as to produce the natural assemblage of zooplankton taxa at ambient density. Juvenile blackfish, one of the most common native fishes in this system, were collected simultaneously by P. Moyle's group with beach seines. These were evenly distributed to four of the eight cages (henceforth fish cages) at a density of approximately nine per $m^2$, which is within the normal range of larval fish densities (P. Moyle *in review*).

At the start of the experiment, and then at 3, 8, 10 and 12 day intervals, we collected water samples in 1 L bottles to measure zooplankton abundance. At each time point, we collected three 1 L samples from within each of the four control and fish cages and as well as three samples from outside the cages to represent natural background abundances. All samples were kept cool, returned to the lab, and fixed with Lugol's, and all taxa counted as above.

We analyzed the results of the experiments using a single factor univariate ANOVA comparing fish vs. control vs. pond treatments with using three dependent variables total zooplankton, total number of copepods and total number of cladocerans as covariates with Tukey posthoc tests of treatment means.

## Results

***Planktonic and Benthic Primary Production.*** Plots for 2001 and 2002 show high variation in the standing biomass of phytoplankton as measured by chl a levels

during the flooding season. The pattern is repeatably that levels are low at the beginning of the season and then immediately after spillover events, phytoplankton densities are reduced through dilution but then recover to high levels within one to two weeks (Fig. 4-1 to 4-4).

The strongest patterns were seen in the dramatic spatial differences in phytoplankton abundance measured in each year. The abundance of phytoplankton was nearly an order of magnitude greater in floodplain sites (Figs. 4-1 and 4-3) than in river sites (Figs. 4-2 and 4-4) (also see Results in Section 3). These site differences increased throughout the season with often dramatic surges in phytoplankton production at the end of the season as zooplankton decline.

***Detrital Inputs.*** We found that there was substantial variation among flood events in the amount of detrital material coming into the floodplain. However, unlike the seasonal decline in nutrients coming into the watershed from terrestrial sources (see Dahlgren section), we found no temporal trend in the biomass (on a per volume basis) of detritus coming into the floodplain from the river (Fig. 4-5 and 4-6)

***Controls of Primary Production.*** The levels of primary nutrients (N,P) in different forms to support plant growth varied substantially throughout the season with a general decrease in availability as the flood season progressed. Levels of nitrate, phosphate, as well as total N and P declined to low levels throughout much of the flood season. Levels of nitrate and phosphate were frequently below detection levels and were likely to have limited phytoplankton production. Also, the ratio of total N to total P (N:P ratio) was frequently less than 10 indicating nitrogen limitation. However, both nitrate and phosphate levels were replenished with each spillover apparently initiating a new

round of phytoplankton production. This repeated input of nutrients can be seen with increases of nitrate and phosphate following spillover events (Fig. 4-7 and 4-8). There were also clear spatial patterns in nutrient levels that also paralleled the abundances of phytoplankton. Nutrient levels were initially higher in floodplain sites although between flood events, these rapidly declined.

***Food Quality for Zooplankton.*** Potential zooplankton (*Daphnia*) production was higher when waters receded from the Cosumnes flood plains and in areas of the flood plain with high water residence time and high algal biomass relative to deep river channels (Figs. 4-9 and 4-10). As in other Delta habitats, microalgae in the flood plain was overall of higher nutritional quality than detrital carbon. In 1999-2000, the algal communities in both flood plains were quite similar, with diatoms, cryptophytes, and euglenophytes making up a large part of the algal community (Mueller-Solger et al. 2000). The greater nutritional value of algae in the flood plain was evidenced by the tighter correlations between *Daphnia* growth and algal indicators (chlorophyll a) than between *Daphnia* growth and bulk or non-algal carbon (Figs. 4-11 to 4-13). POC explained *Daphnia* growth variability similarly well as the highly unsaturated fatty acids EPA and DHA, and as well (2000 draining period) or better (2000 & 2002 flooding period) than chlorophyll *a* (Mueller-Solger et al. 2000) (Fig 4-11). Interestingly, particulate phosphorus and nitrogen best explained *Daphnia* growth in the Cosumnes flood plain during flooding. This is in contrast to more than 40 other measurements from various Delta habitats where these variables were overall less closely related to *Daphnia* growth. Overall, the feeding assays showed significant spatial difference between sites in overall food quality. The assays demonstrated that sites with the higher assumed

residence times also had higher phytoplankton abundances and were better sites for *Daphnia* growth and reproduction.

Another feeding assay was recently conducted during high water levels and flows but warmer temperatures (May 2003). Sample analysis is in progress, and it remains to be seen if these patterns hold. If yes, this would be an interesting finding in light of the ongoing debate about mineral versus biochemical limitation of *Daphnia* growth, and possibly shed some light on this issue (though more in-depth data analyses are needed). In conclusion, algae are important food resources for secondary production in flood plains, and more and better food resources are present during draining periods. To provide optimal food resources for consumers, flood plain restoration should thus aim for several flood pulses followed by sufficiently long draining periods.

***Larval Fish Predation.*** Data from the light traps showed temporal trends that help explain some of the lower trophic level dynamics (Figs. 4-14 to 4-19). Early in the season, larval fish are smaller and less abundant (see section by Moyle for further details) and then they become very abundant towards the end or March and early April (Figs. 4-14 to 4-15). Zooplankton abundances show high values early in March, but in parallel with the increase in fish, they decline rapidly over time. We see both a decline in the size distribution of zooplankton with greater loss of big zooplankters and as well as an overall decrease in abundance (Figs. 4-17 to 4-19). Early in the season, larger zooplankton including *Daphnia* are more dominant in these collections, while later in the season these decline and smaller zooplankton including *Bosmina* and copepods increase in abundance. We also saw significant difference among sites in these data (Fig. 4-16).

***Juvenile Fish Predation***. We found that fish had a significant impact on the abundance of zooplankton in the fish treatment cages in comparison with the control cages (Figs. 4-20 to 4-22). Although there were no significant differences either at time zero, or day 3 ($F= 1.80$, $df=2$, $p=0.23$), we found significant differences by day 12 ($F=6.41$, $df=2$, $p=0.02$) (Fig. 4-20). We found that smaller taxa such as copepods (pooling calanoids and cyclopoids) did not differ between treatments either at the beginning or at day 12 ($F=2.45$, $df=2$, $p=0.15$), although densities were somewhat lower in the fish cages (Fig. 4-21). Densities of copepods in the both the fish and control cages actually increased during the experiment (mean/ml for controls: day 3=10.75, day 12= 41.25, means for fish cages: day 3=6.0, day 12= 22.5). By contrast, larger cladoceran taxa did show significant treatment differences (Fig. 4-22). Control cages differed significantly from fish cages at day 12 ($F=5.35$, $df=2$, $p=0.03$). Interestingly, fish cages

did not differ significantly from the pond samples (natural abundance) and pond samples also significant declines during the period of the experiment (Figure 12). This suggests that the fish predation in the cages accurately approximated natural predation levels in the ponds.

## Discussion

Our results broadly suggest that primary production and the subsequent secondary production that it supports is driven strongly by the flooding cycle. Levels of primary production are repeatably higher in floodplain areas of high residence time in parallel with zooplankton abundances discussed in Section 3. This pattern has been documented in all three years 2000-2002 and appears to be a strong and repeatable feature of floodplain dynamics.

Detrital inputs are likely to be an important source of carbon and nutrients inputs into the floodplain. We see that there is no seasonal decline in these inputs and that the magnitude of the inputs is associated with the magnitude of the flood event. The data from the drift nets suggests that repeated flood events can be significant sources of energy inputs into the floodplain and may help renew cycles of primary and secondary production.

This cycle of primary production is certainly driven in part by nutrient levels that are also increased by repeated flooding. Although our data are limited in this regard, there are clear signals of increased nitrate and phosphate following repeated flooding events. While we need to understand more about recycling of nutrients on the floodplain, the water quality data suggest that levels of these key nutrients clearly, although erratically, increase following flooding events. These data are also consistent with the

idea that repeated and discrete flooding events can renew cycles of primary and secondary production on the floodplain.

Our data also suggest that phytoplankton production is an important part of support for zooplankton. Lab experiments demonstrated that *Daphnia* growth and reproduction were significantly correlated with both chlorophyl a levels and indicated that phytoplankton was of high quality and important food on the CFP relative to detrital carbon, in modest contrast to other floodplains like the Yolo Bypass. These site-specific differences in *Daphnia* growth and phytoplankton abundances mirror the abundances of phytoplankton predicted by higher water temperatures and presumably higher residence times at floodplain sites relative to river sites.

Secondary production of zooplankton was also influenced by a temporal sequence of fish predation that has a strong but variable seasonal component. Based on light trap data and fish exclosure experiments, increasing size and abundance of fishes (see Section by Moyle) resulted in increasing fish predation beginning in late March into April. This increasing fish predation resulted in declining abundances of zooplankton with stronger declines of larger zooplankton including cladocerans with relative to copepods.

The sampling data from the light traps are echoed in the experimental results. We see that as expected fish predation had a significant affect on zooplankton abundance and size class distribution. But we also found that the larger zooplankton taxa showed the most extensive declines while smaller copepod taxa were much less affected by fish predation. So fish predation does result in zooplankton declines witnessed from late March through April, but does so with greater intensity on larger (and slower?) zooplankton taxa. The timing of our experiments also capture some of the natural

patterns of zooplankton reduction. Our Pond controls also experienced parallel declines in zooplankton densities that were very similar to the levels in our Fish enclosure treatments. The Pond controls also showed smaller declines in copepods relative to larger cladoceran taxa in parallel with the results inside the cages.

**References**

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Figure 1. Chlorophyll a vs. river discharge for floodplain sites (Pond 1, Pond 2, Site 7) in 2001. Values are 10X higher than for river sites in Fig. 2. Chlorophyll a values rise quickly after floods in February and early March.

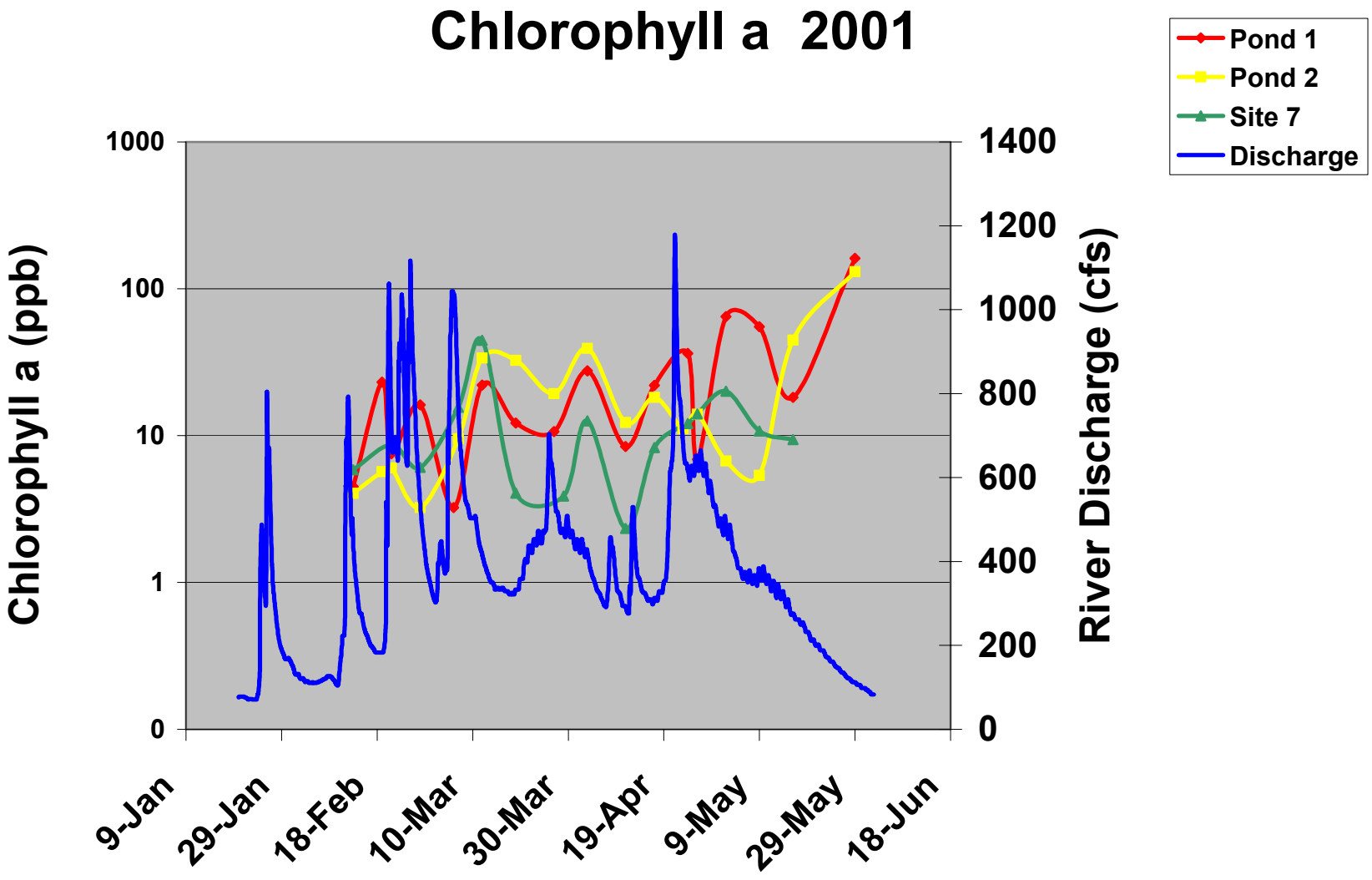

Figure 2. Chlorophyll a vs. river discharge for river sites (Corp Breach, RRB) and a slough site (WDS) in 2001. Values for river sites are 10X lower than for floodplain sites in Fig. 1. Chlorophyll a values at river sites show steady decline over time.

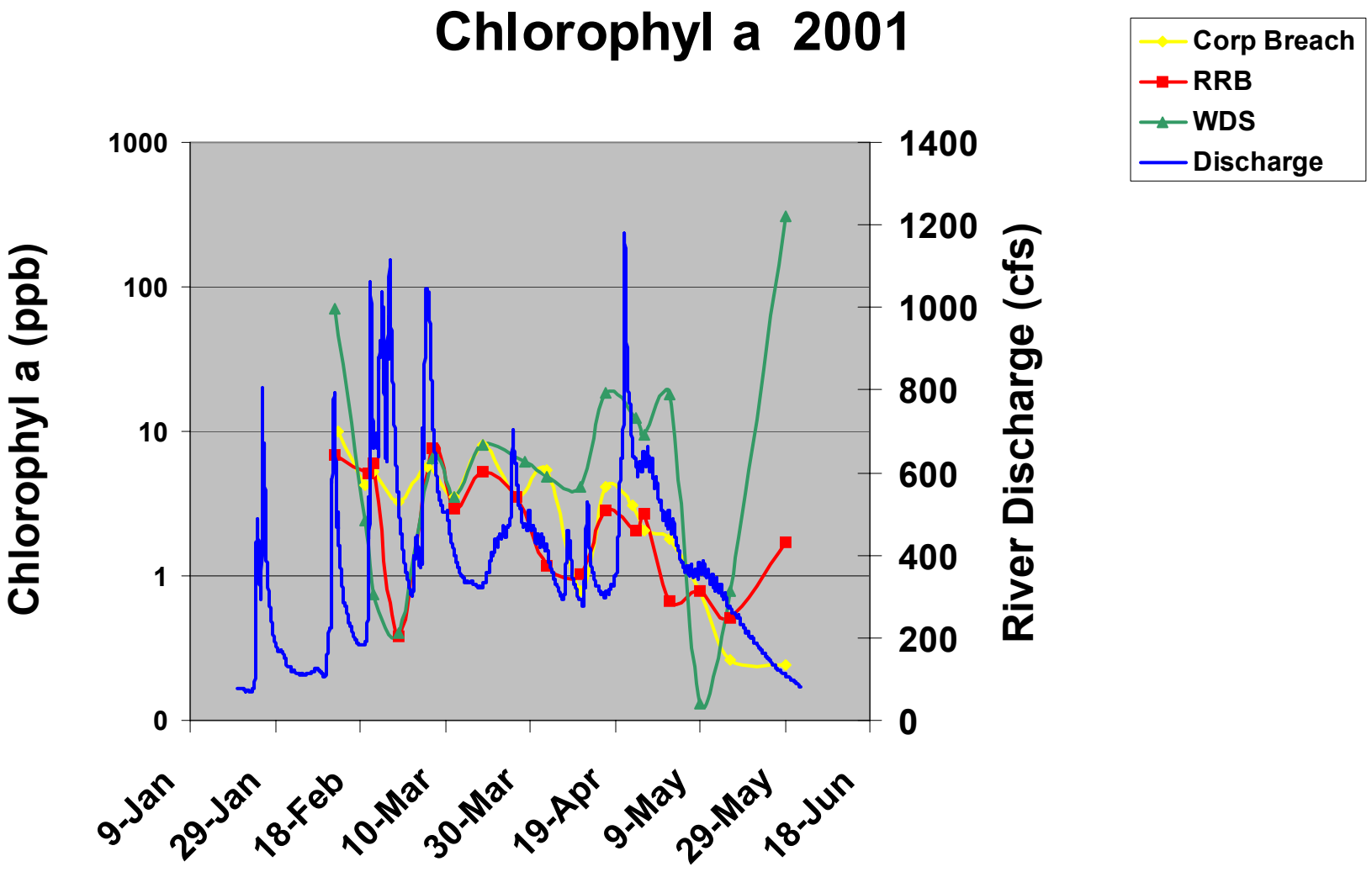

Figure 3. Chlorophyll a vs. river discharge for floodplain sites (Pond 1, Pond 2, Site 7, Site 11) in 2002. Values are 10X higher than for river sites in Fig. 4. Chlorophyll a values rise quickly after floods in early January and in early March

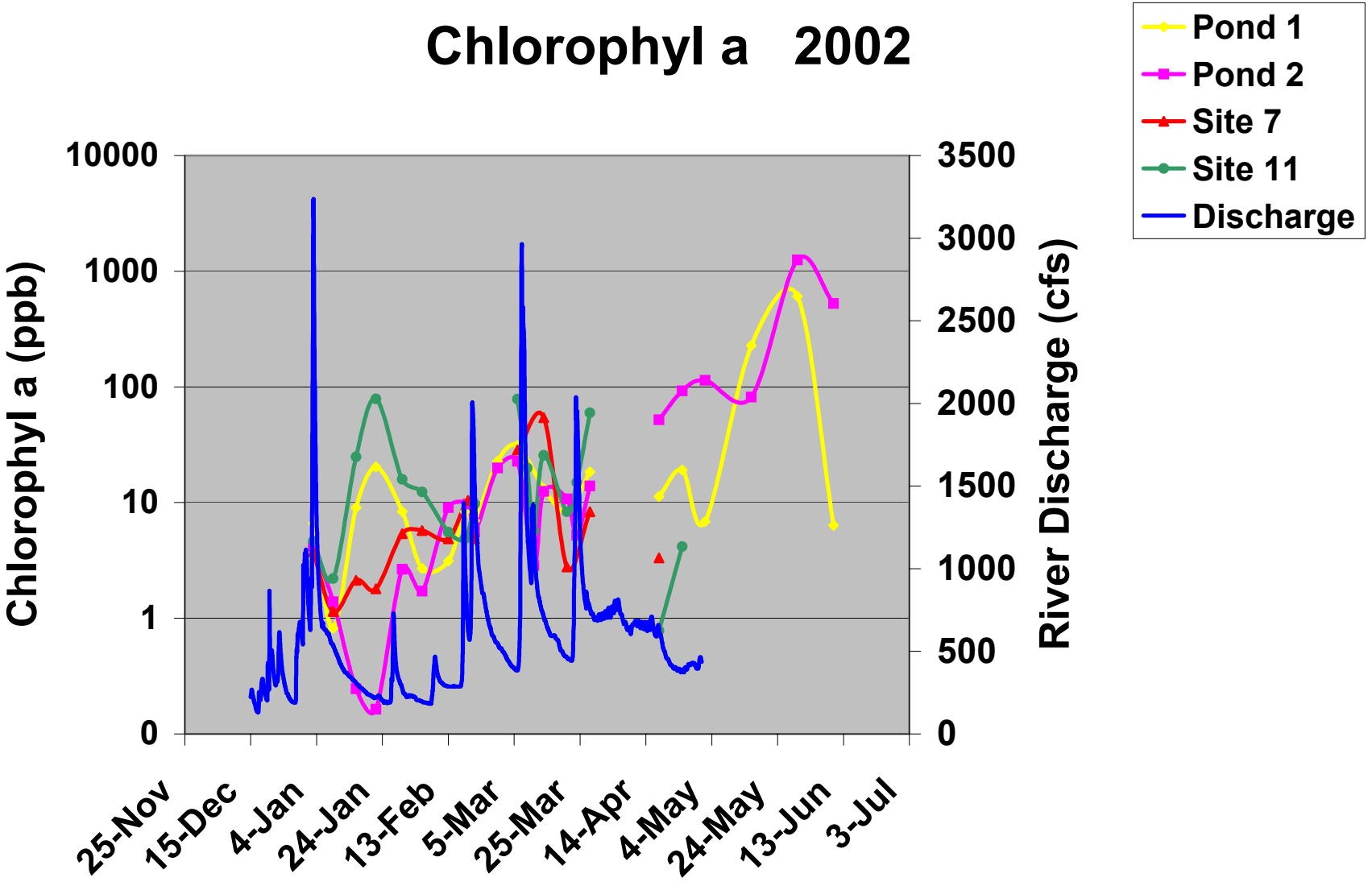

Figure 4. Chlorophyll a vs. river discharge for river sites (Corp Breach, RRB) and a slough site (WDS) in 2002. Values for river sites are 10X lower than for floodplain sites in Fig. 3. Chlorophyll a values at river sites show general decline over time.

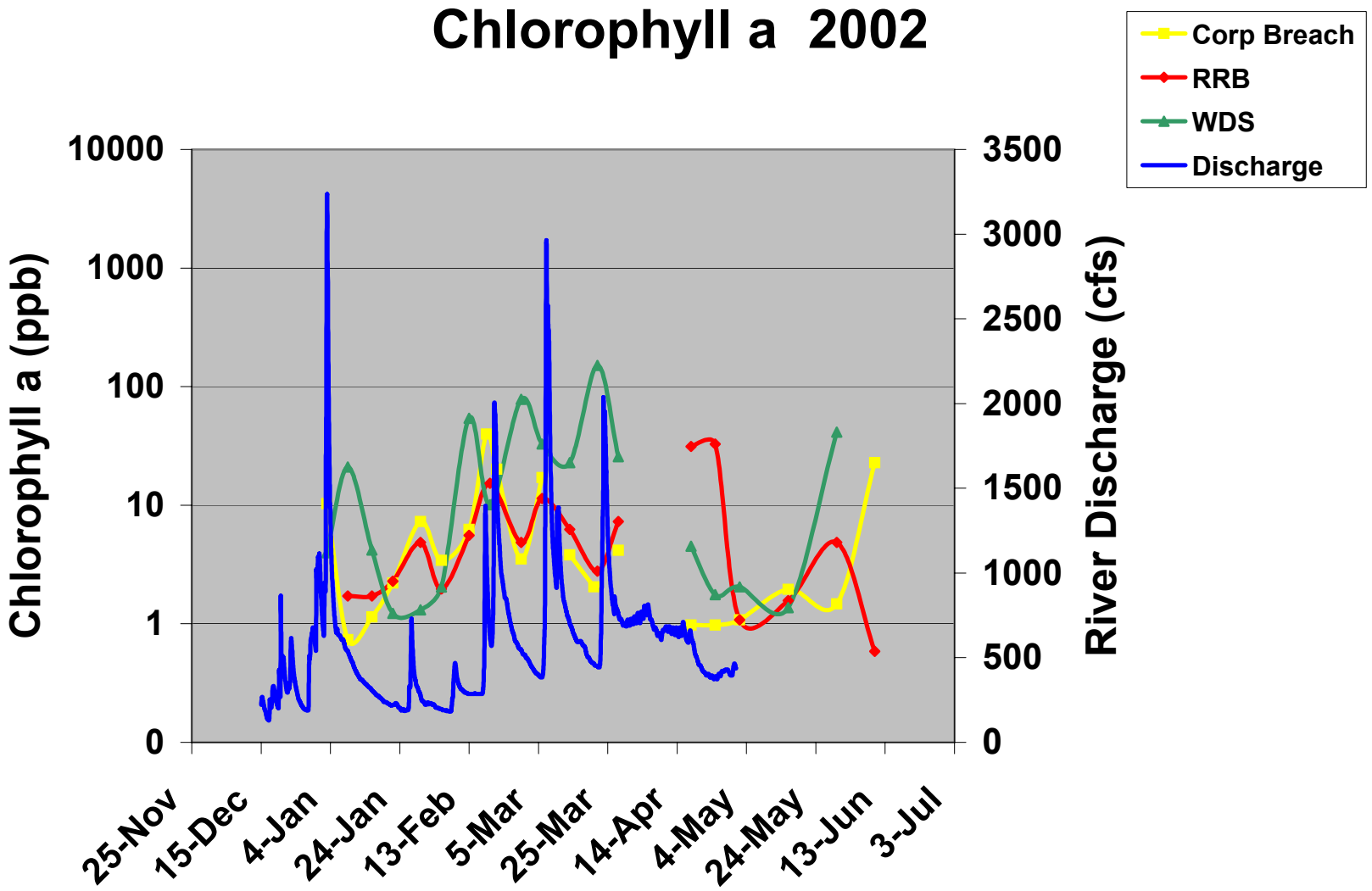

Figure 5. Organic biomass measured as dry weight (gm/L) vs. Cosumnes river discharge measured at Michigan Bar. Values of river discharge in excess of 800 cfs indicates flooding events. Biomass includes all measureable organic detritus as well as zooplankton, aquatic and terrestrial invertebrates. Biomass shows no obvious increase or decrease with time, but appears related to discharge (see Figure 2).

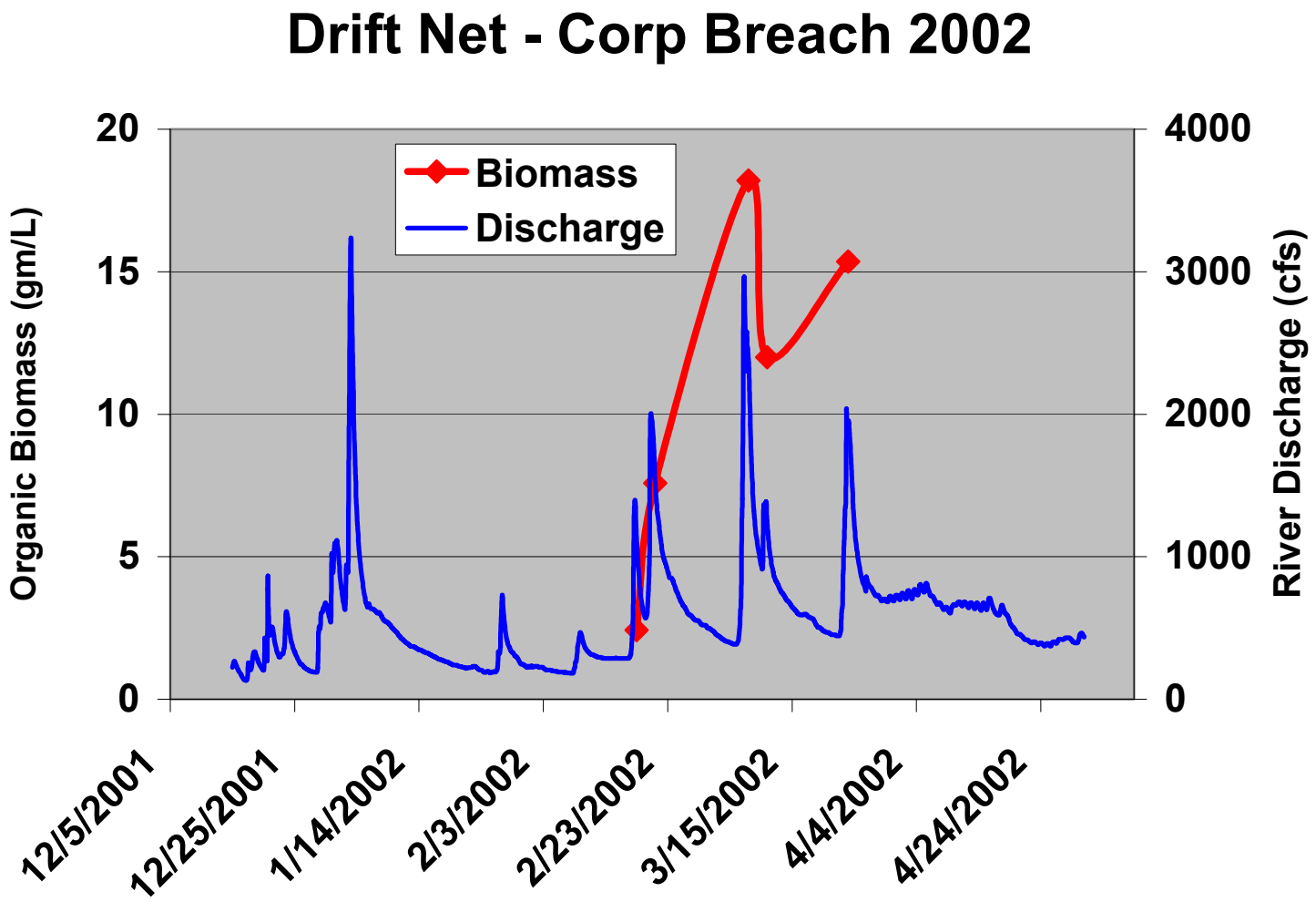

Figure 6. Regression of organic biomass measured as dry weight (gm/L) vs. Cosumnes river discharge measured at Michigan Bar. Values of river discharge in excess of 800 cfs indicates flooding events. Biomass includes all measureable organic detritus as well as zooplankton, aquatic and terrestrial invertebrates. Discharge explains 51% of the variation in biomass, but is not significant (p=0.17)

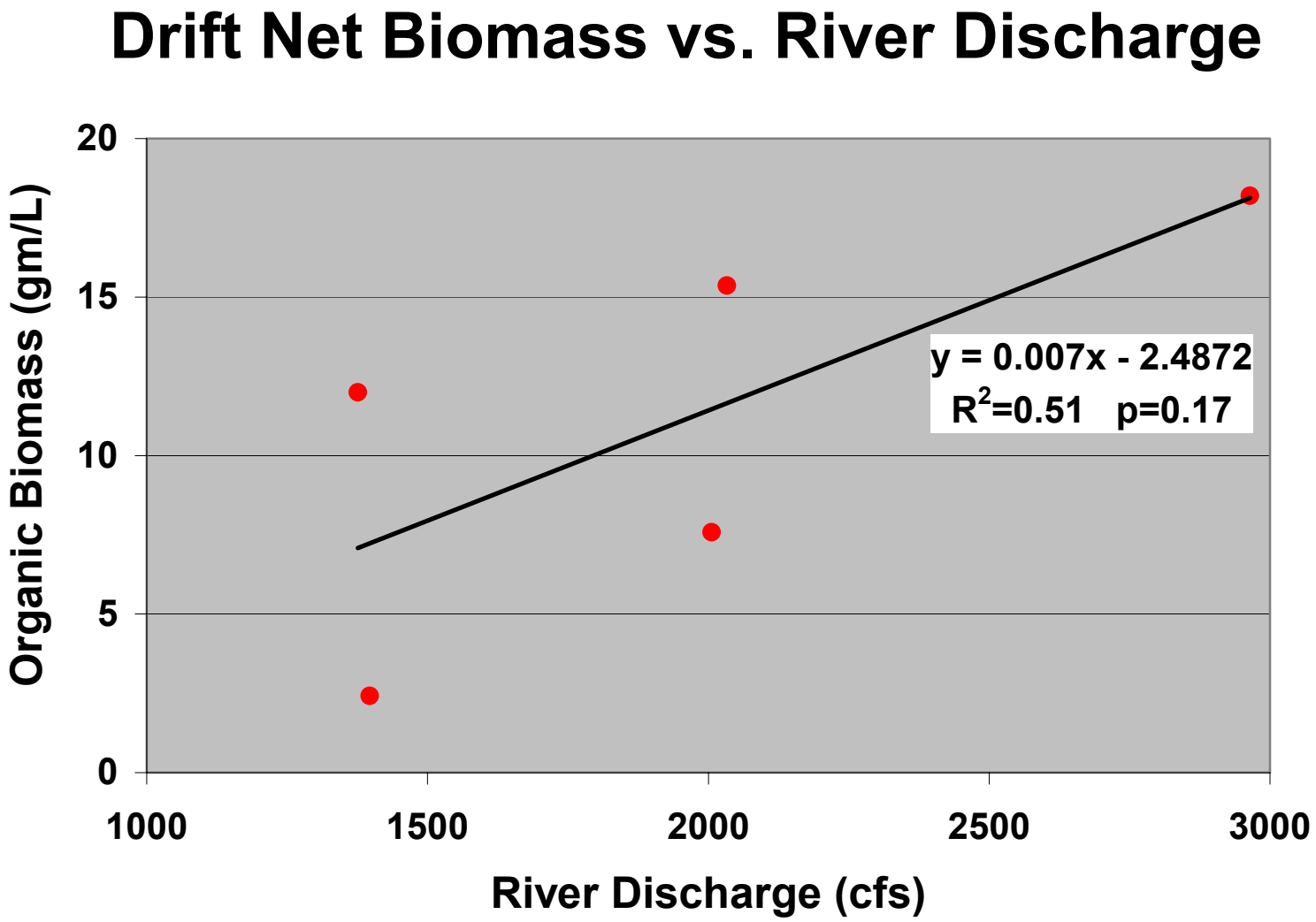

Figure 7. Nitrate and phosphate values vs. river discharge for 2001. Nitrate values show increase after flood events in February and in late April and phosphate levels show similar increases after February and March floods. Both levels decline to very low levels during extensive ponding periods during March and early April.

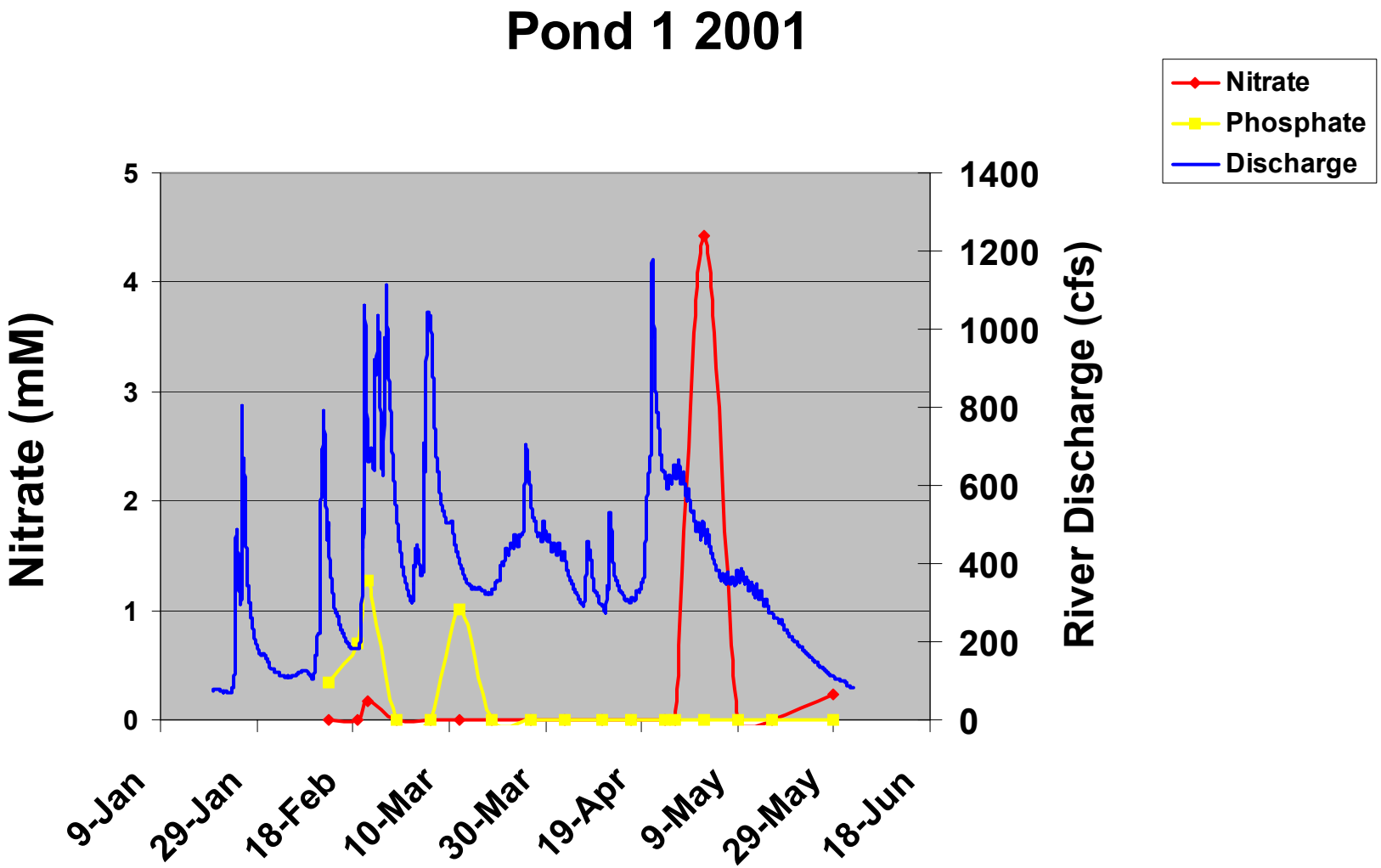

Figure 8. Nitrate and phosphate values vs. river discharge for 2002. Nitrate values show increase after early season flood events again after early March floods (phosphate). Both levels decline during ponding periods from January through early March.

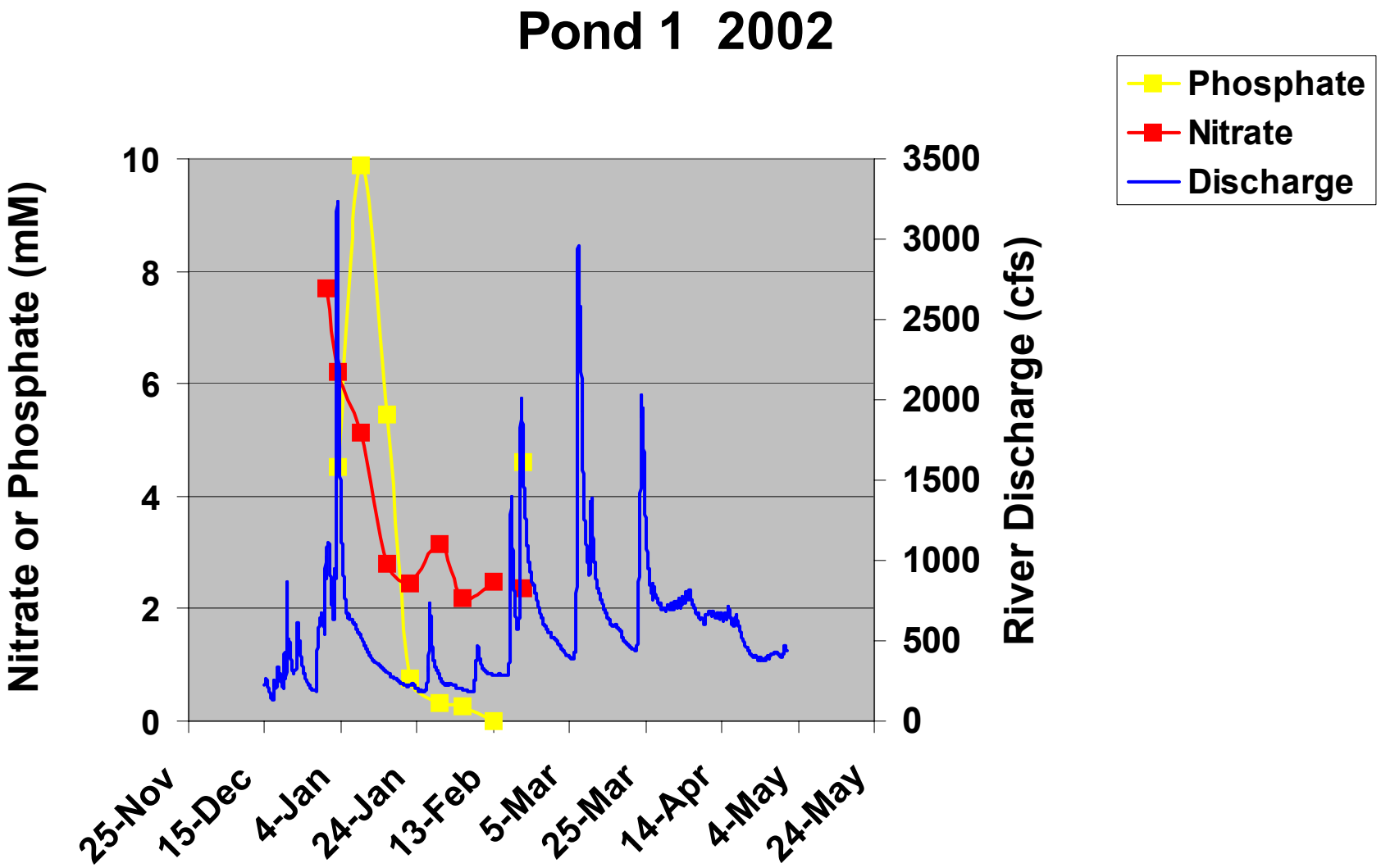

Figure 9. Comparison of zooplankton (Cladocera: *Daphnia* sp.) growth in laboratory assays using water from river vs. floodplain sites. Two left panels compare the Sacramento River vs. the Yolo Bypass floodplain for February and March (respectively) for 1999 and 2000, the middle panel compares the Cosumnes River and the adjacent floodplain for March and April 2000 and the right panel includes numerous sites from the San Joaquin/Sacramento Delta.

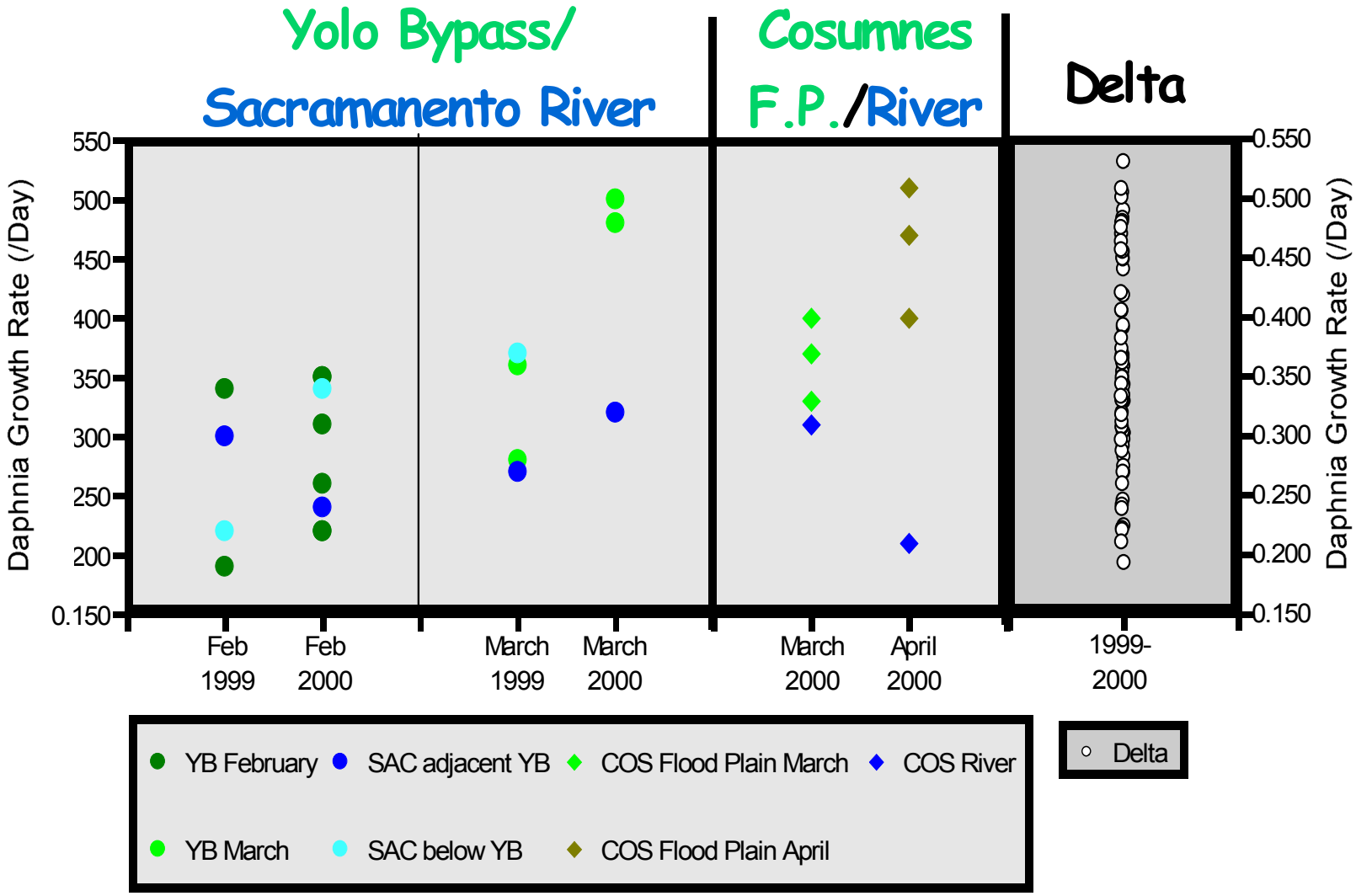

Figure 10. Plot of chlorophyll a comparing values for river vs. floodplain for the Cosumnes River and Floodplain (right panel) and the Sacramento River and the Yolo Bypass floodplain (left panel).

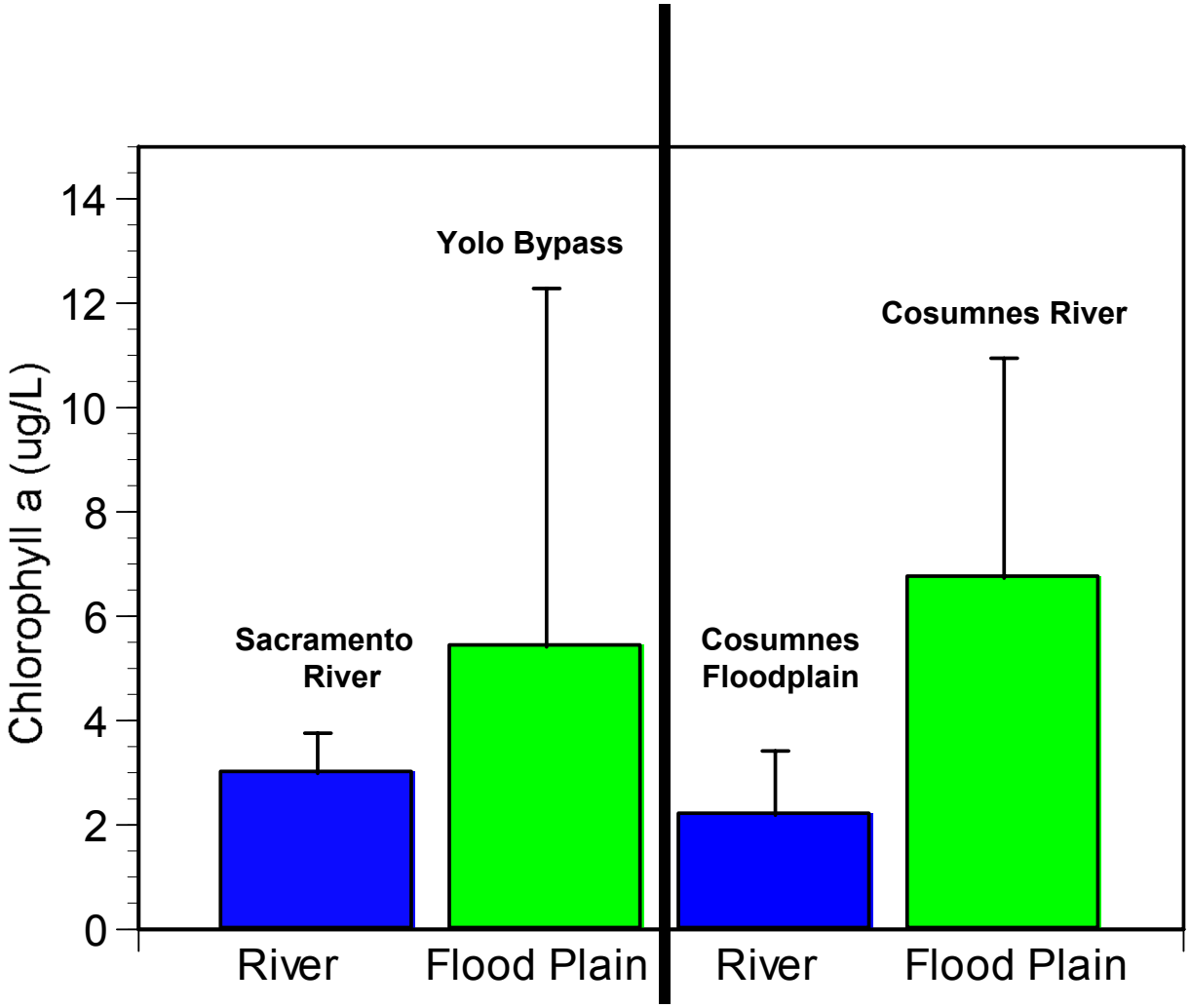

Figure 11. Zooplankton (*Daphnia* sp.) growth in lab assays using water from selected sites on the Cosumnes River floodplain showing the relationship between *Daphnia* growth and chlorophyll a levels.

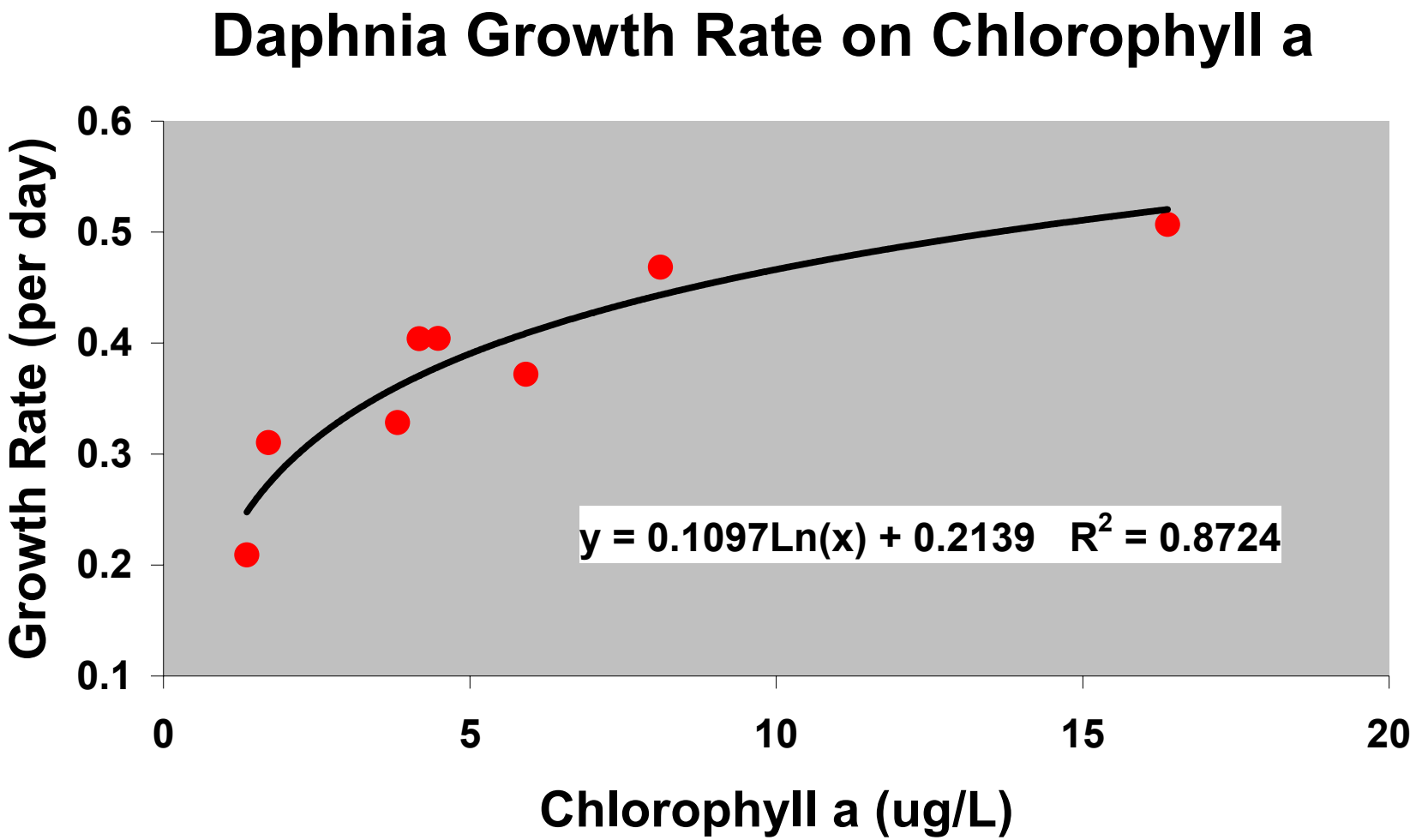

Figure 12. Zooplankton (*Daphnia* sp.) growth in lab assays using water from selected sites on the Cosumnes River floodplain showing the relationship between *Daphnia* growth and particulate organic carbor (POC) levels.

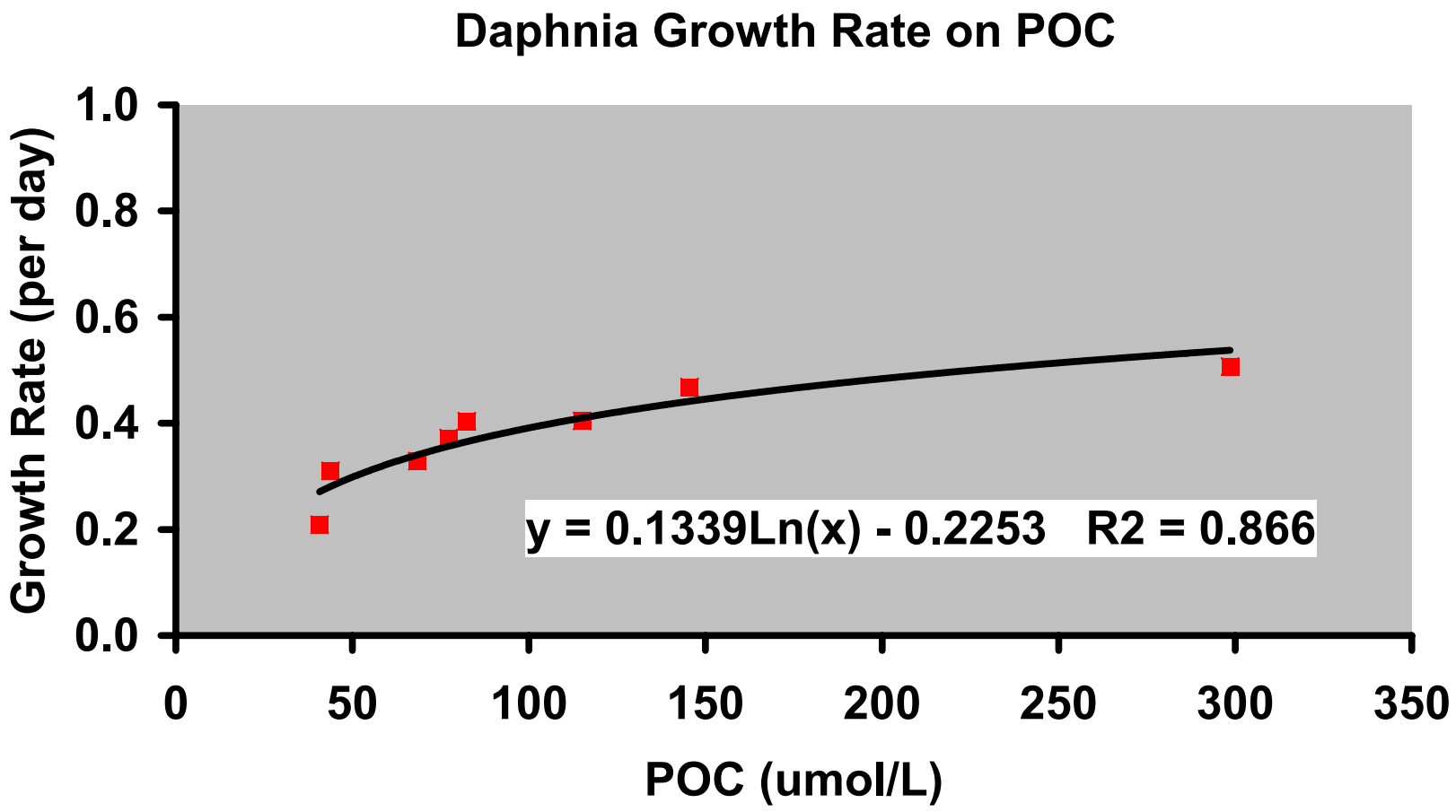

Figure 13. Plots of zooplankton (Cladocera: *Daphnia* sp.) growth in laboratory assays using water from river vs. floodplain sites vs. as a function of particulate organic carbon (POC). Left panel compare the Sacramento River vs. the Yolo Bypass floodplain for February and March 2000 and the right panel compares the Cosumnes River Floodplain for March and April 2000.

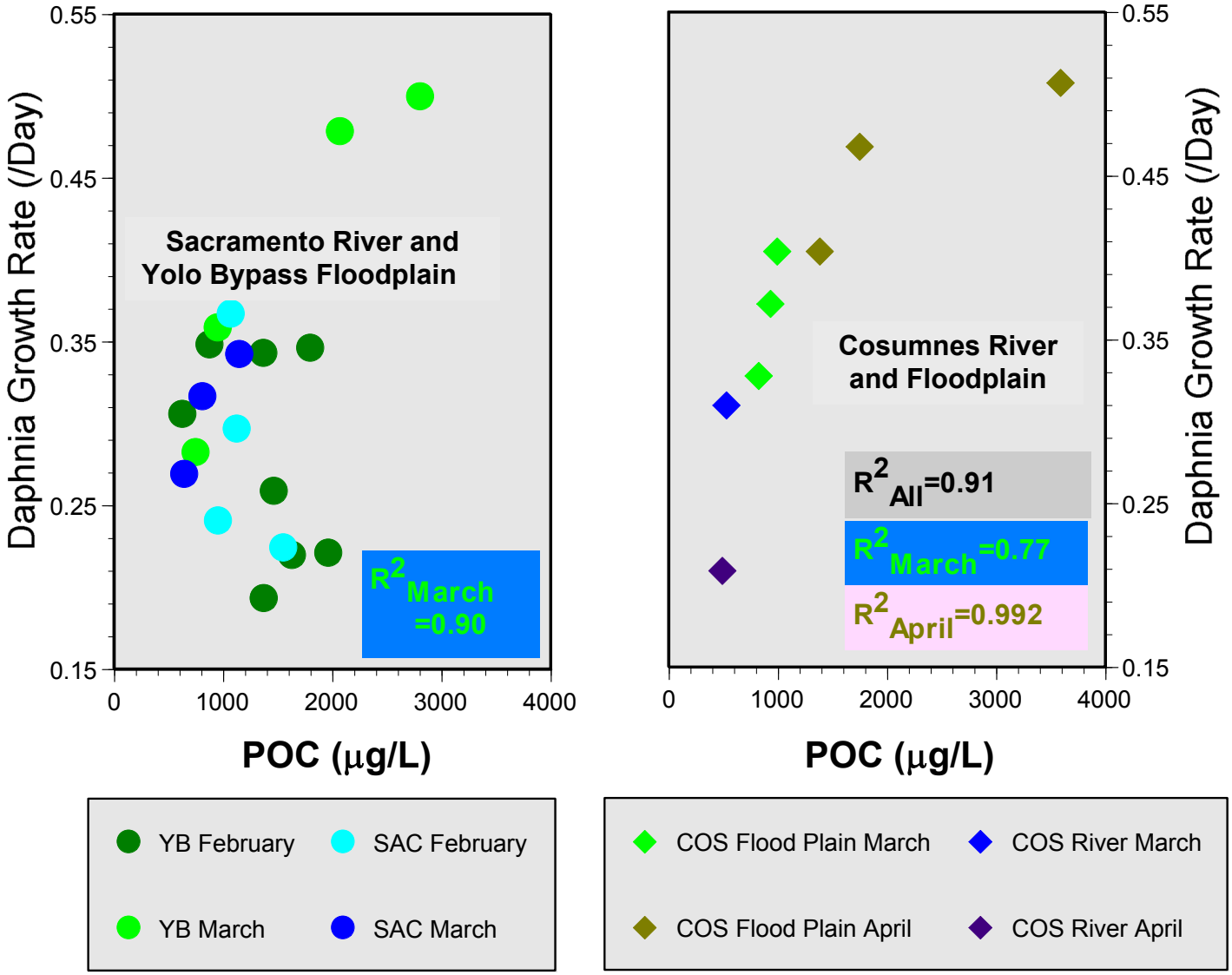

Figure 14. Light traps data for total abundance of either all fish or all zooplankton from a floodplain site (Pond 1) during sampling dates from 2001. Values represent the total abundance from the entire catch for one light trap

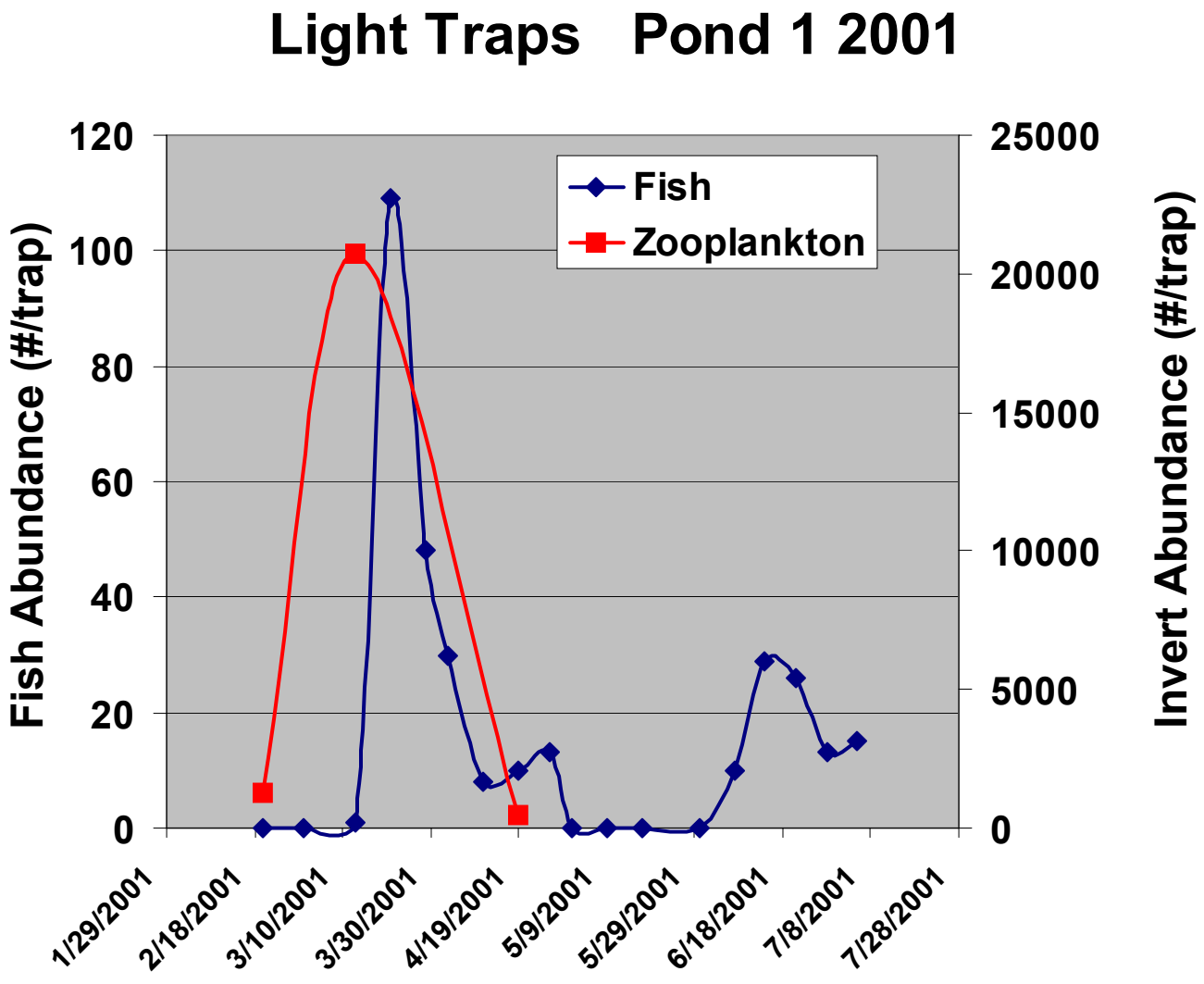

Figure 15. Light traps data for total abundance of all fish or of two common zooplankton taxa (*Daphnia*) and cyclopoid copepods from a floodplain site (Pond 1) during sampling dates from 2001. Values represent the total abundance from the entire catch for one light trap.

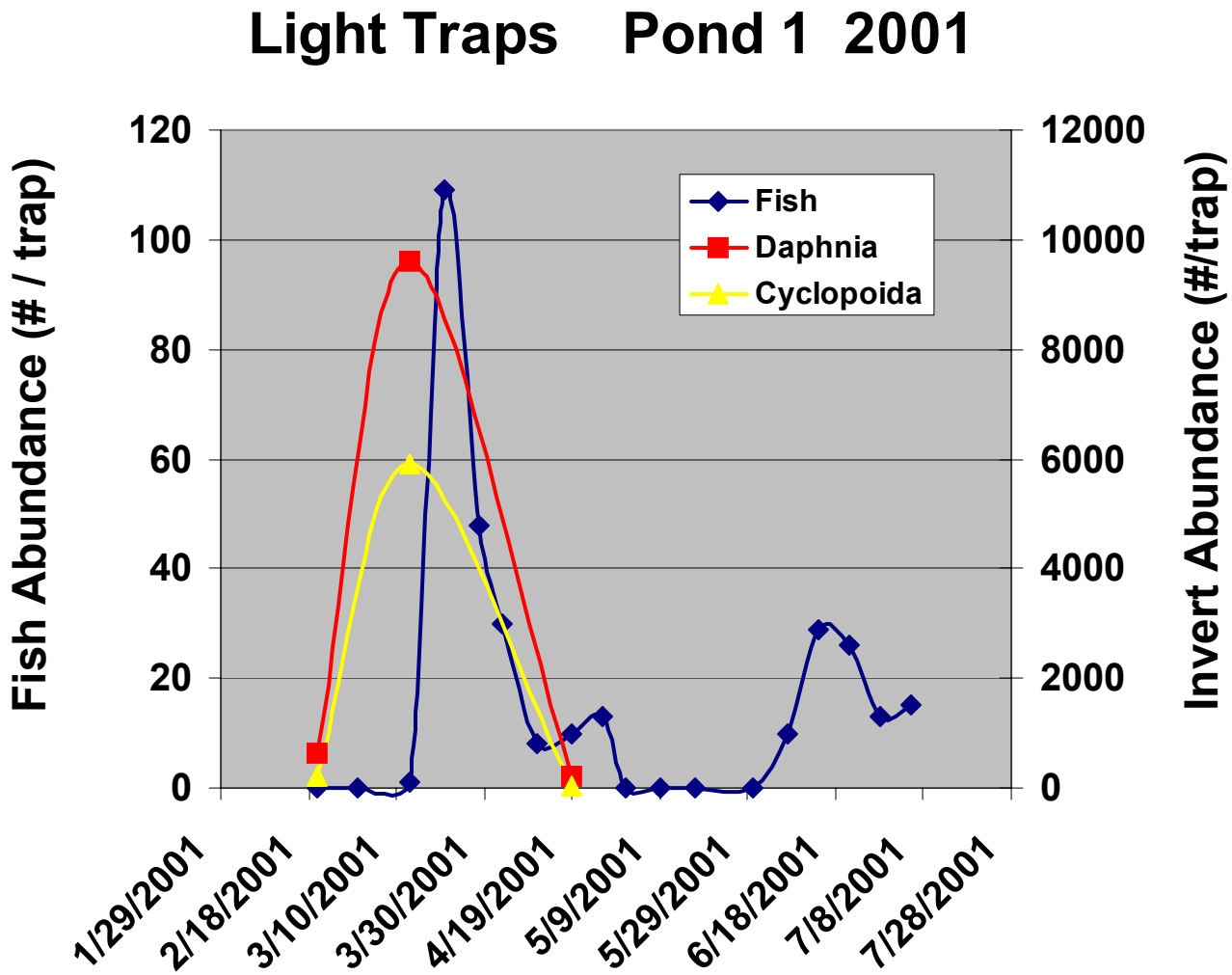

Figure 16. Light traps data for all common zooplankton taxa for floodplain sites (Pond 1, Pond 2) a river site (RRB) and a slough site (WDS) from April 19, 2001. Values represent the total abundance from the entire catch for one light trap.

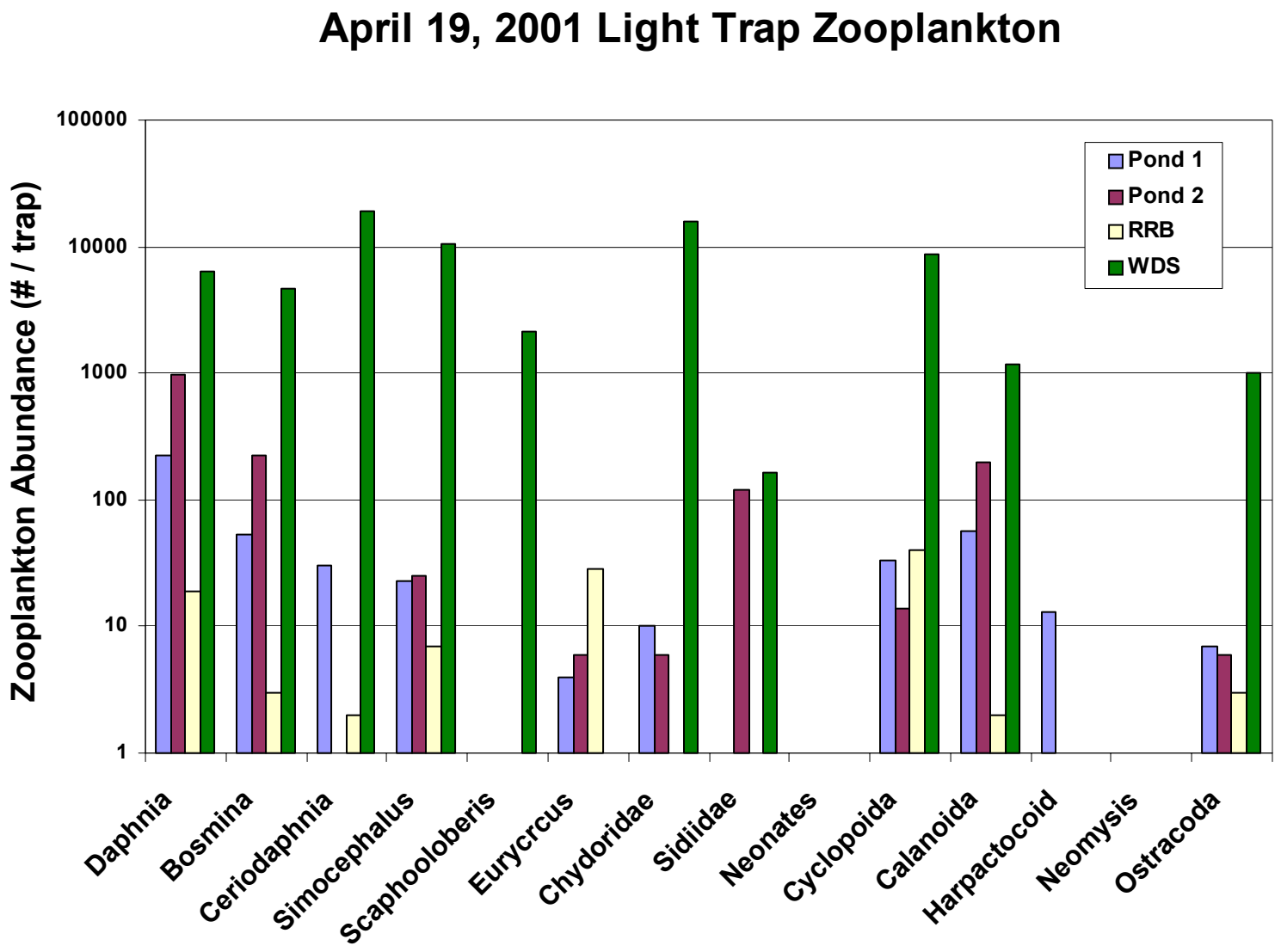

Figure 17. Light traps data for all common zooplankton taxa from a slough site (WDS) on three dates in 2001. Values represent the total abundance from the entire catch for one light trap.

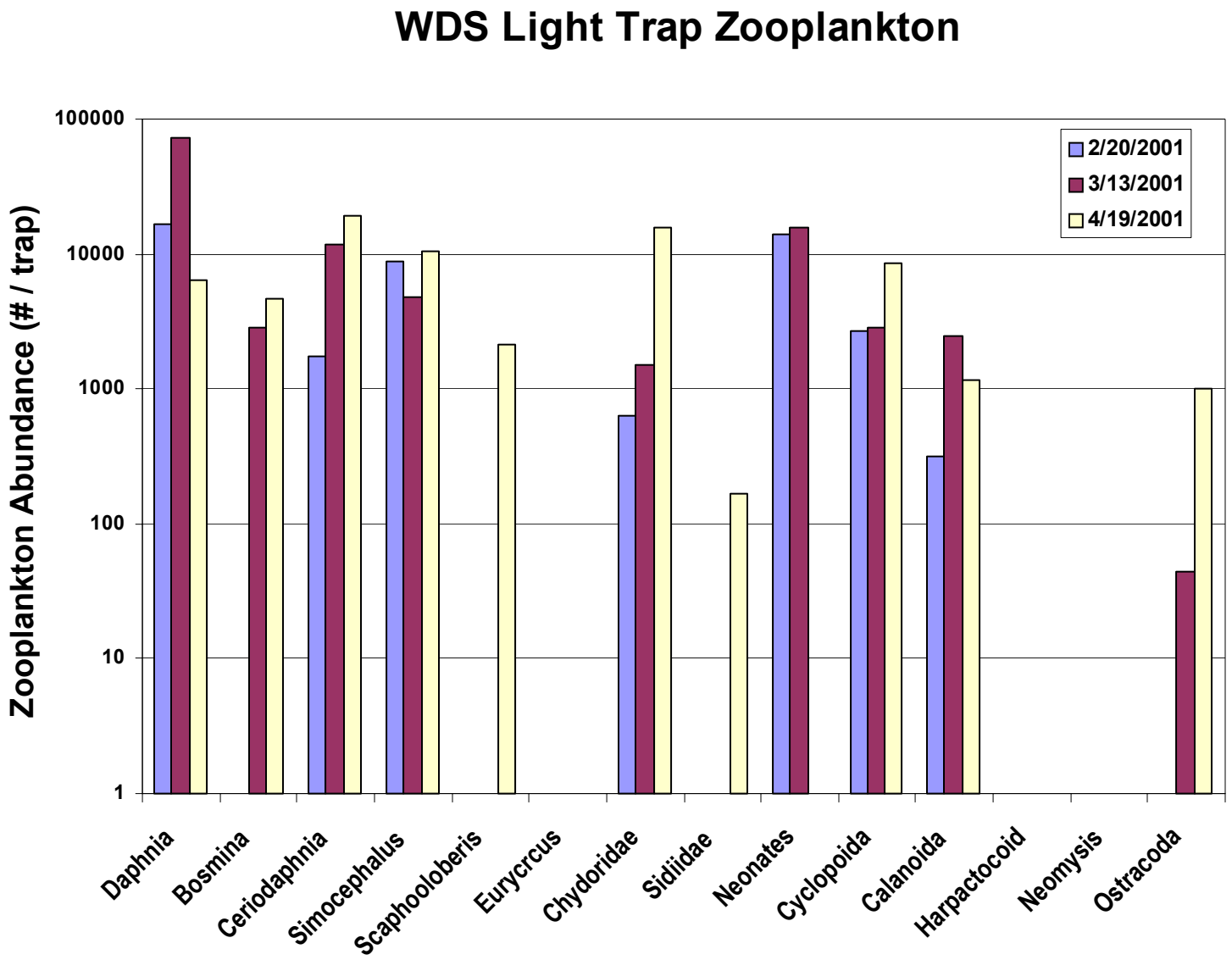

Figure 18. Light traps data for all common zooplankton taxa from a river site (RRB) on three dates in 2001. Values represent the total abundance from the entire catch for one light trap.

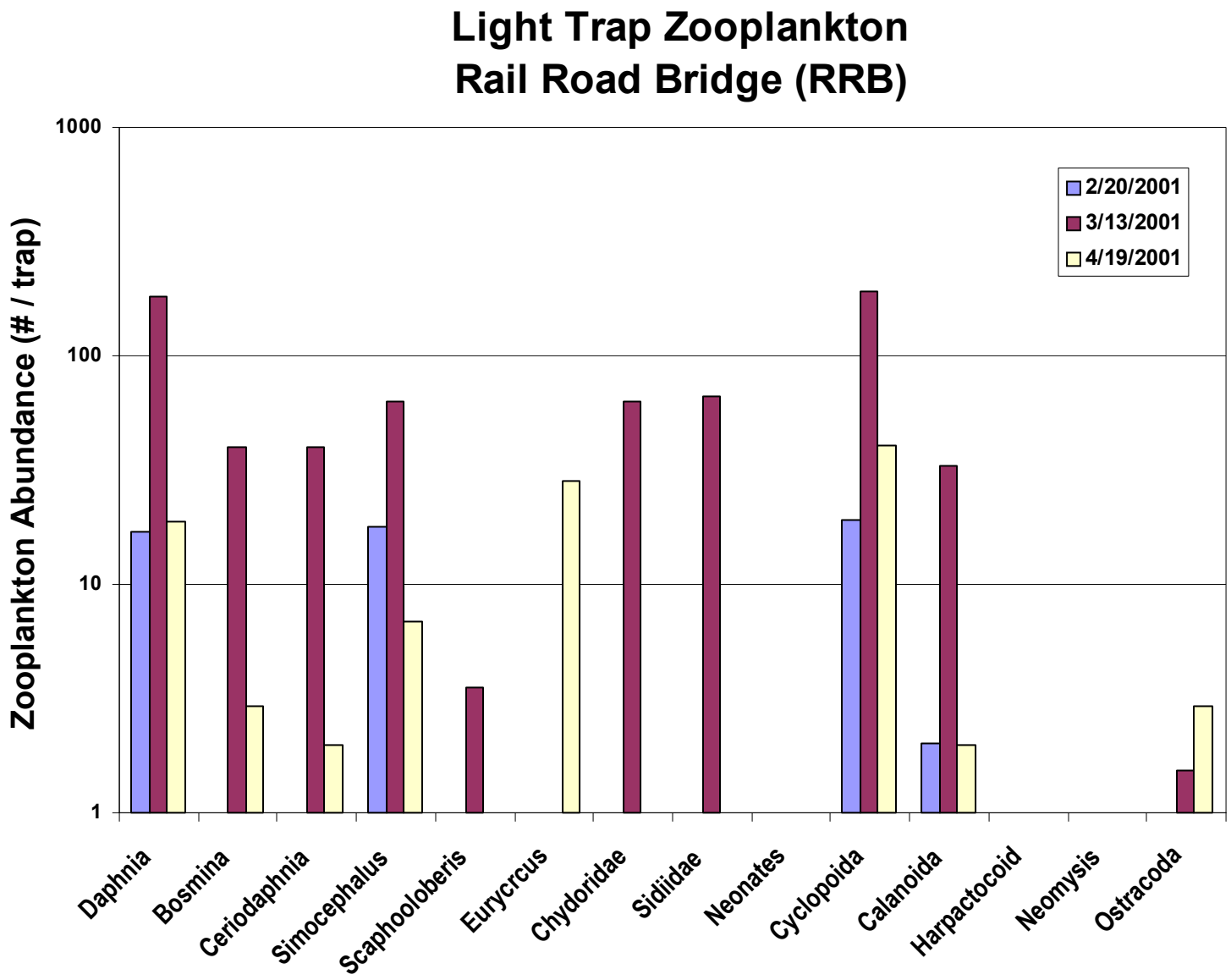

Figure 19. Light traps data for all common zooplankton taxa from a floodplain site (Pond 1) on three dates in 2001. Values represent the total abundance from the entire catch for one light trap.

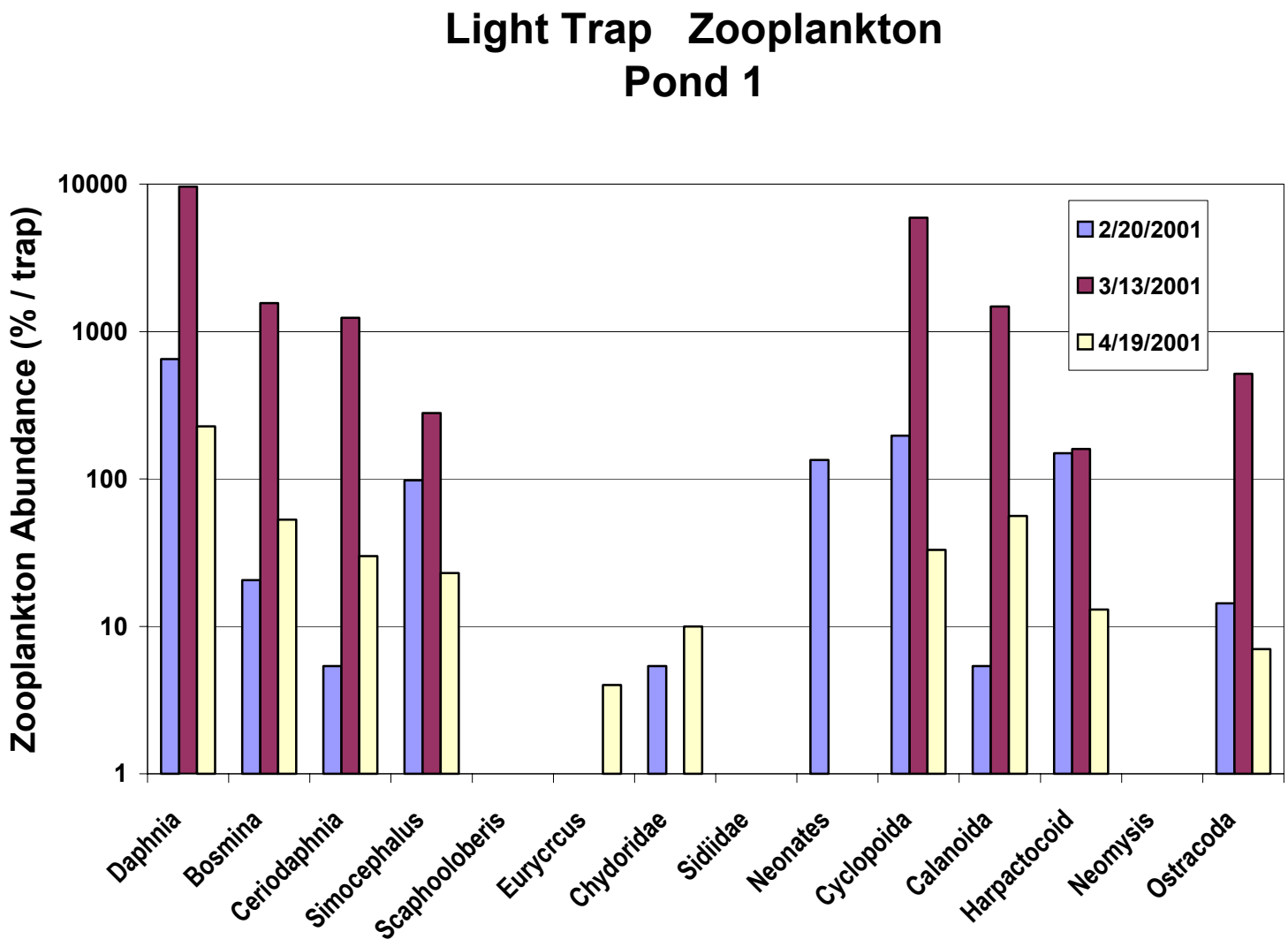

Figure 20. Results from cage experiments all zooplankton pooled (see text for treatments). Bar heights represent mean of four replicates and letters indicate means that are significantly different across treatments ($p<0.05$). Fishes (in Fish and Pond treatments) significantly reduced the abundance of zooplankton relative to controls (no fish).

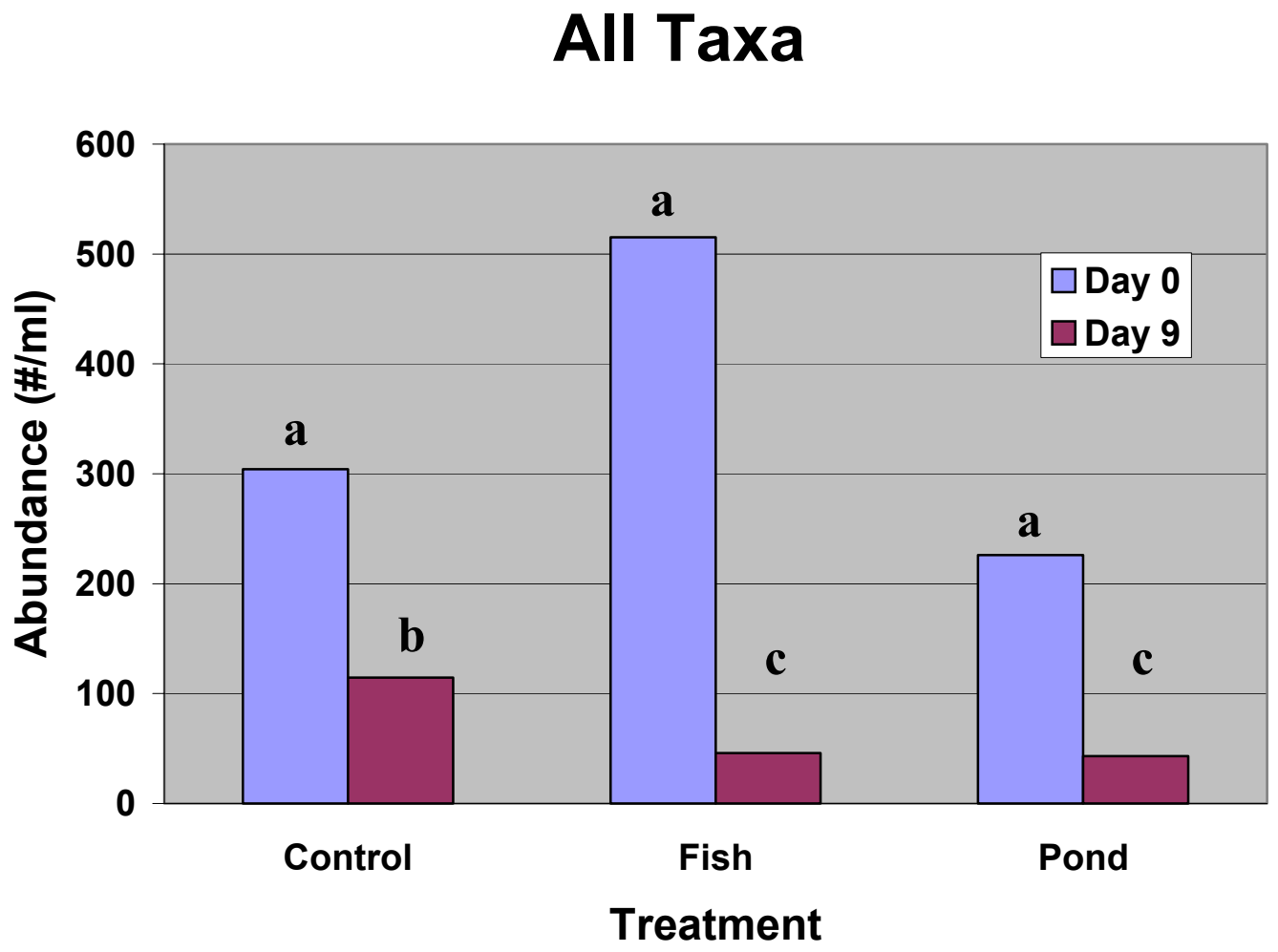

Figure 21. Results from cage experiments for all copepod taxa pooled (see text for treatments). Bar heights represent mean of four replicates and letters indicate means that are significantly different across treatments ($p<0.05$). Fishes (in Fish and Pond treatments) predation slightly but not significantly reduced the abundance of copepods relative to controls (no fish).

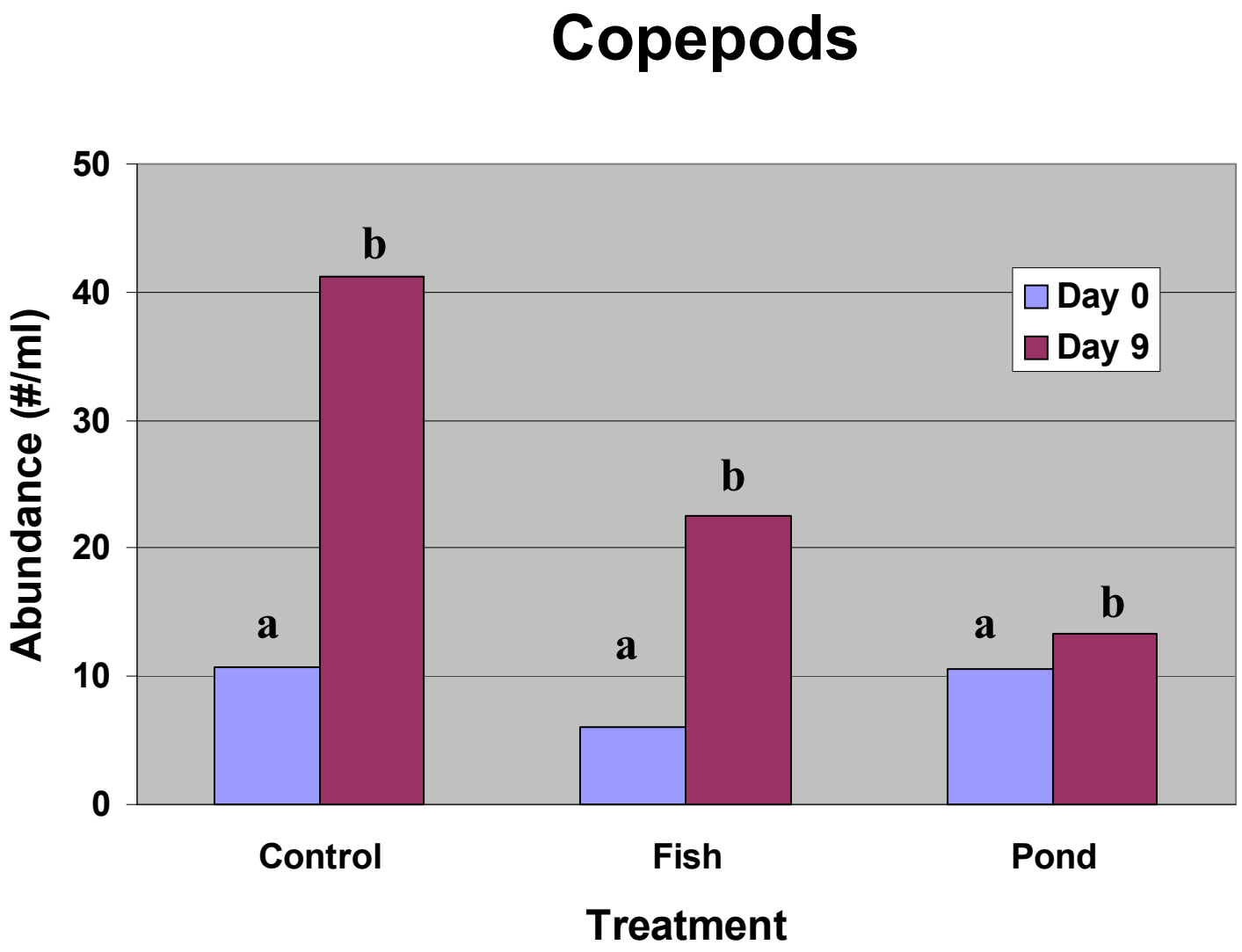

Figure 22. Results from cage experiments for all copepod taxa pooled (see text for treatments). Bar heights represent mean of four replicates and letters indicate means that are significantly different across treatments ($p<0.05$). Fishes (in Fish and Pond treatments) significantly reduced the abundance of cladocerans relative to controls (no fish).