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Task: 9

Deliverable Title: Zooplankton Abundance And Diversity In The Lower San Joaquin River Above The Stockton Deep Water Ship Channel

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Abstract

As part of a larger study investigating algal dynamics in the San Joaquin River, an analysis of zooplankton was coordinated with a dye monitoring study during the summers of 2005 and 2006. Zooplankton were collected from the dye plume along a tidal freshwater reach of the river spanning 30 miles above the Stockton Deep Water Ship Channel (DWSC). Rotifera comprised the most diverse group with 42 species. Rotifer diversity over the study reach varied greatly with several species exhibiting site preferences. Copepoda followed rotifers in diversity however their biomass was generally higher, especially downstream. Approximately four species of copepods occur; all three major orders are represented. The introduced *Pseudodiaptomus forbesi* was the dominant copepod. Nauplii occur throughout the reach, their numbers increasing downstream. Cladocera are represented by six species, but abundance is low and distribution inconsistent. Peaks in zooplankton biomass occurred sporadically over the study period: in 2005 peaks occurred about 15 miles above the DWSC; in 2006 they occur in the five mile reach above the DWSC. In 2006, peaks are strongly correlated with reversal in flow during flood tides. In August and September 2005 and July and August 2006 zooplankton biomass peaked during night hours. The DWSC maintained a considerably higher biomass than other sites in half of the sample periods. Multivariate analysis suggests a strong correlation between total zooplankton biomass and water age. These data suggest that algal dynamics are controlled, in part, by zooplankton grazing.

Introduction

The purpose of this task is to investigate the ecological causes for chlorophyll reduction in the San Joaquin River (SJR) between Vernalis and the DWSC, and diel chlorophyll fluctuations. Data from Task 8 indicate that chlorophyll a levels tend to decrease from Mossdale to the DWSC. This pattern is variable from month to month however a trend does exist. To understand this pattern requires an understanding of the abiotic and biotic factors that influence algal population levels. This is difficult in that the segment of the SJR under investigation has a complex flow regime because the reach above Mossdale is not tidally influenced, whereas below Mossdale the river becomes increasingly more tidal, with flow reversals of several miles possible in the lower reach. One effect of this reversal is to pull components of the biotic community present in the DWSC into the upstream areas of the river. Algae, which are likely well mixed throughout the water column during downstream water flow, probably settle during periods of tidal slowing of flow and tidal reversal, but then are likely resuspended upon reestablishment of flow. Turbidity, which is usually high in the river, and has a shading effect on the algae (Welch, 1952) and therefore likely influences its growth, is also affected by the tidal dynamics. Another factor in the complexity of this reach is that water depth gradually increases downstream, which likely further reduces availability of light for algae. The settling effect in deeper water could be a significant factor on the growth and size of algal populations, however this effect is not clearly understood. Other factors that could influence algal populations include side-water areas of low flow which could serve as algal breeding grounds, tributary inputs such as French Camp Slough, and outfall pipes for storm water and other discharges, and zooplankton grazing.

The major biotic factor influencing algal standing crop and rate of production is grazing by zooplankton, which is typically described as a producer and consumer relationship (Reid, 1961; Ruttner, 1963). The present investigation seeks to describe the abundance and diversity of zooplankton in the study reach to better understand the effect of grazing on the algal population. Another potentially significant source of grazing is by benthic macroinvertebrates, especially bivalve mollusks. It has been shown that an introduced clam in the San Francisco Bay is the cause of chlorophyll and zooplankton decline (Kimmerer et al., 1994). Therefore, an assessment of the bivalve community is another objective of this study.

This study employs the traditional method of determining zooplankton diversity and abundance by microscopic examination and taxonomic identification (APHA, 1998). This method is slow and tedious but highly informative. As an independent check of total zooplankton biomass and degree of zooplankton diversity, a phospholipid fatty acid analysis (PLFA) will be conducted (White et al., 1979). Once the relationship between plankton species diversity/abundance and PLFA patterns is understood, the latter data could eventually provide a rapid tool for checking plankton population status.

Phospholipids, which are the one of the principal chemical constituents of the membrane, can be extracted and used as biomarkers, or specific chemical signatures for a microbial species. All microorganisms have a membrane that interfaces with the surrounding environment. The structure and chemical composition of the membrane depends primarily on the microorganism type, age, and environmental conditions. Phospholipid biomarkers have been identified that indicate the predominant types of microorganisms in a microbial community, the physiological status of the microbial community, and also provide a means for estimating the microbial biomass.

The phospholipid fatty acid analysis (PLFA) is able to identify target phospholipids that can be used to determine relative amounts of green algae, and diatoms, as well as relative proportions of higher plants (from aquatic and terrestrial sources) and bacteria.

Lipid dynamics in aquatic ecosystems is driven by the production of essential fatty acids (EFA) by the phototrophic organisms (e.g. algae) which are consumed and converted by animal species. One of the key lipids, 20:5, is a twenty carbon fatty acid with 5 double bonds, also referred to as a poly unsaturated fatty acid (PUFA). This EFA is synthesized by diatoms and a preferred food to many grazers. Therefore the production and loss of certain fatty acids extracted from the water column can give information about growth and grazing.

Task 9 will coincide with the dye study of Task 8, providing correlation of biological and water quality data.

Materials and Methods

Plankton sampling dates, locations:

13-14 July 2005 sampling: the first data collection event, originally scheduled in June, was delayed until mid-July due to very high flows. For this event, eleven sites were sampled, named SJR1 through SJR12 (Figure 1). Zooplankton sample SJR9 does not exist as the sample was lost. All sites except SJR7 and SJR8 were taken in the dyed water mass of task 8. Sampling times are shown in the figure, and span day and night hours.

16-18 August 2005 sampling: for this event, eighteen sites were sampled, named SJR1 through SJR18 (Figure 1). All samples were taken in the dyed water mass of task 8.

15-17 September 2005 sampling: for this event, 15 sites were sampled, named SJR1 through 23 (Figure 1). All samples were taken in the dyed water mass except for SJR8-10 and SJR16-20, which were taken at fixed positions for several hours using an Isco portable sampler (Teledyne Isco, Inc.).

13-14 October 2005 sampling: for this event, 12 sites were sampled, named SJR1 through 12, and ISCO7 through 9 (Figure 1). All samples were taken in the dyed water mass except ISCO 7 through 9, which were sampled with a portable sampler as in September.

19-21 July 2006 sampling: for this event, 17 sites were sampled, named SJR1 through 15, and the mouth of French Camp Slough and the Turning Basin of the DWSC (Figure 1). All samples were taken in the dyed water mass except French Camp Slough and the Turning Basin. Sampling at several depths occurred with SJR8 (4 depths), SJR13 (3 depths), SJR15 (2 depths), French Camp Slough (2 depths), and the Turning Basin (2 depths).

9-10 August 2006 sampling: for this event, 13 sites were sampled, named SJR1 through 13 (Figure 1). All samples were taken in the dyed water mass. At each site, samples were taken at the bottom, mid-depth, surface or edge.

Benthic macroinvertebrate sampling dates, locations:

Sampling of benthic organisms occurred in 2005 at the following dates and locations:

- 24 May, entrance to Burns Cutoff
- 27 June, Stockton Brick Company, entrance to French Camp Slough
- 1 July, Head of Old River, DWR station
- 13 July, many locations from Vernalis to Burns Cutoff
- 28 July, between Vernalis and Mossdale
- 17 August, approx. 2 mi N of Dos Reis Park dock.
- 15 September, approx. 4 mi S of Mossdale
- 16 September, approx. 4.5 mi N of Mossdale
- 13 October, from Vernalis bridge to 1 mi N of bridge
- 14 October, approx. 4 mi S of DWSC to the DWSC, including all of Burns Cutoff and French Camp Slough

Plankton sampling and preservation:

Zooplankton are collected with a 30 L Schindler-Patalas Trap fitted with a 63 um net (Wildlife Supply Company, Buffalo, NY). Using a power winch, the trap is lowered into the water column to approximately one-half depth or to specific depths depending on the site and date. The 30 L sample is taken at the point in the water column where the trap is pulled upward. The samples are preserved in buffered formalin sucrose (5% final concentration).

In September and October 2005, several samples were taken using a portable Isco sampler. The sampler was fitted with 24 1-liter bottles. Zooplankton volumes varied with the time and location. The date, sites, and volumes sampled (liters) were as follows: 9/16/05, SJR7, 3; 9/16/05, SJR8, 4; 9/16/05, SJR9, 5; 9/16/05, SJR10, 5; 9/17/05, SJR15, 2; 9/17/05, SJR16, 3; 9/17/05, SJR17, 3; 9/17/05, SJR18, 3; 9/17/05, SJR19, 3; 9/17/05, SJR20, 2; 10/14/05, ISCO7, 6; 10/14/05, ISCO8, 6; 10/14/05, ISCO9, 6.

Benthic sampling involved different methods for mid-channel and near-bank locations. A winch-mounted standard Ponar dredge with an 8 L capacity (Wildlife Supply Company, Buffalo, NY) is used to take mid-channel samples. Dredge contents are rinsed into a bucket, mixed with water, and poured into a 500 um mesh sorting frame. A stream of water is used to rinse away all fine sediments. The remaining material is transferred into a 500 mL bottle with buffered formalin sucrose (5% final concentration). For near-bank sampling, hand-digging is performed down to approximately 30 cm depth. Bivalves are placed in 37% buffered formalin for preservation.

Plankton concentration and analysis:

Zooplankton analysis follows U.S. EPA LG403. Briefly, zooplankton samples are thoroughly mixed by inversion and a 5 - 20 mL subsample is taken from each using a Stempel pipette (volume adjusted for sediment amount in sample). The subsamples are added to a settling apparatus (Standard Utermohl Chamber, Aquatic Research Instruments, Lemhi ID), and settled for 5 – 20 hrs depending on volume. Prior to settling, 100 uL of 1% rose Bengal dye is added to facilitate counting of zooplankton.

Examination of zooplankton took place with a Leica DM-IL inverted microscope fitted with a Canon 350D digital camera. Identification of species follows standard texts (Balcer et al. 1984; Chengalath et al. 1971; Pennak 1989; Pontin 1978; Wallace 1991). All species encountered are photo- and specimen-vouchered, and all counted samples are stored for future reference.

For zooplankton counts, the entire chamber floor is examined. For biomass estimates, body measurements are taken from a maximum of twenty individuals of each species using a calibrated ocular Whipple Grid. Conversion of body measurements into biomass follows U.S. EPA publication LG403. Following publication L403, a minimum of 200 individual organisms are counted for each sample. To encounter that many individuals

requires the settling of up to 450 mL of sample volume, depending on the amount of sediment in the samples. All samples have been scored and the data recorded and analyzed.

Benthic macroinvertebrate species identifications:

Bivalve mollusks are identified using standard texts (Burch 1972, 1973).

PLFA sampling and analysis:

Samples from the September 2005 and July – August 2006 sampling periods were analyzed. The samples were preserved with formalin immediately after collection. To extract PLFA from water, 1000 ml of water sample was filtered through a Whatman GF/F glass fiber filter within 24 hours of collection. After filtration, the filter is placed in a 25 mm glass tube and stored at -20°C until extraction. The total lipids are extracted from the filter with a modified Bligh-Dyer solution which consists of 5 ml of chloroform, 10 ml of methanol, and 4 ml of phosphate buffer. The extract is used to estimate chlorophyll concentration by measuring absorbance at 435 and 665 nm on a UV/Vis spectrometer. The phospholipids are then separated from total lipids on C18 silicic acid column (Unisil, Clarkson Chemical, South Williamsport, PA).

Isolated phospholipids are methylated and analyzed on an Agilent 6890N Gas Chromatograph (GC) equipped with a Flame Ionization Detector. Peak confirmation is accomplished on an Agilent 5972A mass spectrometer and double bond position confirmed with a dimethyl disulfide derivation. Peak quantification was accomplished by use of an internal 19:0 phospholipid standard (1,2-Dinonadecanoyl-sn-Glycero-3-phophocholine) (Avanti, Alabaster, AL) which is added immediately prior to extraction, and an external 11:0 carbon fatty acid methyl ester standard (methyl decanoate) (Matreya, Pleasant Gap, GA) which is added immediately before analysis on the GC.

Lipids classes recovered from the samples were assigned to different groups of organisms as shown in Table 1. Fatty acids can be characterized by the shorthand X:YwZ, where X equals the number of carbon atoms, Y equals the number of double bonds, and Z equals the position of the first double bond counting from the methyl end. (Brepohl, 2005). In this table are listed several sources in the literature that identify specific lipids for various types of algae (Galois, 1996).

Data Analysis:

Zooplankton biomass data derived from microscopic analysis were analyzed by multivariate statistics with the software PC-ORD version 5 (McCune and Mefford, 1999). The input data matrices consisted of biomass values organized by sites (rows) and zooplankton species (columns). Separate matrices were constructed for each sampling period. Biomass data were summarized and ecological diversity statistics calculated for each site. The data were then log-transformed and underwent a nonmetric-multidimensional scaling (NMS) ordination procedure to reduce the dimensionality of the

data. Sites were ordinated in species space. A joint plot of environmental variables taken from Task 8 was superimposed on the ordination axes to determine how these variables co-vary with sampling sites. The environmental matrices consisted of parameter values organized by sites (rows) and variables (columns). Environmental matrices differed between sampling periods as complete data sets for each variable were not available for each period. Typical parameters were: dissolved oxygen, turbidity, electroconductivity, pH, alkalinity, chlorophyll a concentration, phaeophytin concentration, total pigment concentration, river mile, time elapsed, temperature, total suspended solids, and volatile suspended solids. In certain cases, environmental data missing for a particular site during a sampling period was replaced with an average of the data from the previous and following sites. Environmental variables were relativized by a general relativization procedure. Prior to the NMS analysis, a multivariate outlier analysis was performed, and outlying sites were deleted from the data matrix. Density data have not been analyzed.

Results

Zooplankton microscopic analysis:

Table 2 lists the zooplankton taxa identified in the six sampling periods, and their abbreviation codes. Zooplankton consist of rotifers, cladocerans, and copepods, both as nauplii (larvae) and adults. These taxa are common constituents of the limnetic environment in rivers (Reid, 1961; Wetzel 1983). In general, the data indicate that rotifers are common throughout the study reach however their biomass is low in comparison to non-rotifer animals. Dominant rotifer taxa shift across months. Rotifer biomass varied over sampling periods and sites. The pattern is similar in all sampling periods where the entire reach was sampled: it is lowest at Vernalis (most upstream site), and highest at the DWSC (most downstream site), with a peak of in the vicinity of Mossdale, and the lowest levels usually seen at the mouth of French Camp Slough. The highest rotifer biomass in the study is seen in July 2006 at SJR15 (DWSC), with 16.6 ug/L. Rotifer species richness (S), which is defined as the number of species present at a given site, varied over sampling periods and sites, with several patterns seen: a decline in S over the reach is seen in September and October 2005 and July 2006; a hump-shaped pattern, with lower values at Vernalis and the DWSC and higher values mid-reach was seen in July and August 2005; a flat relationship with little change over the reach in August 2006. The highest S value was 27 in August 2006 at site SJR13 (DWSC). Rotifer biomass and species richness are not well correlated. A correlation of 0.83 exists between species richness and river mile in October 2005, however in other sampling periods their can be no relationship or it can be negatively correlated. For rotifer biomass, the correlation with non-rotifer species biomass is high in September 2005 and July 2006 (0.75 and 0.71, respectively). In July 2006, rotifer biomass was negatively correlated with total pigment concentration (-0.73). In August 2006, rotifer biomass was negatively correlated with river mile (-0.69).

Three species of Copepoda occur in the river, where two are planktonic and one largely benthic. The benthic species (Harpacticoida) was probably trapped by the plankton sampler because suspension of sediments by high water flow places benthic forms into

the water column. The two planktonic species occur in patches, often with large populations.

Copepods are usually most abundant in the lower half of the study reach (Figures 2 – 7). In general, the alien copepod *Pseudodiaptomus forbesii* (pforb) occurs largely in downstream areas, and the native species *Microcyclops rubellus* (mrubel) generally occurs further upriver, although the two species can overlap their distributions greatly in certain months. In July 2005, pforb was absent from the study reach, with mrubel occurring largely in the downstream half of the reach. In August 2005, pforb occupied most downstream sites below the Head of Old River and mrubel occupied the upstream half of the reach, with co-occurrence in the upstream sites SJR2 and Dos Reis Dock. In September 2005, the pattern was similar to August 2005 however mrubel had shifted downstream as far as SJR14 (just upstream of Garwood Bridge), where it co-occurred with pforb. Below SJR14 only pforb was present. In October 2005, the two species only co-occur at SJR10 (near Stockton Brick Company Stack), with mrubel common in sites upstream and with pforb only occurring at SJR10 and SJR5 (near Mossdale). In July 2006, mrubel was absent from the reach, and pforb occupied most downstream sites below Brandt Bridge. In that month, depth profiling showed that the highest biomass of copepods was near the bottom. In August 2006, the two species were very mixed among sites, with co-occurrence at four sites (SJR7, SJR8, SJR9, and SJR11), although pforb dominated near the DWSC and mrubel was the sole species at the most upstream site. Depth profiling in August 2006 showed that highest copepod biomass was at the bottom in the upstream sites, then more downstream the pattern shifts to mid- or surface depths harboring the most copepods.

Copepod larvae (nauplii) are usually widespread in the river and their density generally increases with water age. Cladocerans are less abundant than either rotifers or copepods, and their distribution is usually patchy, although the pelagic *Bosmina longirostris* is widespread in the river. The other cladoceran species are largely confined to the DWSC or to littoral areas scattered throughout the reach.

Figures 2 – 7 show the relationship between zooplankton biomass and total photosynthetic pigment over all sampling periods and sites. In general, zooplankton biomass increases with the age of the water, with the highest levels generally occurring between the Stockton Wastewater Treatment Facility outfall pipe and the DWSC. Also, zooplankton tend to increase during night hours, and in 2006 this increase is usually associated with tidal reversal. Large zooplankton populations are also commonly seen near Mossdale. Above Mossdale, rotifers generally dominate the fauna.

In all sampling periods except July and October 2005, there are population spikes in zooplankton during night hours, with subsequent sharp population decreases. Population spikes in general are associated with particular areas of the reach, especially the vicinity of Mossdale and the Wastewater Outfall and DWSC. In half of the sample periods, the DWSC maintains a very high biomass of zooplankton, with several species characteristic of that site. The second highest biomass seen in the study, 203 ug/L, occurred at the surface of the DWSC in July 2006. In July 2006 the Turning Basin and French Camp

Slough were sampled. They are most similar in zooplankton diversity and abundance to the other sites closest to them. The Turning Basin maintains the highest level of organisms seen in the study, with a biomass of 282 ug/L at the bottom in July 2006.

Relationship to pigment concentration is varied with the month. In some periods little relationship is seen, and in others the correlation is strongly positive or negative depending on the position along the reach. There are instances where a negative correlation occurs in the upper reach and then a strongly positive correlation downstream, or the reverse relationship.

In July and August 2006, many sites were sampled at two or three depths. Collectively for all zooplankton, biomass generally differs by depth, with the highest biomass usually occurring at mid-depth. Samples taken along the edge of the channel had the lowest biomass.

Figures 8 - 13 show the results of the NMS analysis for the six sampling periods. Except for July 2005, the analysis produced low dimension solutions accounting for most of the variation in the data. The data from July 2005 has very little structure and few inferences can be drawn from it. In other periods, correlations with environmental data, shown as joint plots on the ordinations, indicate that generally the river axis (i.e., travel time) explains a large amount of the variation. The river axis also explains much of the biomass variation among the sites. The sites often fall out in a line resembling the river geography and order of sampling events. Notable is the analysis for July 2006 (Figure 12), which has a one-dimension solution, meaning that 92% of the variation in the biomass data can be explained by one variable, and that variable is most highly correlated with nauplii (r=-0.97) and temperature (r=-0.94) and time (r=-.83). A large discontinuity in biomass data is seen between sites SJR7 and SJR8 (vicinity of Haven Acres), with nauplii accounting for the majority of this change. Why such a large increase in larval copepods occurs at this site is unclear. Other sampling periods show a similar trend but usually without large discontinuities. In general, the NMS analyses indicate that biomass increases as the water moves downstream, with water age and river mile explaining most of the variation in zooplankton biomass. This pattern suggests that zooplankton grow and reproduce as they move downstream.

Benthic macroinvertebrates:

Three species of bivalve mollusks have been found. Two native clams, *Anodonta* sp. (California Floater) and *Pisidium* sp. (Pea Mussel), and one introduced clam, *Corbicula fluminea* (Asian Clam), are found discontinuously throughout the river. Anodonta and Corbicula are in highly clustered positions, largely in shallow water near the banks. Pisidium has only been found in the mid-channel position. In general, density of these organisms is extremely low and the exact density and distribution is not known. Future work will improve our understanding of their importance in grazing. Figure 14 provides a summary of the species present at various locations in the river.

PLFA results:

In Figure 15a-15f are shown the essential fatty acid, Eicosapentanoic acid (EPA, also designated 20:5), that was extracted from the zooplankton trap sample are shown against the rotifer mass on the left column and the non-rotifer mass on the right column. The horizontal axis is SJR river mile, starting with Vernalis (mile 72) to the left and ending at the DWSC (mile 40). On 9/15/06 the amount of EPA was very well correlated with the amount of rotifers present in the water in contrast to the poor agreement with the amount of non-rotifers. On 8/9/06, the opposite case was seen, with the amount of this lipid correlating more closely with the non-rotifer community. The results demonstrate that EPA is capable of estimating zooplankton concentrations at certain sampling periods, however which type of zooplankton are quantified is variable.

Figures 16a-16c shows the total lipid recoveries from the whole water fraction. The total lipid represents the summation of all the lipids, including those from bacteria, terrestrial organisms that have entered the water, and algae. The total lipid number is compared with the chlorophyll-a levels. Out of the three sample dates, the July 2006 measurements most closely match the chlorophyll-a values. For the other two dates, the patterns have similarities but many differences exist. The samples used in Figure 2 were not treated with formaldehyde but instead kept chilled prior to analysis, which may have caused some changes in the lipid content prior to analysis.

To gain further insight into the differences in the 2005 and 2006 samples, the algae community structure was plotted for the samples collected (Figure 17). Both the 2006 samples show a dominance of diatoms whereas the 2005 sample is equally split between the lipids normally associated with green algae and those of diatoms. The different types of algae present can account for the differences in the types of zooplankton that will be present in the water. Some zooplankton (such as copepods) have the ability to select food whereas other types (such as cladocerans) are more non-selective filter feeders. Because of some lack of specificity in lipids for algae species and the complex environment in the SJR and tributaries, phospholipid analysis in this study could not identify specific algae species.

Discussion

The data strongly indicate that the zooplankton community in the SJR is of normal structure and composition, and that zooplankton biomass increases as the water flows downstream. Variation in species composition and biomass varies greatly between sampling periods, and species-specific distributions vary over time, but general trends do exist. Strong peaks in zooplankton abundance occur in some sampling periods, but do not in others. In general, the major contributors to biomass are copepods, and the largest populations of these organisms are seen downstream in the last few miles of the study reach.

The results of this study do not differ markedly from studies of other large river systems. As an example, the zooplankton taxa found in a recent study of the Danube River in Austria (Baranyi et al., 2002) are very similar to those found in the SJR. The Danube

supports 43 species of rotifers whereas the SJR supports 42 species with very similar species composition. For copepods, both systems support two major copepod species, although the species identities differ. The major cladocerans in both systems are *Bosmina longirostris* and one *Daphnia* species, with a few other species scattered in various locations, and these few others are in similar or the same taxonomic families. They also found a strong positive correlation between water age (i.e., travel time) and zooplankton biomass, and that rotifer species dominate in younger water and crustaceans (copepods and cladocerans) dominate in older waters. These results are consistent with the concept that rotifers should be better able to dominate younger waters rather than crustaceans because of their shorter development time (Ecker and Walz, 1998; Townsend et al., 1997). Because of their longer development time, crustaceans should dominate in slower, older waters, such as is the case in SJR downstream areas influenced by tides. Furthermore, the influence of the sluggishly-flowing Turning Basin and the DWSC, which support high levels of crustaceans, likely have a biotic influence on the SJR when tides reverse.

Diel vertical migration (DVM) has been studied extensively in the past (Dini and Carpenter, 1992) and is a well known phenomenon that characterizes many crustacean zooplankton species. A typical pattern is for animals to ascend to the surface waters during the night hours to feed, and then to descend to the bottom during the day. It is believed that this behavior is a predator-avoidance mechanism. DVM is known to occur in some species at certain times but not at other times, and other species do not have this behavior. In the present study, the data from August 2006 do indicate a movement of copepods from the bottom to the mid-depths during night hours, however the surface depths do not support the highest biomass. There is, however, a large increase in total non-rotifer biomass during night hours for that sampling period and in July 2006, but that increase is not strongly associated with a vertical movement, with the largest increases occurring in the species pforb at mid- and bottom depths. The lack of a strong DVM pattern has been associated with highly turbid waters like the SJR (Castro et al., 2007), and it is assumed that vision-based predation is less important under low visibility conditions.

The PLFA study has had mixed results. It is clear that the lipid quantities do somewhat reflect biomass values derived from the microscopic analysis, however the correspondence is not very high in many samples. It may be that lipid values may correspond more closely with algal biovolume data derived from microscopic analysis, however those data do not exist. Work on PLFA should continue in conjunction with a traditional phytoplankton study. Such a study is not yet funded.

Bivalves are present in the river however their abundance is low and their distribution is very patchy. Very little suitable habitat exists in the lower reach for these organisms. There is evidence that high flows scour out the sediments and sweep away these organisms. Until flows subside for long periods it is unlikely that these organisms will contribute significantly to grazing in the study reach.

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Table 1: Identification of Lipid Biomarkers used.

Descriptor	Biomarker/characteristic Fatty Acid	Reference
Diatom	16:3w3 20:5 Eicosapentaenoic acid (EPA)	Pond, 1998; Parrish (1998, 2000); Boshker, 2005; Desvilettes, 1997, Muller-Solger, 2002, Galois, 1996; Brepohl, 2005
Dinoflagellates	22:6w3 Docosahexaenoic acid (DHA)	Brepohl, 2005, Desvilettes, 1997; Parrish, 2000; Galois, 1996
Bacteria	i15:0, a15:0	Parrish, 2000; Boschker, 2005; Desvilettes, 1997
Green Algae	18:3w3 Linolenic acid (ALA)	Napolitano, 1997
Terrestrial	25:0, 26:0	Galois, 1996; Desvilettes, 1997; Napolitano, 1997

Table 2. Zooplankton taxa identified and scored for six sampling periods.

Species	Code	Species	Code
Rotifera		*Lepadella*	Lepad
Anureopsis	anure	*Monostyla quadridentatus*	Mquad
Ascomorpha	ascom	*Mytilina*	Mytil
Asplancha	aspla	*Notomatta*	Notom
Asplanchnopus	aspls	*Platyias quadricornis*	Platy
Brachionus angularis	bangu	*Ploesoma truncatum*	Ploes
Brachionus budapestinensis	bbuda	*Polyarthra remata*	Polya
Brachionus calyciflorus	bcalyc	*Pompholyx sulcata*	Pomph
Brachionus caudatus	bcauda	*Squatinella*	Squat
Brachionus havanaensis	bhavae	*Synchaeta longipes*	Synch
Brachionus quadridentatus	bquadr	*Testudinella patina*	Testu
Brachionus rubens	bruben	*Trichocerca rousseleti*	Trrou
Brachionus urceolatus	burceo	*Trichocera similis*	Trsim
Cephalodella gibba	cepha	*Trichotria*	Trichx
Collotheca pelagica	collo		
Colurella adriatica	colur	Copepoda	
Conochilus	conoc	*Pseudodiaptomus forbesi*	Pforb
Epiphanes senta	epiph	*Microcyclops rubellus*	Mrubel
Euchlanis dilatata	euchl	Harpacticoida	Harpa
Filinia longiseta	filin		
Gastropus	gastr	Cladocera	
Hexarthra	hexar	*Bosmina longirostris*	Bosmi
Kellicottia longispina	kelli	*Ceriodaphnia lacustris*	Cerio
Keratella cochlearis	kerco	*Daphnia parvula*	Daphn
Keratella valga	kerva	*Diaphanosoma brachyurum*	Diaph
Lecane dysorata	ldyso	*Disparalona dadayi*	Ddada
Lecane luna	lluna	*Macrothrix laticornis*	Macro
Lecane thalera	lthal	*Monospilus dispar*	Monos
Lecane sp.	oldx		

Figure 1. Sampling locations for zooplankton. Numbers indicate sampling locations. Abbreviations are as follows: V: Vernalis; M: Mossdale; HOR: Head of Old River; Brandt: Brandt Bridge DWR station; SBC: Stockton Brick Company Stack; FCS: Mouth of French Camp Slough; Gar: Garwood Bridge Station (USGS); DWSC: Stockton Deep Water Ship Channel; O: Wastewater Outfall.

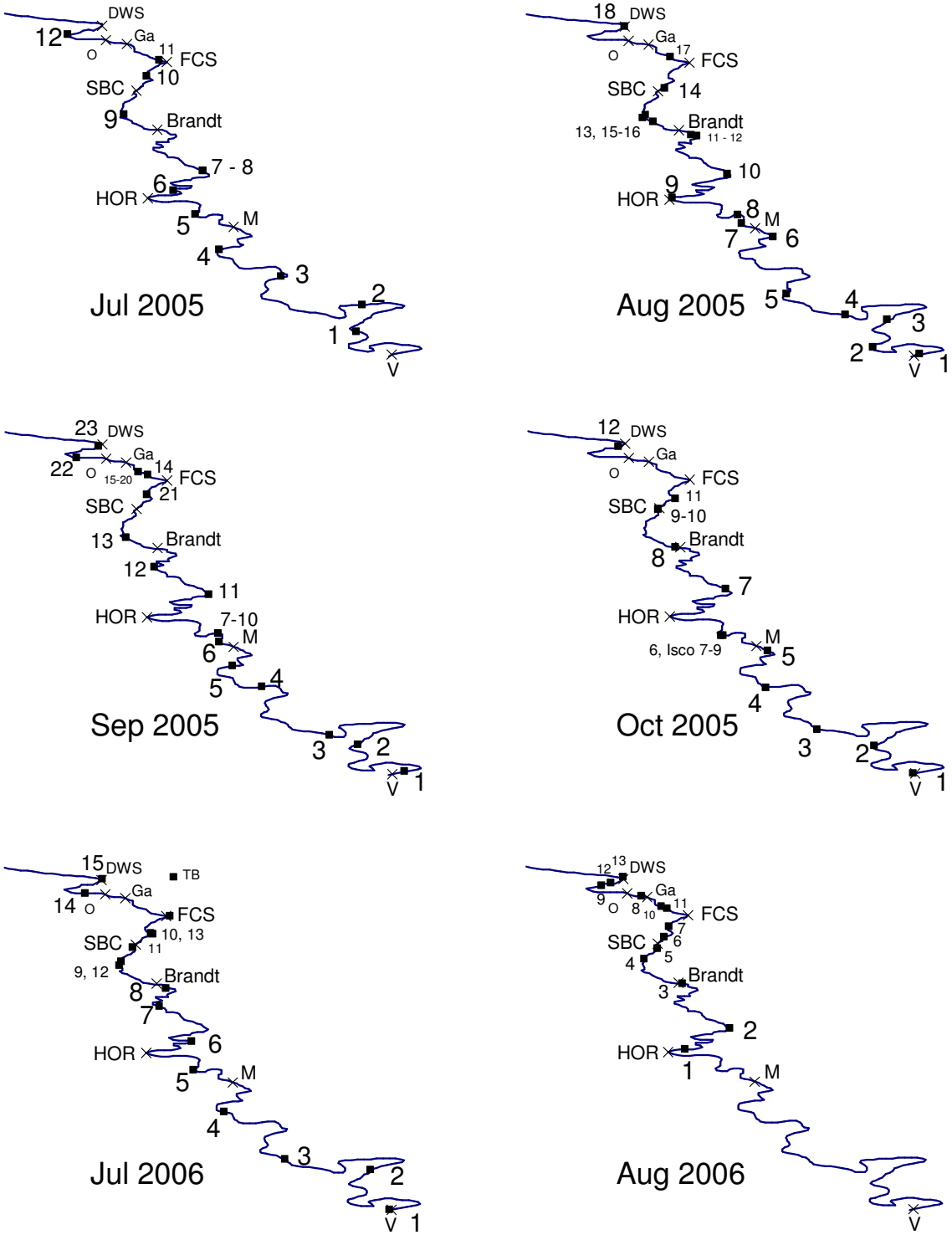

Figure 2. July 2005 relationships between zooplankton and total photosynthetic pigment (chlorophyll a and pheophytin). Sample site numbers are below the time values. M: Mossdale; HOR: Head of Old River; OF: Outfall pipe.

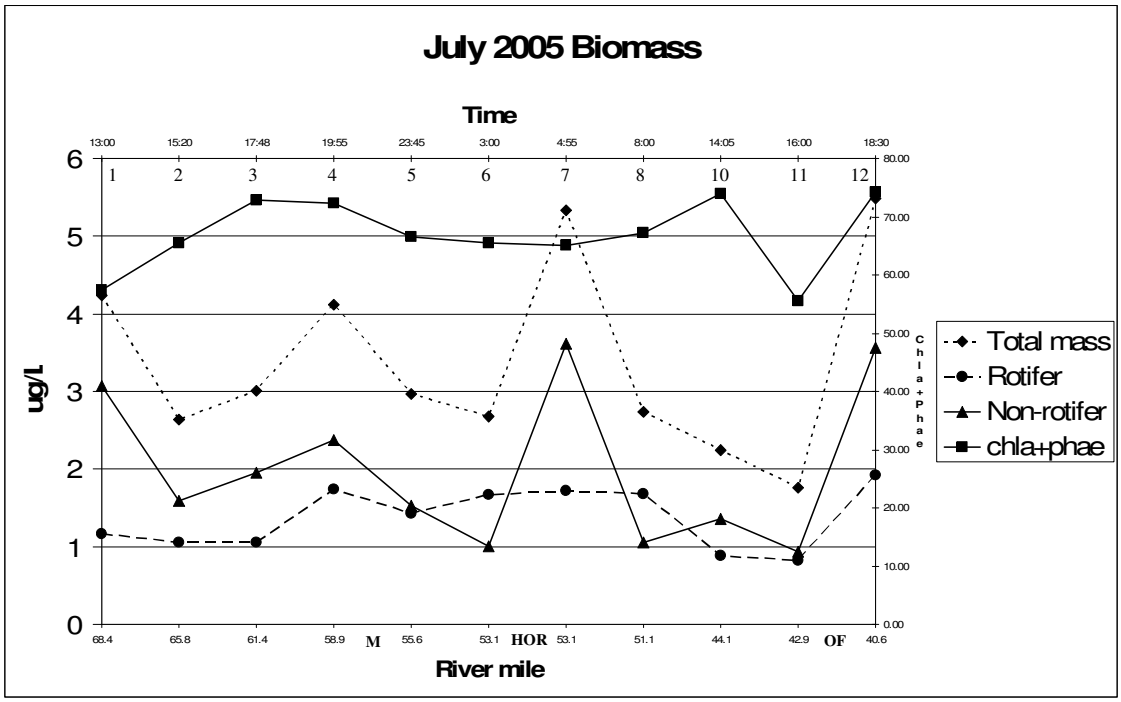

Figure 3. August 2005 relationships between zooplankton and total photosynthetic pigment (chlorophyll a and pheophytin). Sample site numbers are below the time values. M: Mossdale; HOR: Head of Old River; OF: Outfall pipe.

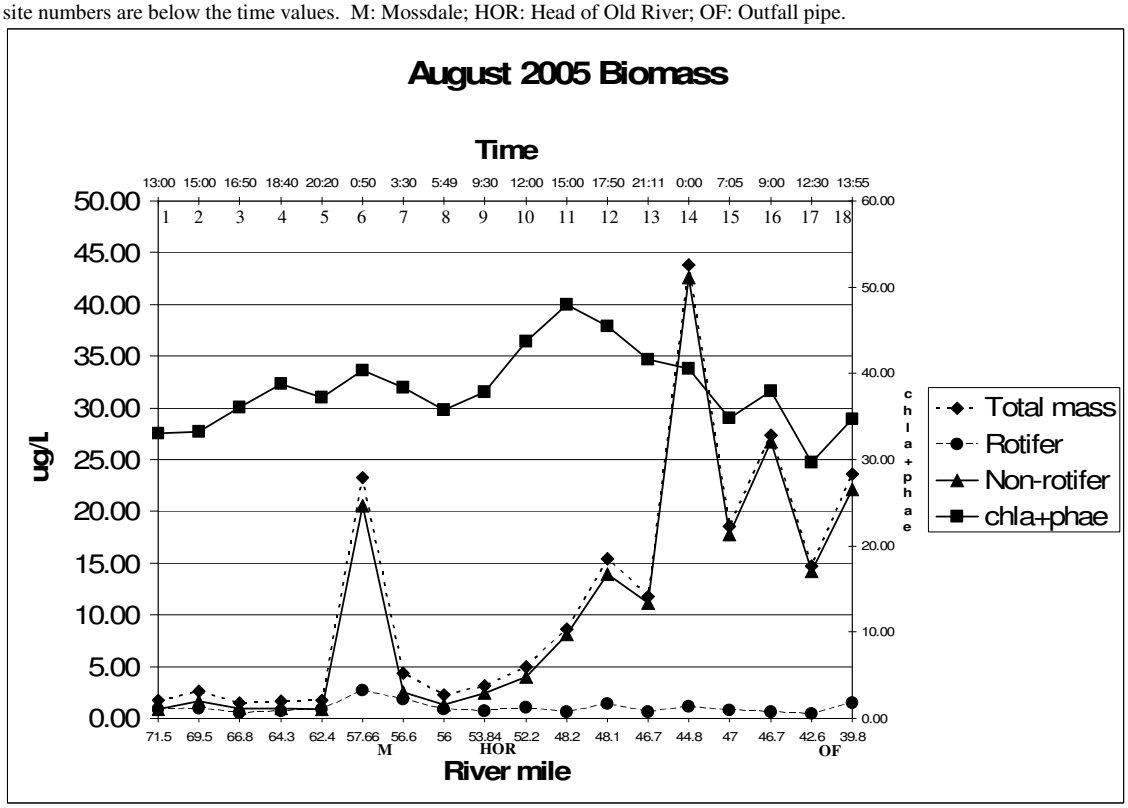

Figure 4. September 2005 relationships between zooplankton and total photosynthetic pigment (chlorophyll a and pheophytin). Sample site numbers are below the time values. M: Mossdale; HOR: Head of Old River; OF: Outfall pipe.

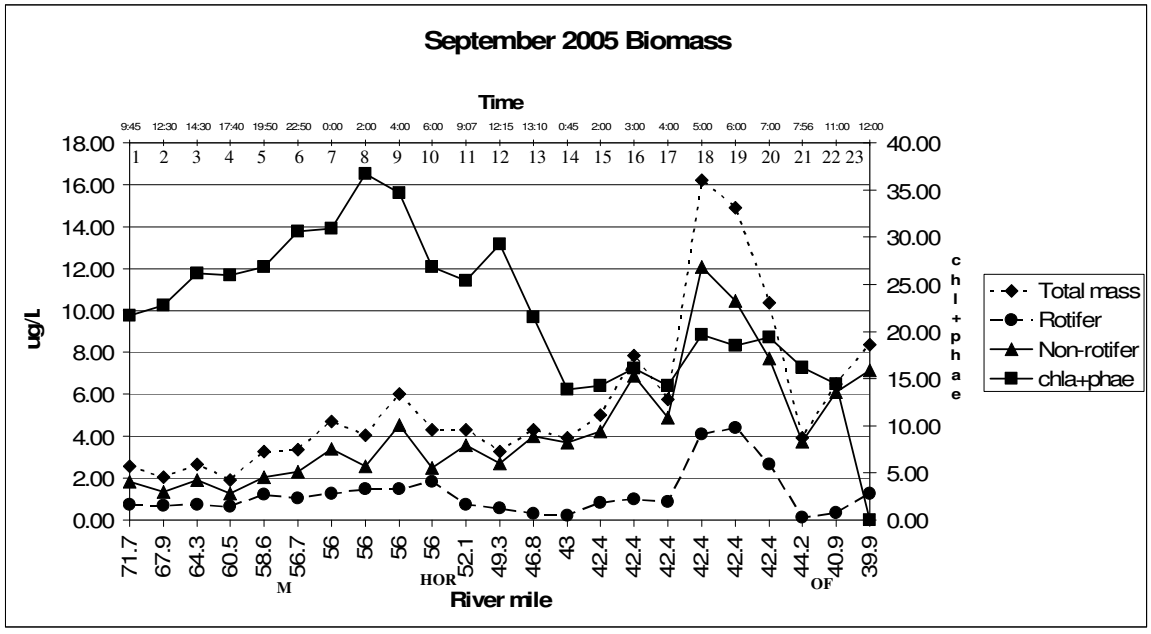

Figure 5. October 2005 relationships between zooplankton and total photosynthetic pigment (chlorophyll a and pheophytin). Sample site numbers are below the time values. M: Mossdale; HOR: Head of Old River; OF: Outfall pipe.

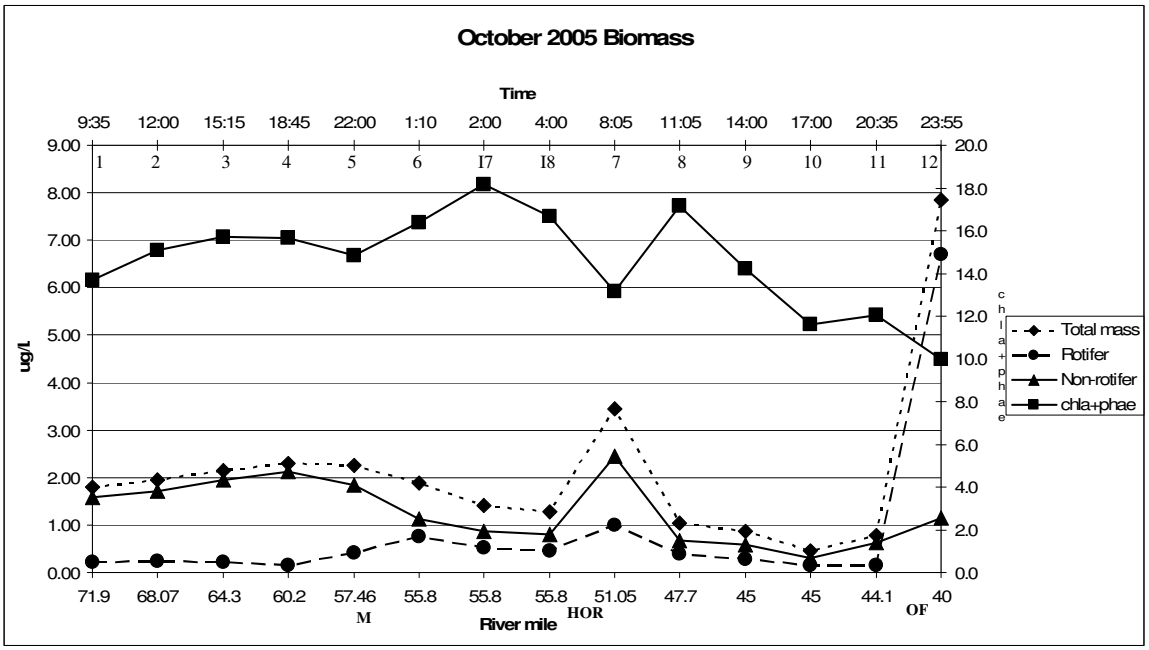

Figure 6. July 2006 relationships between zooplankton and total photosynthetic pigment (chlorophyll a and pheophytin). Sample site numbers are below the time values. M: Mossdale; HOR: Head of Old River; OF: Outfall pipe.

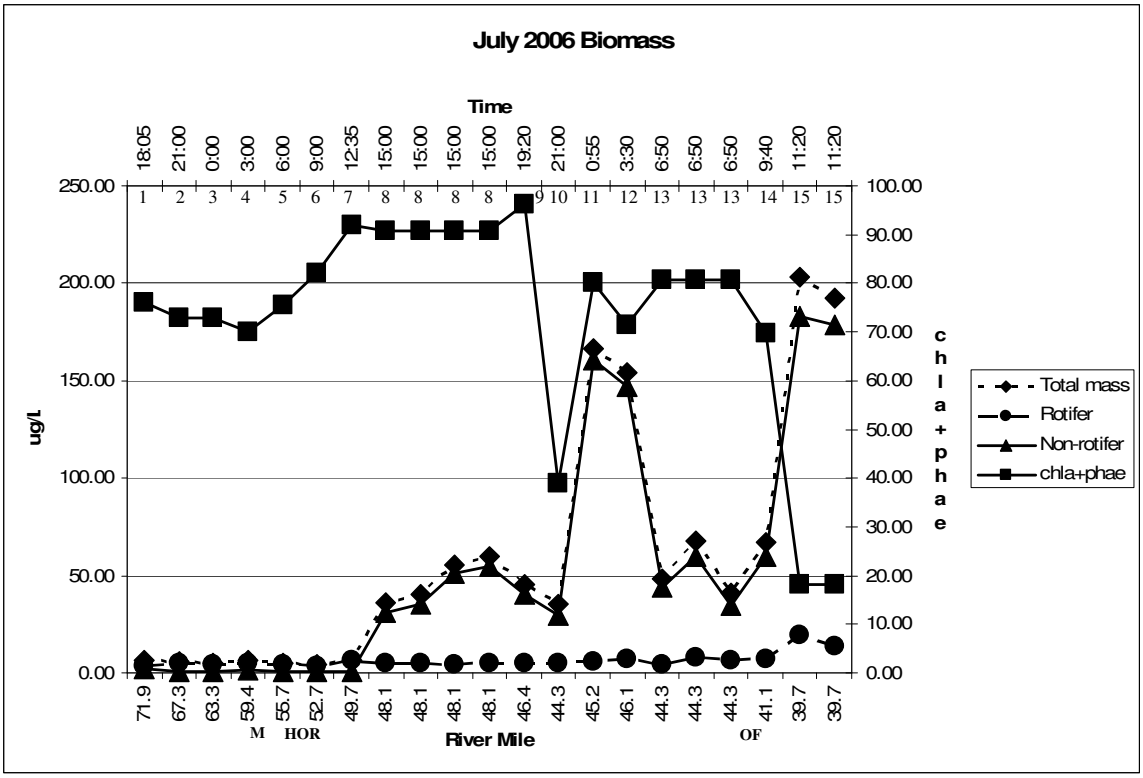

Figure 7. August 2006 relationships between zooplankton and total photosynthetic pigment (chlorophyll a and pheophytin). Sample site numbers are below the time values. M: Mossdale; HOR: Head of Old River; OF: Outfall pipe.

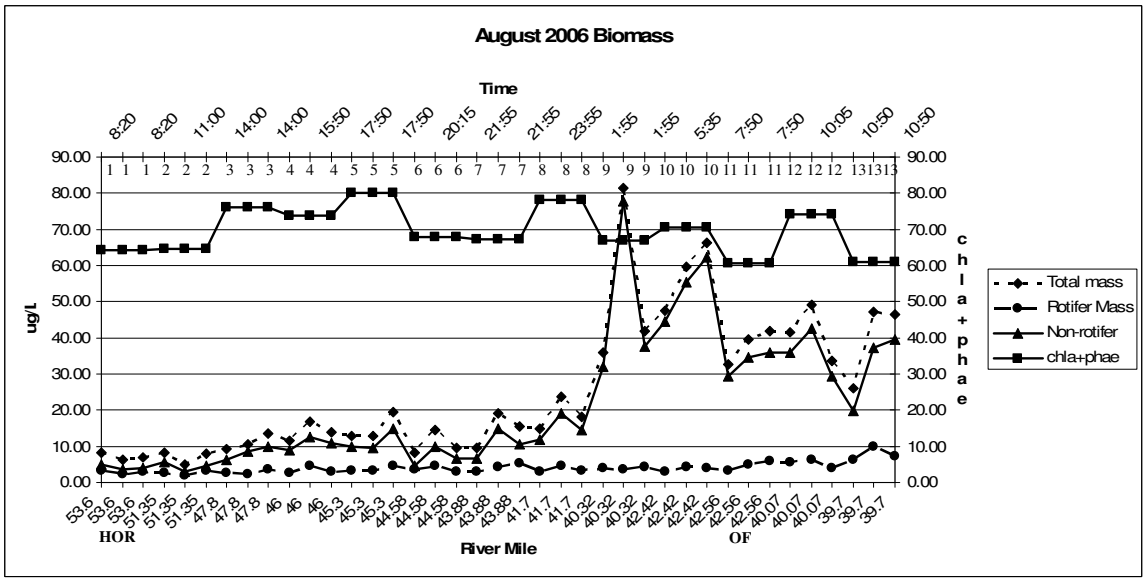

Figure 8. NMS ordination of July 2005 sites in species space, with environmental variable joint plot superimposed. First two axes shown. Abbreviations are as follows: Pha: Phaeophytin; EC: electroconductivity; TSS: total suspended solids; Turb: turbitity; rm: river mile; temp: temperature.

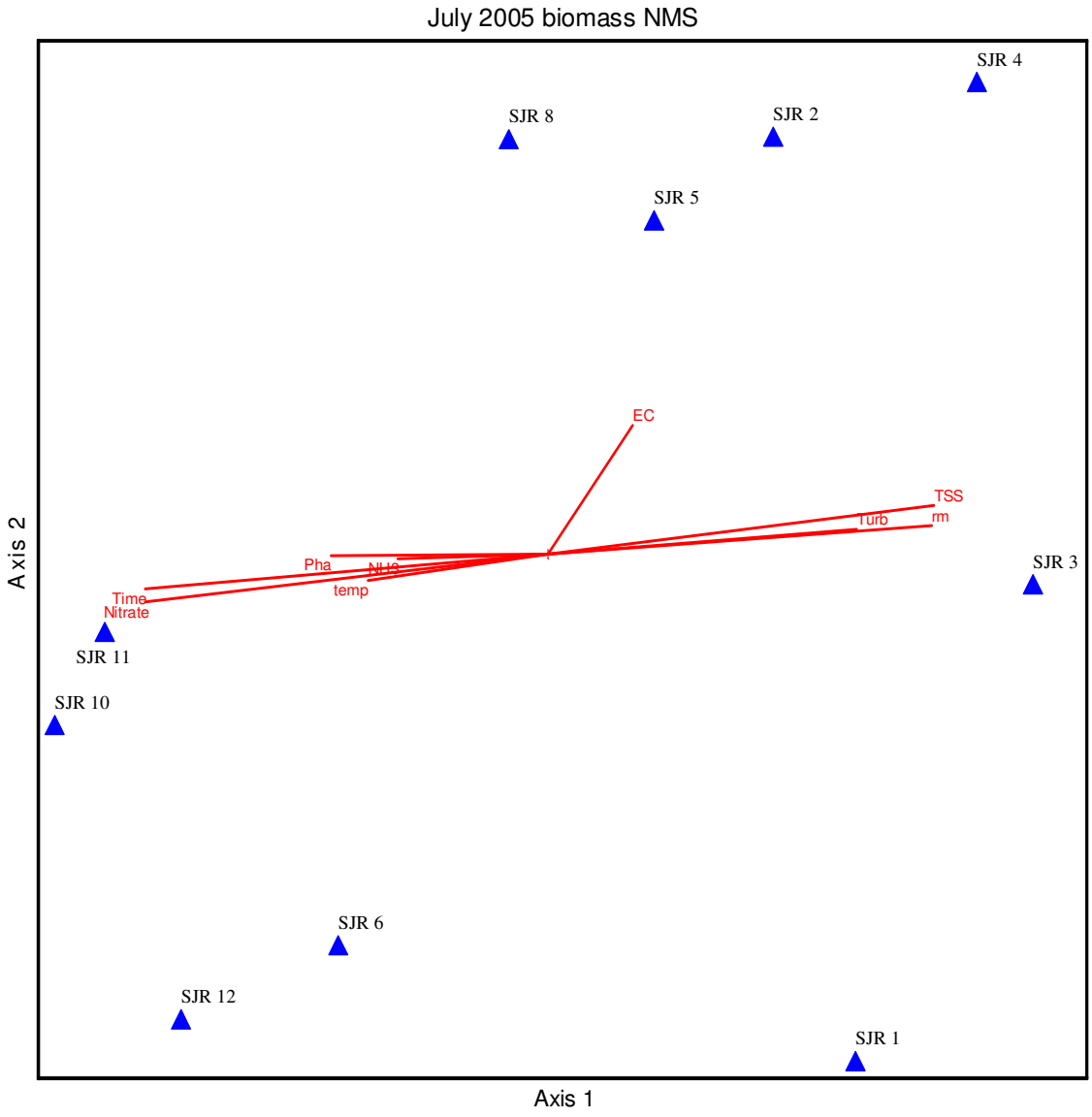

Figure 9. NMS ordination of August 2005 sites in species space, with environmental variable joint plot superimposed. First two axes shown. Abbreviations are as follows: Pha: Phaeophytin; EC: electroconductivity; TSS: total suspended solids; Turb: turbitity; rm: river mile; temp: temperature; Chla: chlorophyll a concentration; VSS: volatile suspended solids; DO: dissolved oxygen.

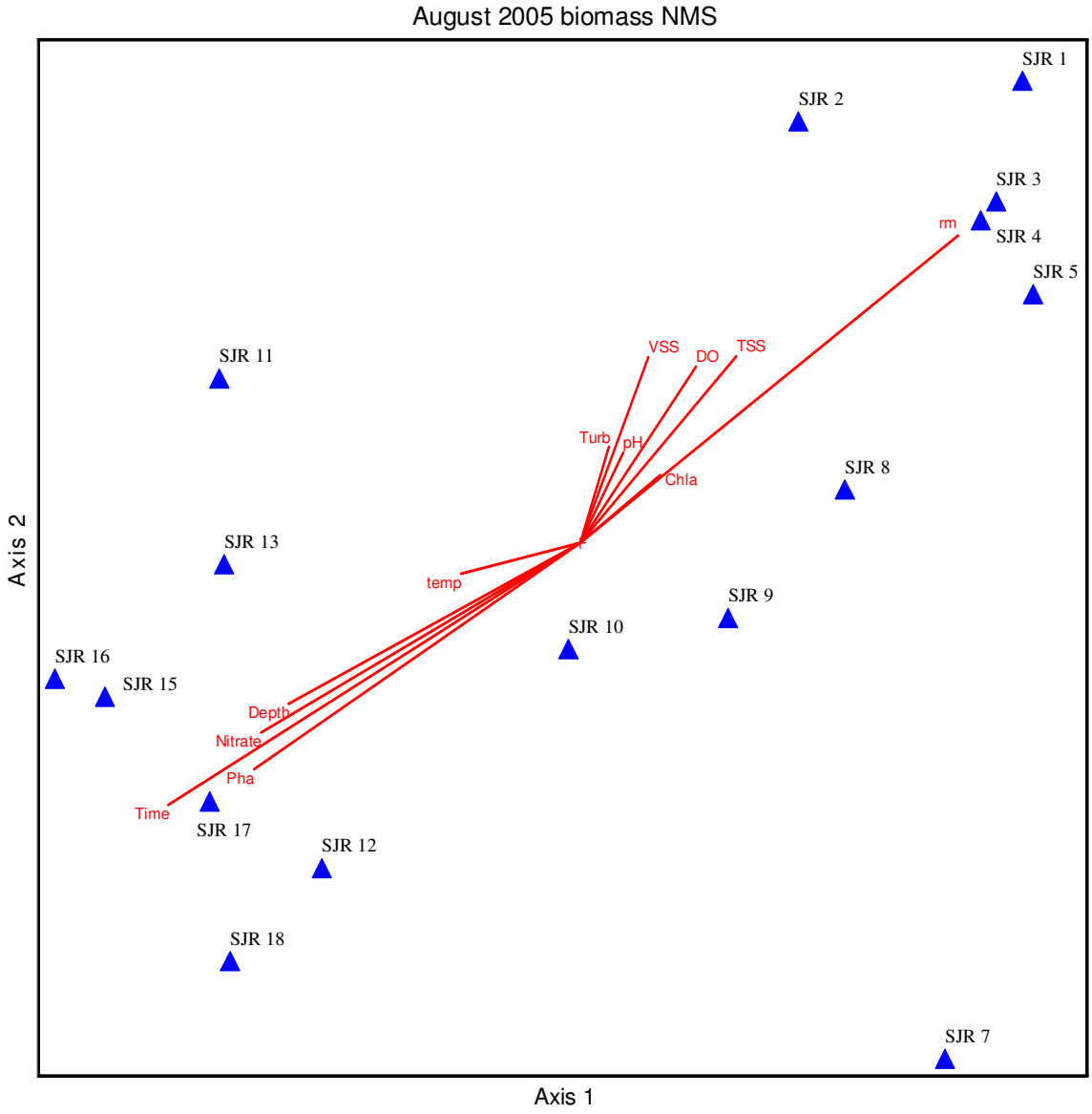

Figure 10. NMS ordination of September 2005 sites in species space, with environmental variable joint plot superimposed. First two axes shown. Abbreviations are as follows: Pha: Phaeophytin; rm: river mile; Chla: chlorophyll a concentration; Pigsum: total pigment (chla + Pha).

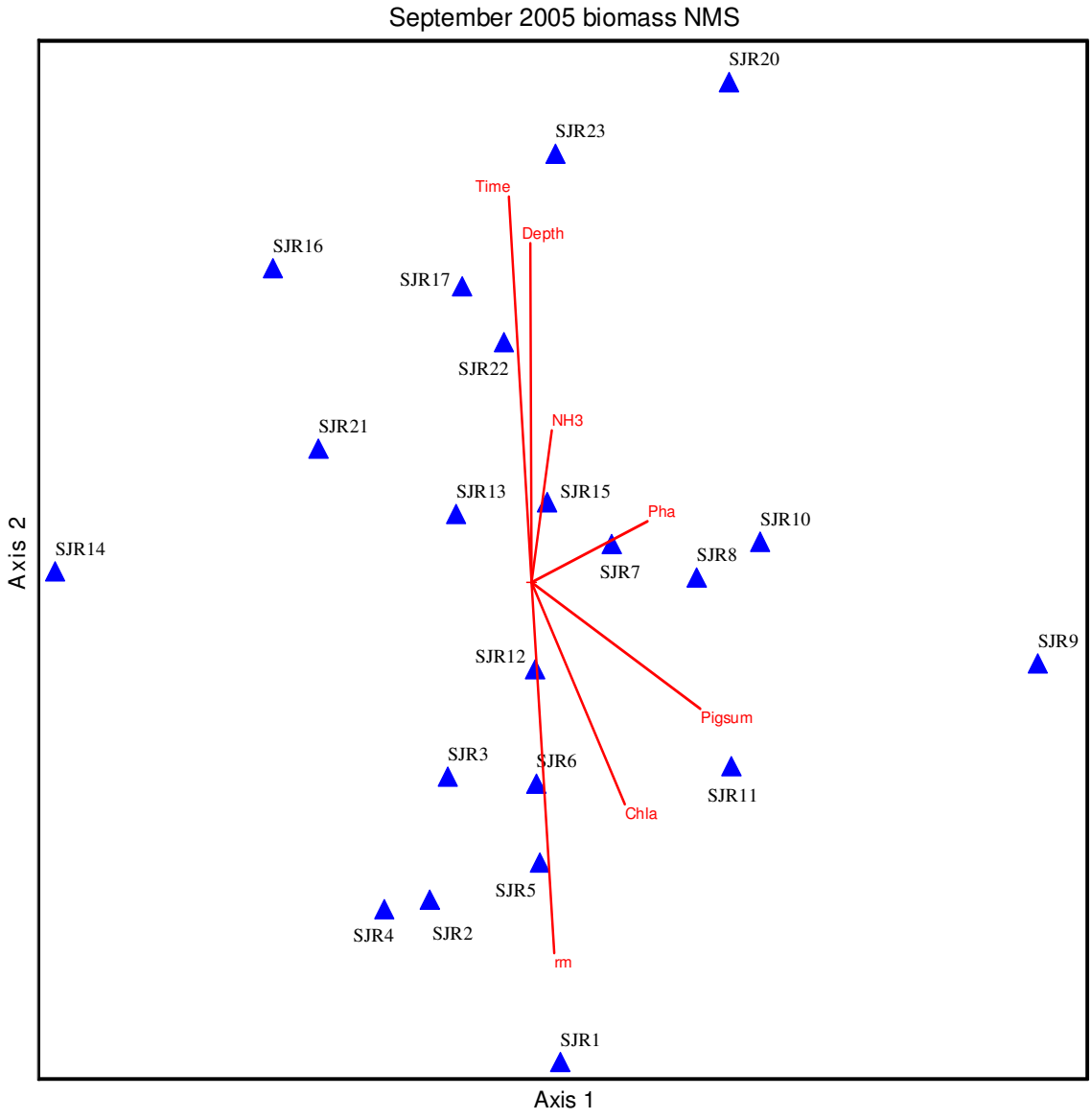

Figure 11. NMS ordination of October 2005 sites in species space, with environmental variable joint plot superimposed. First two axes shown. Abbreviations are as follows: Pha: Phaeophytin; rm: river mile; Chla: chlorophyll a concentration; Pigsum: total pigment (chla + Pha); Alka: alkalinity; VSS: volatile suspended solids; DO: dissolved oxygen; EC: electroconductivity.

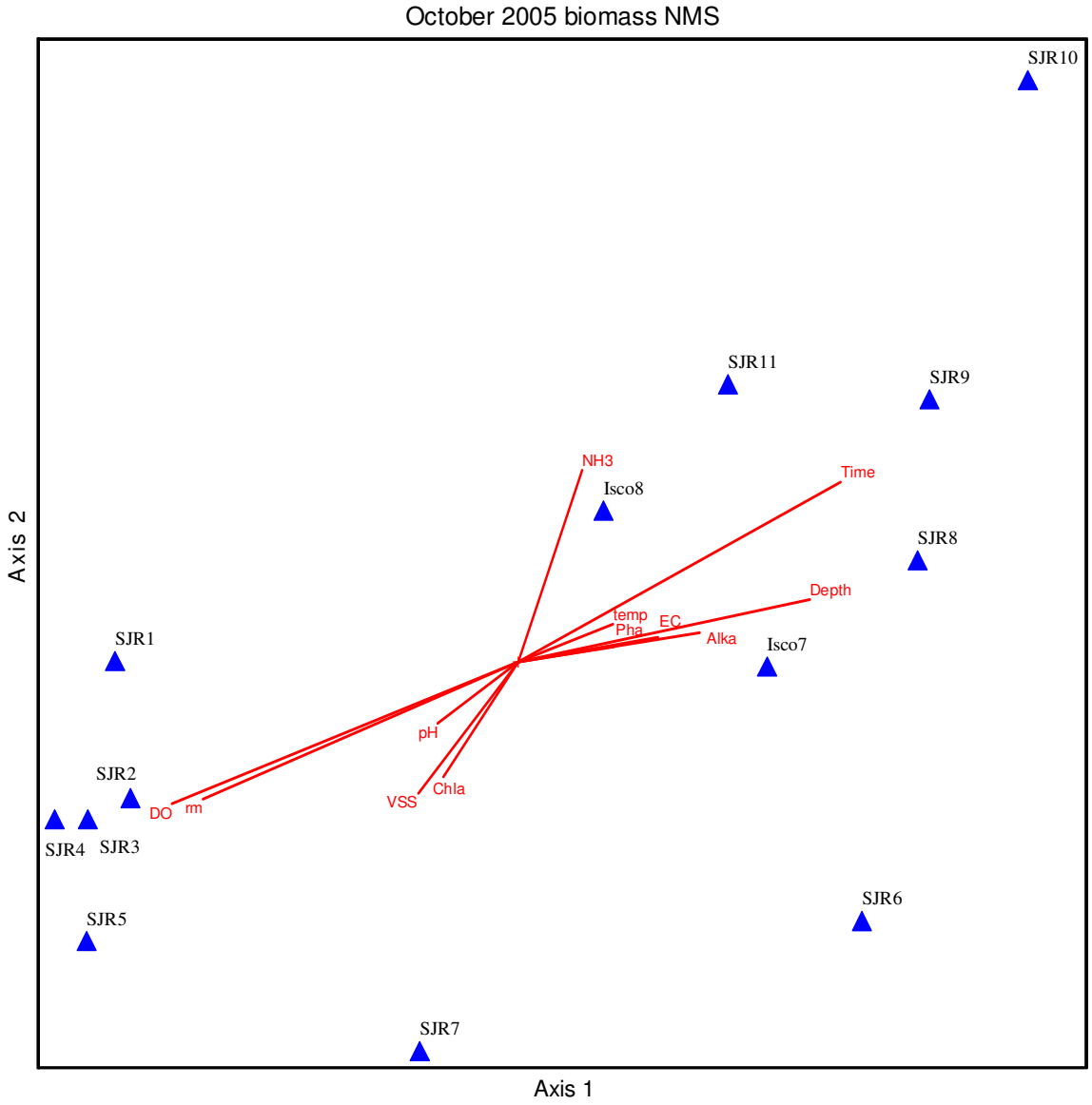

Figure 12. NMS ordination of July 2006 sites in species space, with environmental variable joint plot superimposed. The single axis is shown.

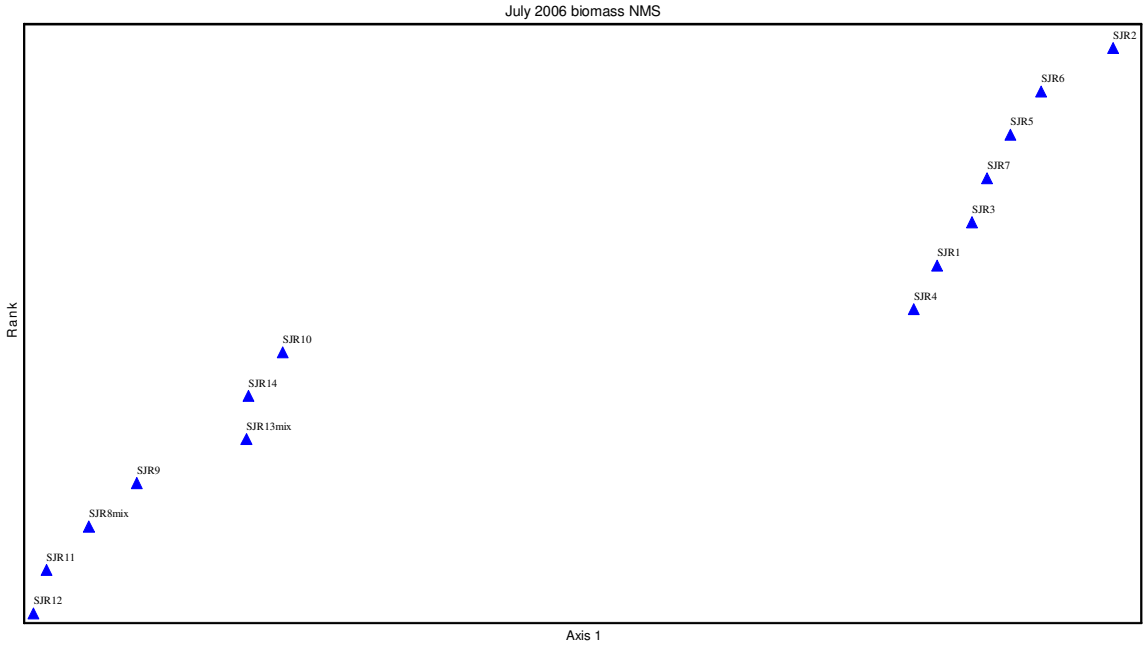

Figure 13. NMS ordination of August 2006 sites in species space, with environmental variable joint plot superimposed. First two axes shown. Abbreviations are as follows: Pha: Phaeophytin; EC: electroconductivity; Turb: turbitity; rm: river mile; temp: temperature; Chla: chlorophyll a concentration; DO: dissolved oxygen.

Figure 14. Bivalve sightings for 2005 plotted by UTM coordinates.

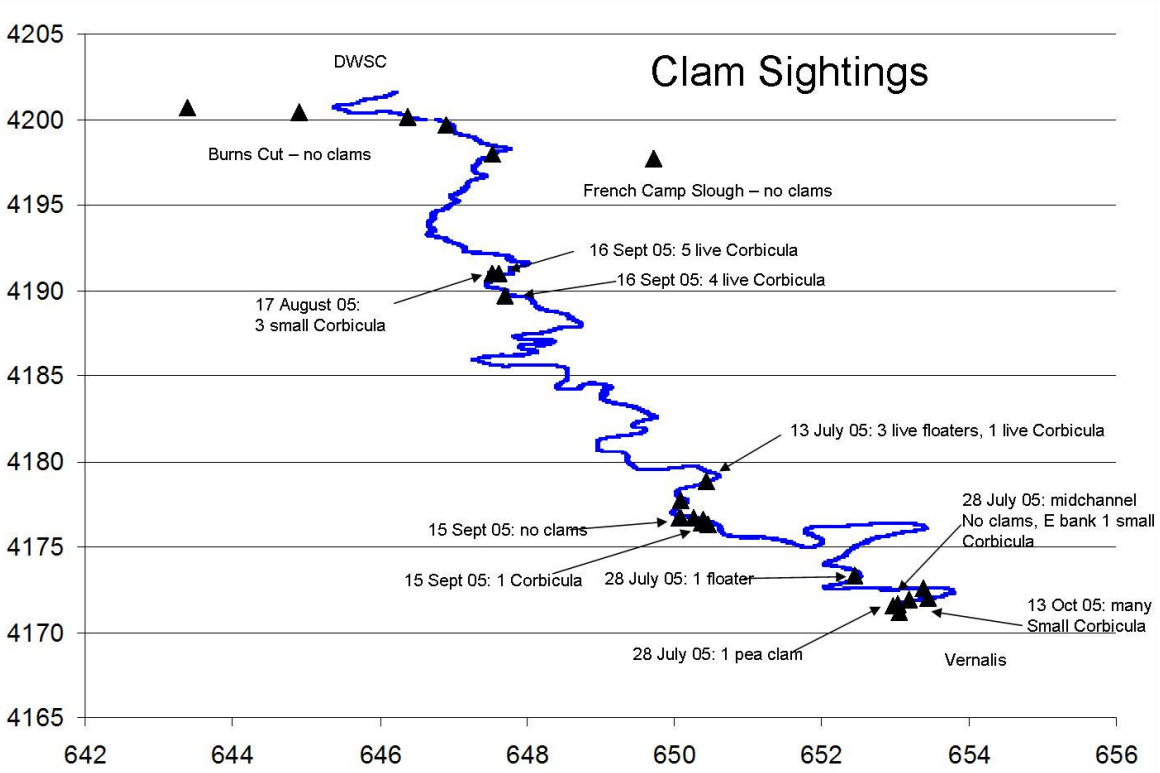

Figure 15. Panels a – f show comparison of the phospholipid Eicosopentanoic acid (20:5) from the zooplankton trap fraction with Rotifer and non-rotifer zooplankton data for 9/15/05, 7/19/06, and 8/9/06.

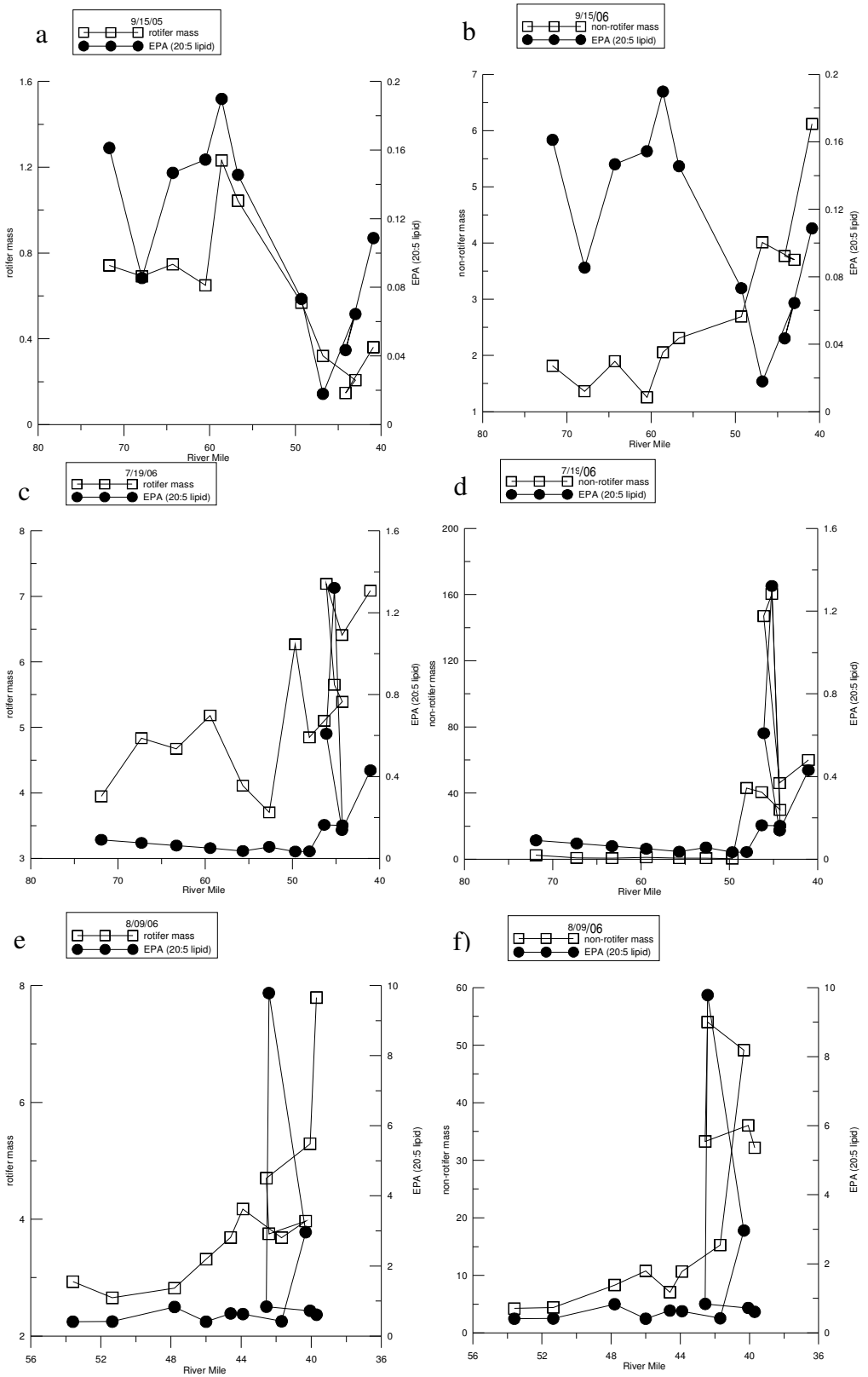

Figure 16: Panels a – c show chlorophyll-a (chl-a) and total phospholipid fatty acid concentrations for 9/15/05, 7/19/06, and 8/9/06 from the whole water fraction.

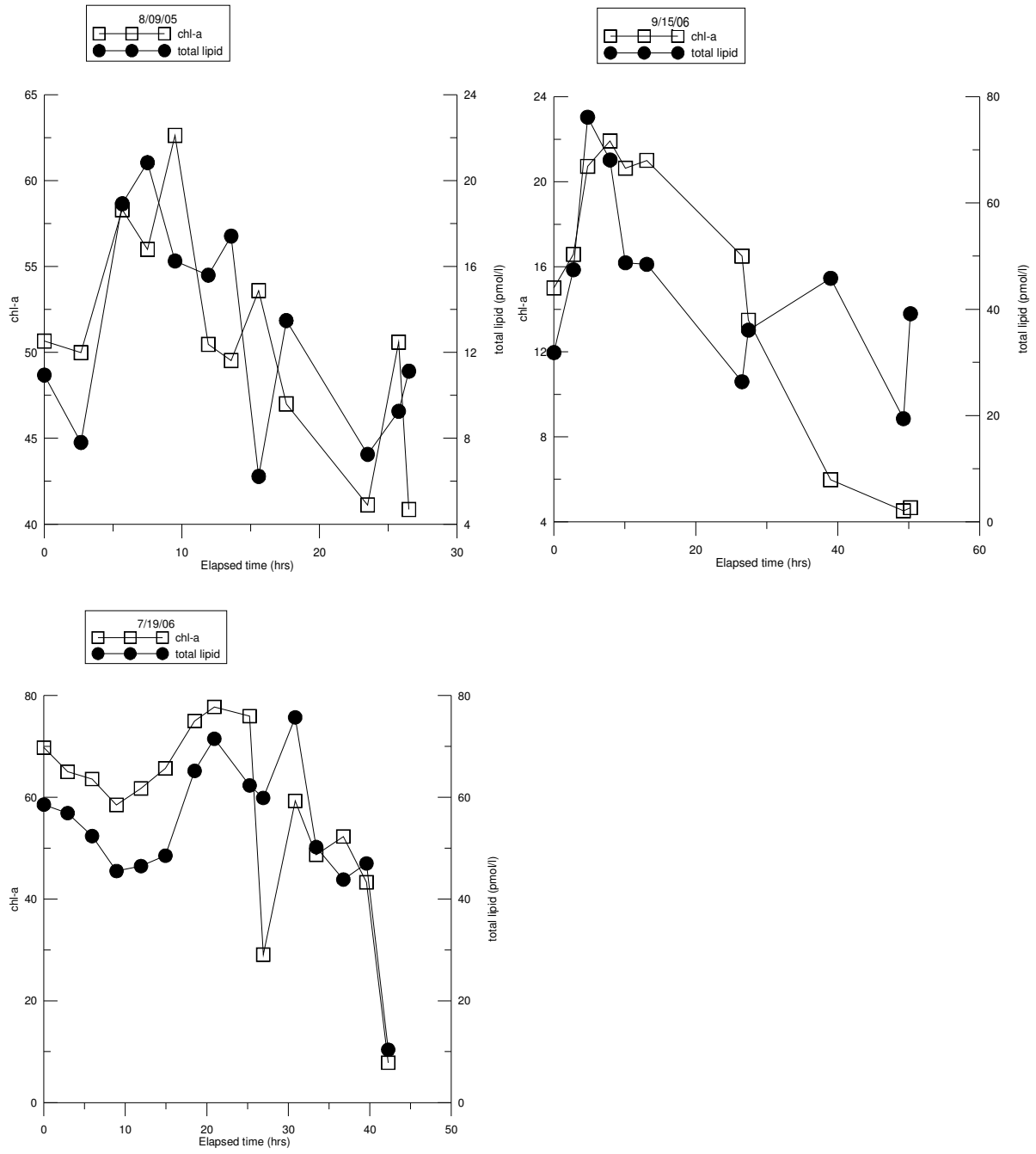

Figure 17: Community structure of the algae from the whole water fraction.