STRUCTURE AND FUNCTION OF THE PHYTOPLANKTON COMMUNITY OF THE KANSAS RIVER

By

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ABSTRACT

Relatively little work has been done regarding the structure of river phytoplankton communities and how these communities differ from those of lakes. The Kansas River is a prairie river with sandy substrate and a highly variable, thunderstorm driven hydrograph. During times of high flow, it functions as a single channel. However, low flow creates complex habitats, with some portions of the river having a single channel, some with point bars, and others braided with backwaters and side channels. This study examined the effect of these habitats on both the structure and function (primary production) of the Kansas River phytoplankton community. Algal samples were collected from backwater, side channel, and main channel sites during 2007 and 2009. Site did not have a significant effect on the number of cells, total biovolume, or the diversity of the phytoplankton community, but date was significant. Green algae and diatoms were the dominant algal groups and followed a seasonal successional pattern similar to that of other rivers in the United States. The high ratio of centric to pennate diatoms was also similar to that found in other rivers. Date was also significant for gross primary production at the lateral sites and net primary production at the longitudinal sites. Phytoplankton community structure and function was similar across all habitat types during these studies. However, the study years had many thunderstorm events, and sites were often reconnected between sampling periods. Additional studies are needed during years with low flow and base flow conditions to determine whether these conditions affect the structure and function of the phytoplankton community.

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INTRODUCTION

Riverine Phytoplankton Community Studies

Although phytoplankton had been studied in lakes for quite some time, scientists did not being to study riverine phytoplankton until the late 1800's and early 1900's. Kofoid (1903) conducted a five year study of the Illinois River in the United States, while Fritsch (1902, 1903) examined the phytoplankton of the Thames River in the United Kingdom. Kofoid (1903) sampled the Illinois River nearly every month from 1894-1899 and found that several peaks in phytoplankton biomass occurred over the course of a year. Diatoms and green algae dominated the samples, and more algae were collected in the Illinois River main stem than its tributaries Quiver Creek and Spoon River. The Spoon River also had more blue-green algae (cyanobacteria) than the other two rivers. Kofoid also noted that the common method of using a silk net for sample collection selected against smaller algae and underestimated algal abundance.

Fritsch (1902, 1903) also collected samples via silk net. Like the Illinois River, diatoms were consistently the dominant algal group in the Thames River. However, green and blue-green algae were also present, particularly in the backwater areas of the river. He concluded the river was able to support a phytoplankton community throughout the year, likely as a result of reproduction that occurred in the backwater areas (Fritsch 1902, 1903). He conducted similar studies in the Rivers Trent and Cam during August 1905 and found similar results for those rivers (Fritsch 1905).

Bennin (1926) found that diatoms also dominated the algal community of the Warthe River (Prussia). However, the Warthe exhibited two separate algal maxima, with flagellates second in abundance during the spring maxima and green algae second in abundance during the summer maxima. A study of the Rivers Itchen, Test, and Hampshire Avon found these rivers also varied from the Illinois, Thames, Trent, and Cam Rivers (Butcher 1946). The phytoplankton

communities in the Rivers Itchen, Test, and Hampshire Avon were comprised of just three algal species: *Cocconeis, Ulvella,* and *Chamaesiphon* (a diatom, a green alga, and a blue-green alga). Though other algae were present, they occurred in low numbers. However, he did find that these riverine samples were different from those collected in a nearby pond, contributing to evidence that riverine phytoplankton assemblages differed from their lentic counterparts. A review conducted by Blum (1956) suggested that this *Cocconeis-Ulvella-Chamaesiphon* assemblage was fairly common in English rivers, but was not seen in studies of rivers in Europe or the United States.

Since then, several riverine phytoplankton studies have found diatoms to be the dominant algal group, with centric diatoms occurring more often than pennate. This pattern was observed by Swale (1964, 1969) in the Rivers Lee (Ireland), Stour (England) and Severn (United Kingdom). Similar patterns were observed by Weber and Moore (1967) in the Little Miami River (U.S.), Crayton and Summerfield (1977, 1979) in the Colorado River (U.S.), Descy and Willems (1991) in the Moselle River (France), Wehr and Thorp (1997) in the Ohio River (U.S.), Ietswaart et al. (1999) in the River Rhine (Europe), and Salmoso and Braioni (2008) in the River Adige (Italy). Williams and Scott (1962) surveyed 73 stations on various rivers across the United States and found that most were dominated by centric diatoms, but the authors did note the algal community in the Ohio River exhibited some blue-green and green algae dominance following periods of low rainfall during the warm season. Lack (1971) found extreme diatom dominance in the Rivers Thames and Kennett (England), with diatoms comprising >94% of the Thames River phytoplankton community in the spring and autumn and 78-85% of the Kennett River phytoplankton community. Diatoms comprised approximately 90% of the phytoplankton community in the Moruya River (Australia) (Potter et al. 1975). Salmaso and Zignin (2010) found diatoms accounted for 85%-70% of the diatom community in the River Adige (Italy).

However, the southern station was dominated by centric diatoms, while pennate diatoms were dominant at the northern station. Pennate diatoms were also dominant in the Upper Skunk River (U.S.) (Roeder 1977). Stevenson and White (1995) found pennate dominance upstream in the Kentucky River Basin, but centric diatoms became dominant downstream.

This diatom dominate community is far from prevalent. Stoyneva (1994) found green algae dominated the Bulgarian section of the Danube River. Green algae also dominated the Helpe Majeure and Sambre Rivers in France (Prygiel and Leitao 1994). Other studies have found a mix of seasonal dominance by diatoms and green algae or by other algal groups altogether. This seasonal pattern occurred in the Lower River Murray (Australia) (Shiel et al. 1982), the River Meuse (Belgium) (Descy and Gosselain 1994, Gosselain et al. 1994), and the Middle Loire (France) (Lair et al. 1999). A review by Reynolds and Descy (1996) suggested that spring diatom dominance followed by green-algae dominance in the summer is common in rivers of the United Kingdom, as well as some European rivers.

Less often, algal groups other than diatoms and green algae dominate the phytoplankton community. Baker and Baker (1981) examined the phytoplankton community of the upper Mississippi River (U.S.) and found spring and fall dominance by diatoms and summer dominance by green algae, blue-green algae, and cryptomonads. Bahnwart, et al. (1999) followed parcels of water in the Warnow River (Germany) downstream and found changes in the algal community occurred both over time and as the water moved downstream. Blue-green algae were dominant upstream and increased in biomass during the summer and autumn. However, centric diatoms increased seasonally and downstream and eventually became dominant. The Melen River (Turkey) also had different communities at different stations, with some dominated by dinoflagellates and others by diatoms, with green algae generally being the second most common algal group (Baykal et al. 2011). Finally, Ha, et al. (2002) reported some of the largest

seasonal changes to date in their study of the Kakdong River (Korea). The centric diatom dominated winter community was followed by pennate diatom and flagellate dominance in May and June, blue-green dominance in the summer, and a combination of diatoms and green algae in the fall. While the number of riverine phytoplankton studies has increased over the last thirty years, we still know much less about phytoplankton in rivers than in lakes and wetlands. We need additional studies in order to determine large-scale trends in dominance and abundance.

Origin and Maintenance of Riverine Phytoplankton Communities

The studies by Fritsch (1902, 1903, 1905) and Kofoid (1903) were some of the first to conclude that rivers could indeed support their own phytoplankton populations. Fritsch (1902, 1903, 1905) concluded that reproduction likely occurred in backwater areas, and Kofoid (1903) reached a similar conclusion, stating that, "The reservoir backwaters are thus of great importance both as a source of the channel plankton of the Illinois River and in its maintenance." Nearly thirty years later, Butcher (1932) would conclude that small green algae and blue-green algae were more important to the riverine phytoplankton community than diatoms. He also theorized that phytoplankton depend on standing water areas such as impoundments and backwater areas and that a river or stream without such an area would not be able to support a phytoplankton community. This theory became widely accepted amongst riverine phytoplankton scientists. However, it is important to note that Butcher was sampling using slides left in the river for one to several weeks, rather than collecting samples via net or whole water collection. The slide sampling method selects for those algae that are able to colonize hard surfaces, while the nets commonly used in the early part of the century selected for colonial and other large body algae, as noted by Kofoid (1903). In his 1956 review, Blum hypothesized that most riverine phytoplankton were either opportunists, species that had been washed from nearby impoundments and backwaters, or species derived from the periphyton community

Margalef (1960) hypothesized that true potamoplankton occur only in very long rivers and then only because damned and slow portions contribute algae to the river. He also assumed downstream transport would make it difficult for algae to reproduce at a rate capable of maintaining the community. Swale addressed the idea that riverine phytoplankton were merely algae displaced from impoundments upstream in his studies of three English rivers: the Rivers Lee, Stour, and Severn (1964, 1969). He found all three rivers had diverse phytoplankton communities that included diatoms, green algae, cryptomonads, and golden algae. He stated that these results, ". . . helps to dispel the still prevalent opinion that phytoplankton does not occur in British Rivers" (Swale 1969). Though scientists began to accept that phytoplankton populations did indeed exist in rivers, there was debate over whether these were truly planktonic algae. Roeder (1977) found that the same species were abundant in both the phytoplankton and periphyton communities and concluded that the phytoplankton population of the Upper Skunk River (IA) was maintained by sloughed periphyton. In contrast, Baker and Baker (1981) concluded that the algal community in the upper Mississippi River was true potamoplankton rather than sloughed periphyton because, along with other differences, the riverine phytoplankton community was dominated by centric diatoms while the periphyton was dominated by pennate diatoms. It is difficult to determine the influence of periphyton on phytoplankton because we are often not able to distinguish between those algae that are obligate benthic organisms versus. those that are able to reproduce on the benthos after sedimentation (Reynolds and Glaister 1993).

It is only fairly recently that scientists have begun to address what Reynolds defined as the "paradigm of the potamoplankton" (Reynolds 1988). This addressed that fact that several studies had found that algae abundance was much greater than predicted by water residence time and light availability (i.e. Lack 1971). It was suggested that "dead zones", or "areas of dynamic

storage, usually located around the periphery of open channel flows, where some form of mixing takes place", may be one solution to the paradox (Wallis et al. 1989). These areas, including eddies, wakes, and reverse flow areas in pools and bends, could increase actual mean transport time over that of predicted mean transport time, thereby increasing algal abundance (Wallis et al. 1989). Algal abundance data from the upper and middle River Severn (United Kingdom) supported this hypothesis (Reynolds and Glaister 1993). Descy (1993) suggested Connell's Intermediate Disturbance Hypothesis (IDH) might explain phytoplankton persistence (Connell 1978). The IDH did fit the data for the River Moselle; diversity lowest at extremely low and extremely high discharge and was highest when disturbances occurred at intermediate intensity and frequency (Descy 1993). Data from the River Meuse indicated three possible hypotheses might explain phytoplankton abundance: the storage zone ('dead-zone') hypothesis (slower flow areas within the river are algal sources), the removal hypothesis (grazing and sedimentation play a role in population regulation), and the importation hypothesis (biomass originates in productive reaches upstream), which was favored by the authors (Descy and Gosselain 1994). However, more data were needed to explain the persistence of riverine phytoplankton populations; no one hypothesis had more support than the others.

Reynolds posited that riverine phytoplankton communities tend to be comprised of "light-antenna" that are able to reproduce quickly (Reynolds 1994). Those r-selected properties enable those species to reproduce in well-flushed, turbid rivers. However, slow-growing algae can dominate in slow-flow areas without much flushing. While floodplains, backwaters, and other impoundments may serve as algal "nurseries", rivers have their own phytoplankton communities as a result of physical properties such as turbulence and flow (Reynolds and Descy 1996). This riverine phytoplankton community occurs in 3rd order and larger rivers and includes centric diatoms, some pennate diatoms, some genera of green algae, and cryptomonads. The

physical properties of the river play a large role in community composition often exerting more influence than top-down or bottom-up control. Intermediate conditions are most favorable for growth, as high-flow conditions lead to increased downstream transport and low-flow conditions lead to sedimentation (Reynolds and Descy 1996). We are not yet sure whether dead-zones and other flow refuges or meroplankton plays a larger part in maintaining riverine phytoplankton populations (Reynolds 2000). On the one hand, it is possible an aggregate of low-flow within the channel maintains the population. On the other, it may be that variation in flow selects for meroplankton and therefore shapes the community composition (Reynolds 2000).

Algal Community Function/Ecosystem Metabolism

It is possible that the same factors that shape the structure of the phytoplankton community affect its function as well. Both phytoplankton and periphyton contribute to the energy available to the river via photosynthesis. Net primary production (NPP) is calculated by subtracting respiration (R) from gross primary production (GPP):

$$NPP = GPP - R$$

(Odum 1956, Fisher and Likens 1973, APHA 1998). Odum's work (1956) using diurnal dissolved oxygen curves to measure NPP led to investigations of NPP in rivers and streams around the world. There are now more studies of NPP in rivers than of the composition of riverine algae communities. GPP tends to be highest in arid regions and annual GPP is related to canopy cover; the greater the cover, the lower the GPP (Lamberti and Steinman 1997). GPP also tends to decrease as stream and river size increase, likely due to a decline in light availability (Lamberti and Steinman 1997, Mulholland et al. 2001). Odum (1956) also used diurnal dissolved oxygen curves to determine the ratio of production to respiration (P/R ratio); he defined a system as autotrophic when $P/R>1$ and heterotrophic when $P/R<1$.

Prairie Rivers

Prairie rivers and streams in the United States tend to be wide, shallow, turbid systems (Jewell 1927, Matthews 1988). Very little water input comes from groundwater or snowmelt; instead these systems are driven by a combination of thunderstorm and rain events and evapotranspiration (Matthews 1988, Dodds et al. 2004). Although these rivers and streams drain nearly one-third of the contiguous United States (Thorp and Mantovani 2005), little research has been conducted in these systems compared to those in the forested portion of the eastern United States. Some climate change scientists have predicted that less frequent, but more intense thunderstorm events will occur as a result of climate change (Easterling, et al. 2000, Frederick and Major 1997.) Untangling the impact of flow variability in Great Plains systems may provide insight into the impact of these high intensity events on other systems.

The bulk of the research that has been conducted in Great Plains aquatic systems has involved fish communities (Taylor et al. 1993, Knight and Gido 2005, Oakes et al. 2005, Falke and Gido 2006, Franssen et al. 2006, Matthews and Marsh-Matthews 2006, Moore and Thorp 2008, Gido et al. 2010, Murdock et al. 2010, Matthews and Marsh-Matthews 2011, Hudman and Gido 2013, Martin et al. 2013, Perkin et al. 2015). However, a few studies have been conducted on invertebrate communities (Evans-White et al. 2003, Bertrand et al. 2009, Murdock et al. 2010, O'Neill and Thorp 2011, Bertrand et al. 2013) and on nitrogen cycling and primary productivity (Duffer and Dorris 1966, Dodds et al. 2000, Kemp and Dodds 2001, Dodds et al. 2002, Kemp and Dodds 2002, Dodds et al. 2008). Matthews (1988) wrote that little research has been conducted regarding lower trophic levels and Thorp and Mantovani (2005) reached a similar conclusion. Indeed, most of the algal information regarding prairie rivers comes from just four studies. Wilhm et al. (1978) studied periphyton in the Arkansas River. Bahls (1974) examined

phytoplankton in the Yellowstone River and Berner (1951) and Knowlton and Jones (2000) sampled the Lower Missouri River.

The Kansas River is a 7th order tributary of the Missouri River. The Kansas River basin covers approximately 159,000 km^2 and drains portions of Colorado, Nebraska, and Kansas (Galat et al. 2005). It is formed by the confluence of the Republican and Smoky Hill Rivers in the Great Plains, with the main stem of the river primarily located in the Central Lowlands. Like all prairie rivers, it is characterized by highly variable flow, with high discharge events occurring as a result of thunderstorm events in the late spring and early summer months. The flow regime has been less variable since the construction of reservoirs on many of the Kansas River's tributaries in the 1950's and 1960's, but the river proper does not have flood control structures and continues to experience weather driven flow peak (Moore and Thorp 2008, O'Neill and Thorp 2011). During these peak flow events, the river functions as a single channel with very few permanent islands. During periods of moderate to low flow, the river exhibits characteristics of a point bar and braided system, creating side channels and slackwater habitats in the river valley. The river substrate consists of sand, silt, and small gravel, with some larger rocks introduced as bank erosion control near cities; this highly mobile substrate results in a near constant rearrangement of the bar and slackwater areas, even during periods of low flow. The point bars are fairly permanent structures, but the area and edges change frequently. Slackwater areas are consistent during periods of low flow but reconnect with the main channel during moderate flow. These slackwaters may persist for years, surviving many periods of reconnection with main channel, or they may be erased as a result of river bed movement during moderate or high flow.

Research Questions

The purpose of this study was to examine the structure and function of the algal community in the Kansas River. More studies are needed to discern trends in the structure, or composition, of riverine phytoplankton communities and research is particularly lacking in prairie and sanded rivers.

The objective of the structural portion of my study was to: 1) determine the biodiversity and abundance of phytoplankton in the Kansas River, a large prairie river, 2) examine whether there are differences in phytoplankton communities found in the lateral habitats of this river; and 3) to determine whether season affects phytoplankton biodiversity and abundance. The importance of these slower flow areas has been demonstrated by Wallis et al. (1989), Reynolds and Glaister (1993), and Walks (2007). Often, the main channel is populated by diatoms and green algae (Swale 1964, 1969, Wehr and Thorp 1997, Ietswaart et al. 1999, Salmaso and Braioni 2008, and others), while areas of low flow can be dominated by green algae (Stoyneva 1994) or have large amounts of blue-green algae (Fritsch 1902, 1903, Williams and Scott 1962). In addition, Descy (1993) found maximum diversity occurred at an intermediate range of disturbance frequency and intensity. The most complex area of the Kansas River occurs in the braided areas. Three types of lateral habitats occur in these areas: the main channel, side channels, and backwaters, with the main channel the area of highest flow and disturbance and the backwaters the areas of lowest flow and abundance. I predicted that the intermediate flow side channels would have the greatest biodiversity and abundance and the main and side channels would be dominated by centric diatoms and green algae. Furthermore, the main channel and backwaters would be similar after periods of high flow, but the longer the backwater areas are isolated from the main channel the more the two diverge, with the backwater becoming dominated by blue-green algae.

The objective of the functional portion of my study was to determine whether ecosystem metabolism in the Kansas River varies by month and/or habitat. Shaded headwater streams often have low or negative NPP, while medium-sized streams (4-5th order) generally have positive NPP values (Mulholland et al. 2001). The Kansas River is a wide (~300m) 7th order stream with very little gallery forest. This lack of shade creates prime conditions for high levels of primary productivity. However, high turbidity in this system limits light penetration; 1% light extinction often occurs as little as 10 cm below the surface (personal observation). Also, streambed scouring caused by frequent disturbance may reduce both respiration and production (Uehlinger and Naegeli 1998). I predicted that ecosystem metabolism and the related measures (GPP, NPP, R) would vary by both longitudinal and lateral habitat. Sedimentation in low flow areas results in reduced turbidity, increased light, and increased NPP. These reduced flow areas occur laterally in braided areas of the river during moderate to low flow periods and include habitats with moderate flow (side channels) and no flow (backwaters). The backwater areas may experience a temporary increase in NPP immediately following isolation. However, as they areas remain isolated, they will likely become nutrient limited and NPP will drop to levels below those in the main channel. I hypothesized that, among the lateral habits, NPP would be highest in the side channel and lowest in the backwater after a period of isolation. I also hypothesized that, among the longitudinal habitats, NPP would be highest in the complex braided area and lowest in the high flow single channel.

METHODS

Algal Community Structure

Study sites

All study sites were located in a braided area of the Kansas River within an area approximately 11.3 km upstream and 9.2 km downstream of the Rising Sun Boat Access ramp in Perry, KS (between River Mile 77 and River Mile 54). One set of lateral sites (main channel, side channel, and backwater) was sampled in 2007. One set of lateral sites and six additional pairs of main channel and side channel sites were sampled in 2009.

Field sampling

A main channel, side channel, and backwater site were sampled on three different dates during 2007. These samples were collected concurrently with dissolved oxygen measurements. The 2009 sites were sampled approximately every two weeks from mid-June through the end of September, for a total of eight sampling dates. During sampling, whole water pelagic samples were collected in the photic zone at each site. Water was collected from within the channel at river left, river right, and mid-channel and then homogenized. Triplicate 100 mL samples were preserved in the field with Lugols solution (APHA Standard Methods 1998). Temperature, turbidity, pH, conductivity, salinity, and dissolved oxygen were measured with an YSI™ 6600 sonde. Depth was measured using a marked pole; flow was measured with a Swoffer™ 2100 Current Velocity Meter.

Sample identification

In the lab, 3 mL subsamples were settled for 12 hours before identification. The 2009 samples had more fine sediment than the 2007 samples and 2 mL of water was added to these samples before settling. The samples were allowed to settle for 2 minutes before being decanted. The decanted portion was allowed to settle for an additional minute before decanting again. This

process resulted in four total settling chambers for each sample and all four chambers were settled for 12 hours prior to identification. Algae were identified to genus using a Wild™ inverted microscope and standard methods (APHA 1998). Diatoms were not identified to genus; they were recorded as pennate or centric and listed as Diatom 1, Diatom 2, etc. A gridded ocular piece was used for size measurements. Seven groups were used to classify taxa: blue-green algae, cryptomonads, diatoms, dinoflagellates, euglenoids, green algae, and other. Hillebrand et al. (1999) and Sun and Liu (2003) were used to calculate biovolume for each taxa. Diversity indices were calculated using the Ecomeas Database (Huggins et al. 1986); these indices were calculated using both cell counts and biovolume.

Statistical Analysis

MINITAB™ was used to run General Linear Model (GLM) testing of the average number of cells and biovolume, taxa richness, Simpson's Reciprocal, and Shannon's Index versus date and site; $p < 0.05$ was considered significant. The hydrographs from 2007 and 2009 were compared by Jude Kastens using an S-transform time-frequency analysis.

Algal Community Function/Ecosystem Metabolism

Study sites

Most of the study sites were located on the Kansas River within an area approximately 11.3 km upstream of the Rising Sun Boat Access ramp in Perry, KS. These sites included one point bar site, one braided site, and one set of lateral sites with a main channel, side channel, and backwater. The point bar site was located most upstream and the braided site most downstream. The lateral sites were located between those two longitudinal sites. The single channel site longitudinal site was located farther downstream near River Mile 25 near DeSoto, KS.

Field sampling

YSI™ 6600 sondes were deployed in the thalweg to determine primary production and respiration values at the longitudinal sites (point bar, braided, single channel). Each site was a single station at the downstream end of the reach. The sondes recorded pH, turbidity, temperature, salinity, and dissolved oxygen every five minutes during a 48-hour period during mid-August, mid-September, and mid-October 2007. Depth was measured using a marked pole and flow was measured with a Swoffer™ 2100 Current Velocity Meter.

At the lateral sites (main channel, side channel, backwater), dissolved oxygen was measured using glass 300mL Biochemical Oxygen Demand (BOD) bottles and Winkler titrations (APHA standard methods). Depth and flow were measured with the same pole and flow meter used at the longitudinal sites. A LI-COR™ light meter was used to determine the photic zone and when possible, pairs of light and dark bottles were deployed at the surface and just below the photic zone. High turbidity values often reduced the photic zone to < 10cm. In these instances, bottles were only placed just below the surface, as the bottom of the bottle was just outside the photic zone. The BOD bottles remained in the river for a minimum of four hours during the afternoon. Sampling was conducted approximately every two weeks beginning mid-July 2007 and ending mid-September 2007; samples were collected a total of five times. Samples were preserved *in situ* using the Hach™ Winkler Method (Azide Modification) kit and titrated in the lab within 12 hours of collection.

Statistical Analysis

Longitudinal metabolism data were downloaded in the lab using YSI™ software. Respiration, Gross Primary Production (GPP), Net Primary Production (NPP), and P/R were calculated using the "Calculating Stream Productivity" program (Anderson and Huggins 2007). Reaeration values were calculated using depth, flow, and dissolved oxygen data and reaeration

calculations were selected according to the criteria laid out in the productivity manual. NPP and P/R were tested with a General Linear Model (GLM) for date and site using MINITAB™.

Ecosystem metabolism measures were calculated for the BOD bottles using the following equations (APHA 1998):

Respiration = initial dissolved oxygen - dark bottle dissolved oxygen

Gross primary production = light bottle dissolved oxygen - dark bottle dissolved oxygen

Net primary production = light bottle dissolved oxygen - initial dissolved oxygen

Respiration, GPP, and NPP were tested with a GLM for date and site using MINITAB™.

RESULTS

Algal Community Structure

2007: A total of 70 unique taxa were identified, with 20 of those taxa occurring at just one site and on just one sample date. Of those unique taxa, 11 were found in main channel samples (occurring over all 3 sample dates) and 11 were found in samples from July 14. Taxa richness ranged from 27 to 40, with an average of 35 taxa (Fig. 1). Green algae taxa included *Actinastrum*, *Ankistrodesmus*, *Chlamydomonas*, *Closterium*, *Coelastrum*, *Crucigenia*, *Kirchneriella*, *Oocystis*, *Pediastrum*, and *Scenedesmus spp.*, among others. Blue-green algae taxa consisted mainly of *Anabaena*, *Merismopedia*, *Microcystis*, and *Oscillatoria spp*. Samples contained an average of 1440 cells, with an average biovolume of 235210.78 μm^3. The dominant algal group varied by site and date. When calculated by number of cells, the dominant algal groups were generally green and blue-green algae, with diatoms dominating the main channel and side channel on July 14 (Fig. 2). However, diatoms were the dominant algal group for all sites on July 14 when calculated using biovolume (Fig. 3). Euglenoids dominated the main channel and side channel on July 25; green algae dominated the other samples. No one algal

group dominated the sites or dates; this was true whether dominance was calculated using cell counts or biovolume (Table 1, Table 2). Most of the diatoms were centric diatoms by count and biovolume (Fig. 4, Fig. 5). However, most diatoms were pennate diatoms in the August 25 backwater sample. Generally, the backwater site had more pennate diatoms than the other sites.

The General Linear Model was not significant for the average number of cells for site ($F_{2,4}$=6.06, p=0.062) or date ($F_{2,4}$=1.22, p=0.385). Average biovolume versus site and date was not significant ($F_{2,4}$=1.54, p=0.320; $F_{2,4}$=4.31, p=0.100). Taxa richness versus site and date was not significant, either ($F_{2,4}$=0.31, p=0.752; $F_{2,4}$=2.12, p=0.235). The GLM was also not significant for Simpson's Reciprocal versus site and date for count ($F_{2,4}$=2.89, p=0.168; $F_{2,4}$=0.04, p=0.958) or for biovolume ($F_{2,4}$=0.62, p=0.584; $F_{2,4}$=2.27, p=0.220). Shannon's Index versus site and date was not significant for count ($F_{2,4}$=2.38, p=0.208; $F_{2,4}$=0.32, p=0.743) or biovolume ($F_{2,4}$=0.10, p=0.906; $F_{2,4}$=2.29, p=0.217), either.

2009: A total of 112 unique taxa were identified from the 2009 samples. Of these, 16 were found in just one sample; no taxa were found in all of the samples. However, 3 taxa were found in 99% of all samples. Taxa richness ranged from a low of 13 (SC5 on September 28) to a high of 44 (MC2 on August 14), with an average of 28 taxa per sample (Table 3). When examining the average number of taxa per site only, MC4 and SC7 had the lowest average (25 taxa), with BW2 having the highest average (31 taxa). When examining the average number of taxa by date only, the lowest average occurred on September 28 (21 taxa) and the highest on August 14 (31 taxa). Taxa richness by date was fairly similar for all main channel sites (Fig. 6), but less similar for side channel sites (Fig. 7). As in 2007, green algae taxa included, among others, *Actinastrum*, *Ankistrodesmus*, *Chlamydomonas*, *Closterium*, *Coelastrum*, *Crucigenia*, *Kirchneriella*, *Oocystis*, *Pediastrum*, *Scenedesmus*, and *Schroederia spp*. and blue-green algae taxa included *Anabaena*, *Merismopedia*, *Microcystis*, and *Oscillatoria spp*. The number of cells

per sample ranged from a low of 98 (SC4 on September 28) to a high of 2530 (MC2 August 14), with an overall average of 601 (Table 3). Biovolume was also lowest on September 28 (SC2) and highest on August14 (MC3).

The dominant algal group varied by date and site and by whether dominance was calculated using cell counts or biovolume. On June 13, approximately half of the sites were dominated by green algae, while the remainder were dominated by diatoms (Fig. 8). However, when using biovolume information, diatoms were dominant for all sites except SC4, which was comprised of 95% green algae (Fig. 9). Blue-green algae counts increased for nearly all sites on the next sampling date and this was the dominant group for five sites. The remaining sites were dominated by green algae and diatoms (Fig. 10). Diatoms continued to dominate biovolume at most sites, but four sites, MC3, SC3, MC5, and SC5, were dominated by green algae and two, SC1 and SC6, were dominated by cryptomonads (Fig. 11). Green algae, diatoms, and blue-green algae dominated approximately the same number of sites on July 18 (Fig. 12), with diatoms continuing to dominate the majority of sites when calculated using biovolume (Fig. 13). Again, two sites were dominated by green algae (SC1, BW), though these were not the same sites as the previous date. Also, MC3, MC7, and SC7 saw a substantial increase in dinoflagellate biovolume.

Green algal counts decreased on August 1 and that group dominated just three sites: MC1, SC4, and MC6 (Fig. 14). The remaining sites were split between diatoms and blue-green algae. Biovolume dominance was similar to July 1, with diatoms having the greatest biovolume at most sites, but green algae dominant at four sites, SC1, MC3, MC4, and SC7, and cryptomonads dominant at two sites, SC4 and MC7 (Fig. 15). These green algae and cryptomonad sites were not the same sites as those on July 1. Dinoflagellate biovolume remained high at MC7 and increased in the BW. In mid-August, diatom counts dropped and green algae and blue-green algae were the dominant algal groups (Fig. 16). Diatom biovolume remained

high, however, at six sites (Fig. 17). Green algae dominated the other nine sites, with six of those having over 87% of their biovolume comprised of green algae. Dinoflagellate biovolume was again high at two sites, MC1 and MC6, though these were different sites than the two with high dinoflagellate biovolume the previous sampling period. The last sampling date in August was similar to July 1, with a split between diatoms, green algae, and blue-green algae using count data (Fig. 18). Biovolume dominance was similar to August 14, with a split between diatoms and green algae, with the green algae sites comprising 87% or more of the total biovolume (Fig. 19).

Dominance was similar for both count and biovolume on September 14 (Fig. 20 and Fig. 21). MC7 was the only site with green algae dominant according to biovolume, with that group comprising 91% of the community. Dinoflagellate biovolume increased at the BW site again. Finally, count dominance on September 28 was similar to August 30 and July 18 (Fig. 22). As during most other sampling periods, diatoms dominated biovolume at most sites (Fig. 23). However, MC5 was comprised of 96% green algae, while SC4 was comprised of approximately 25% each green algae, euglenoids, diatoms, and cryptomonads. This was the only site/date that was not dominated by one algal group. Dinoflagellate biovolume remained elevated at the BW site.

In general, green algae, diatoms, and blue-green algae were dominant if calculations were made using cell counts. All other groups had fairly low counts. The number of cryptomonad cells increased on September 14, but remained below 20%. On the other hand, calculations using biovolume exhibited more variation, particularly in algal groups other than green algae and diatoms. The other five algal groups were relatively low on June 13. Cryptomonads began to increase on July 1 and continued to increase through August 1; they comprised the third most dominant group for July 1, July 18, and August 1. Euglenoids also increased on July 18 and August 1 and were the fourth most dominant group for those sampling dates. Cryptomonad and

euglenoid biovolume decreased on August 14, while dinoflagellate biovolume increased, becoming the third most dominant group. Dinoflagellate biovolume decreased in the August 30 samples. Cryptomonad and euglenoid biovolume remained low in these samples before increasing on September 14, when cryptomonads were the third most dominant algal group again. Cryptomonads continued to increase and this group was again the third most dominant algal group on the final sampling date.

The proportion of centric to pennate diatoms also varied according to counts and biovolume. Centric diatoms generally outnumbered pennate, with the highest number of pennate occurring on August 14 (Figs. 24-31). Count and biovolume proportion was similar on June 13, with more centric than pennate diatoms (Fig. 24, Fig. 32). However, after that the proportion of pennate as calculated by biovolume was generally higher than that calculated by cell count. The proportion of pennate diatoms increased on July 1 and continued to increase through August 14, when the greatest proportion of pennate diatoms, as calculated using biovolume, occurred (Figs. 33-36). Pennate biovolume decreased slightly on August 30 (Fig. 37). It continued to decrease at most sites, but did increase at four sites, MC1, MC2, SC2, and BW, on September 14 (Fig. 38). MC1, MC2, and SC2 had decreased pennate biovolume on September 28, while pennate biovolume in the BW site increased (Fig. 39). It also increased at SC6, MC7, and SC7.

Although data was collected from paired sites, not all sites were sampled on all dates. This uneven sample size prevented a paired statistical analysis and the General Linear Model was run with all main channel sites as a group and all side channel sites as a group. The GLM of number of cells versus date and site was significant for date ($F_{7,90}$=30.21, p<0.001), but not for site ($F_{14,90}$=0.84, p=0.627). The GLM was also run for number of cells versus date and site type (MC, SC, BW) and was not significant for site type ($F_{2,102}$=0.88, p=0.418). The GLM was significant for biovolume versus date ($F_{7,90}$=3.40, p=0.003) but not site ($F_{14,90}$=0.73, p=0.735) or

site type ($F_{2,102}$=0.46, p=0.630). The number of taxa versus date was significant ($F_{7,90}$=37.75, p<0.001), but number of taxa versus site and site type was not ($F_{14,90}$=1.21, p=0.286; $F_{2,102}$=4.65, p=0.012). Shannon's Index and Simpson's Reciprocal versus date were also significant ($F_{7,90}$=3.57, p=0.002; $F_{7,90}$=3.04, p=0.006). Finally, the GLM for Shannon's Index and Simpson's Reciprocal versus site and site type was not significant ($F_{7,90}$=0.52, p=0.914; $F_{2,102}$=0.01, p=0.989). After conducting the GLM tests, the data were combined for each date to determine overall trends in algal dominance (Figs. 40 and 41). Green algae, diatoms, and blue-green algae were the dominant groups by cell count, with all three groups equally dominant on three dates: July 1, August 30, and September 30. There did not appear to be a temporal pattern to the dominant group. Together green algae and diatoms accounted for 48-88% of the community (Table 4). When calculated using biovolume, diatoms and green algae were the dominant groups and each sampling date was dominated by just one algal group (Table 4). Together diatoms and green algae accounted for 67-98% of the community (Table 4). There did appear to be some seasonal succession of these groups.

Hydrographs: The 2007 hydrograph exhibits one intense period of variation from August through September with little variation during other time periods (Fig. 42). The 2009 hydrograph exhibits smaller, more frequent variation over the course of the summer and early fall (Fig. 43).

Algal Community Function/Ecosystem Metabolism

Respiration values ranged from a low of 0.62 gO_2 /m^2/day to a high of 5.18 gO_2 /m^2/day, with both of these values occurring at the single channel site in August and September, respectively (Table 19). Respiration values did not appear to have a common pattern, as the high values for each site occurred in different months. The lowest values for the point bar and braided

site both occurred in September, but the lowest value at the single channel site occurred in August. GPP values for the longitudinal sites ranged from a low of 0.62 gO_2 /m^2/day at the point bar site in August to a high of 9.76 gO_2 /m^2/day at the single channel site in September. At all three sites, the highest GPP values occurred in September and the lowest in August. NPP ranged from a negative value of -2.57 gO_2 /m^2/day at the point bar site in August to a high of 4.59 gO_2 /m^2/day at the single channel site in September.

The single channel site had the highest average NPP value (1.7759 gO_2 /m^2/day), while the average NPP values for the point bar and braided sites were less than half that (0.52 59 gO_2 /m^2/day and 0.7059 gO_2 /m^2/day, respectively; Table 5, Fig. 44). All three sites had an average P/R over 1, indicating net autotrophy (Table 6). The single channel site had the lowest P/R at 1.36, but it was the only site that consistently had a P/R > 1. The point bar and braided sites both had P/R < 1 for two separate sampling periods and an extremely high P/R for the third sampling period, thereby increasing the average P/R (Table 5).

Statistical analysis using a General Linear Model (GLM) for NPP versus. date and site was significant for date ($F_{2,4}$=60.58, p=0.001) but not for site ($F_{2,4}$=3.16, p=0.150). The General Linear Model for P/R versus. date and site was not significant for either ($F_{2,4}$=6.19, p=0.060; $F_{2,4}$=0.41, p=0.691) (Fig. 45).

The GLM for respiration versus. date and site for the lateral sites was not significant for either ($F_{4,19}$=2.17, p=0.112; $F_{2,19}$=1.08, p=0.359 (Fig. 46). The GLM for gross primary productivity was significant for date ($F_{4,19}$=3.22, p=0.035) but not site ($F_{2,19}$=2.13, p=0.147) (Fig. 47). The GLM for NPP was not significant for either date ($F_{4,19}$=2.83, p=0.053) or site ($F_{2,19}$=2.17, p=0.141) (Fig. 48).

DISCUSSION

Algal Community Structure

I found that the Kansas River supports a riverine phytoplankton community similar to those found in other large rivers and this community exhibits seasonal succession. In both years, the community varied more by date than site, which is likely due to the influence of thunderstorm events. The dominant algal group varied slightly when comparing dominance calculated by cell count with that calculated using biovolume; this may have important implications in food web studies.

In 2007, date and site did not have an effect on algal abundance or on taxa richness. However, site did appear to have an effect on community composition. Green algae, diatoms, and blue-green algae were the dominant groups when dominance was calculated with cell counts (Table 1). Blue-green algae dominated in the backwater and side channel sites, which is consistent with the results reported by Stoyneva (1994), Fritsch (1902, 1903), Williams and Scott (1962). Blue-green algae contributed little to the community when using biovolume calculations. Instead, the dominant groups consisted of diatoms, green algae, and euglenoids (Table 2). The large percentage of euglenoids in the community has not been reported in other studies. The differences between the cell count and biovolume results are likely due to size differences. While the euglenoids did not occur in large numbers, they are generally large algal cells. On the other hand, most of the blue-green algae identified in the samples were *Merismopedia spp*, which are extremely small cells. Therefore, while it does occur in large colonies and large numbers were reported, the total biovolume contribution is low. The diatom taxa were nearly all centric diatoms, which is similar to other rivers in the United States (Williams and Scott 1962). While I predicted that site would have an effect on community composition, this was not the case. It is possible that this is related to the hydrograph. The July samples were collected after a period of

relatively stable flow, but the August sample was collected after a sizeable flow event that reconnected the backwater to the main channel.

As in 2007, site did not have an effect on algal abundance, taxa richness, or taxa diversity in 2009. However, sampling date was significant for these measures. Green algae, diatoms, and blue-green algae were once again the dominant algal groups when calculated using cell counts, with green algae and diatoms comprising most of the community when calculated as a percentage of biovolume. One difference between 2007 and 2009 is relatively low contribution of euglenoids to the community in 2009. Indeed, diatoms and green algae comprised 67-98% of the community, with euglenoids never ranking more than fourth in dominance. Instead, cryptomonads and dinoflagellates were the other contributors to community composition, though they never approached the biovolume totals of the diatoms and green algae. The significance of date is likely due to a seasonal effect. Green algae were predominant at the beginning of the study on July 13 but were replaced by diatoms during July. Green algae were prevalent in August and the first part of September but were surpassed by diatoms again in the middle of September. This seasonal pattern is similar to that found by Shiel et al. (1982), Descy and Gosselain (1994), Gosselain et al. (1994), and Reynolds and Descy (1996), though those studies found a more pronounced shift from spring diatom dominance to summer green algae dominance rather than an oscillation between the two groups. It is important to note that the green algae found in the Kansas River are similar to that found in other rivers. Futhermore, a large number of the green algae taxa found in the Kansas River have been reported as phytoplankton, rather than benthic, taxa. These included *Actinastrum*, *Coelastrum*, *Crucigenia*, *Pediastrum*, *Scenedesmus*, and *Schroederia spp*. (Reynolds and Glaister 1993, Reynolds and Descy 1996). The ratio of centric to pennate diatoms was more variable in 2009 than in 2007, though pennate diatoms only approached dominance on August 14. The River Adige (Salmaso and Zignin 2010) and the

Kentucky River (Stevenson and White 1995) both had different ratios of pennate to centric diatoms in upstream versus downstream locations, but the change in ratio across time has not been previously reported. Furthermore, most of the blue-green algae identified in the samples were *Merismopedia spp*., which is not typically found in large numbers in reservoirs. *Anabaena, Oscillatoria, and Microsystis spp.* are capable of producing blooms (Loftin et al. 2008), but these did not occur in large numbers (never in large colonies) and the river did not experience any blue-green algae blooms during the 2007 and 2009 sampling periods. Other reservoir species such as *Aphanizomenon, Synechoccus and Anabeanopsis* (Loftin et al. 2008), were not found in the Kansas River samples. The presence of large numbers of centric diatoms, commonly planktonic green alga species, and low numbers of bloom producing blue-green algae species found in the algal samples indicate that the phytoplankton community found in the Kansas River is likely a true potamoplankton community rather than an extension of the Tuttle Creek and Perry Lake reservoir communities.

My predictions regarding difference in communities across lateral habitats were not supported by either study, but it is possible that this is due to the flow conditions of those years. As stated previously, the river had relatively stable flow before the first 2007 sampling date, but then experienced a substantial change before the last sampling date, thereby reconnecting the backwater to the main channel (Fig. 42). The small sample size (sample date n=3) may also have been a factor. The flow pulses in 2009 were not as great in magnitude as those in 2007, but they did occur more frequently (Fig. 43) and the river did not experience base flow conditions. As a result, the backwater was frequently reconnected with the main channel. At the same time, flow conditions in the side channel were similar to those in the main channel. It is possible that when the river experiences base flow conditions for a period of several weeks the conditions become more favorable for blue-green algae growth in the backwater areas.

The studies conducted in 2007 and 2009 contributed to our knowledge of the phytoplankton community in a sand bed river. The Kansas River supports a phytoplankton community and exhibits seasonal succession. However, because the hydrograph is so variable, long-term studies are needed to capture the wide range of conditions that affect the river from year to year. I predict that years with highly variable hydrographs will have more homogenous phytoplankton populations than years with relatively stable flow conditions. It is also important to note that releases from the Tuttle Creek Lake, Perry Lake, and Clinton Lake reservoirs may impact flow conditions in the Kansas River. These reservoirs typically release small amounts of water daily, but may release large amounts of water during high water conditions. In 2007 and 2009, the hydrograph exhibits flow peaks that are reflective of the thunderstorm events that occurred rather than any reservoir water release. However, during extremely wet years, flow peaks are extended as a result of reservoir water release.

Algal Community Function/Ecosystem Metabolism

Metabolism results were similar to the algal community results; date was significant for some variables, but site was not. Gross primary production was significant for the lateral sites for date ($F_{4,19}$=3.22, p=0.035) but not site ($F_{2,19}$=2.13, p=0.147) (Fig. 47). Net primary productivity was not significant for either date ($F_{4,19}$=2.83, p=0.053) or site ($F_{2,19}$=2.17, p=0.141) (Fig. 48). These results did not fit my prediction that the side channel would have the highest NPP while the backwater would have the lowest. The BOD bottles do have some limitations in that you are using a closed bottle to measure a process that occurs in an open system. It is also difficult to approximate the 24-hr dissolved oxygen curve using light and dark bottles. The main channel site exhibited a great deal of variability while the backwater site was much less variable. It is possible that using the sondes rather than the BOD bottles would reduce this variability and

better determine whether the lateral habitats have an effect on metabolism. The metabolism results do fit with the algal community results; the backwater, main channel and side channel all had similar algal communities in 2007 and therefore differences in metabolism measures were not significant. However, like the community results, it is possible that the lack of stable flow had an effect and additional studies are needed to determine the effect of hydrograph on metabolism.

The longitudinal sites were also significant for some variables by date. The GLM for NPP was significant for date ($F_{2,4}$=60.58, p=0.001) but not for site ($F_{2,4}$=3.16, p=0.150, Table 21). The highest NPP values were recorded in September, which corresponded with the highest P/R ratios for each site. However, the GLM for P/R was not significant ($F_{2,4}$=6.19, p=0.06, Table 22). Although all three sites had an average P/R >1, indicating autotrophy, only the single channel habitat had a P/R > 1 for all three sampling dates (Tables 20, 19). The point bar and braided habitats were both heterotrophic in August and October but autotrophic in September. This fits with the study conducted by Dodds et al. (2008); they measured metabolism in the main channel in October and found that the Kansas River was heterotrophic. They also noted that processes occuring in the lateral habitats could be important but were not included in their measurements. The swing from heterotrophy to autotrophy and back indicates that the common practice of measuring metabolism for one or two 48-hr periods a year may not adequately capture metabolic processes in sandbed rivers. Monthly, multi-year studies are needed to determine the importance of lateral habitats and to truly characterize the river. However, other methods may be more informative than attempting to measure metabolism. Deploying recording equipment for several days can be difficult in a sandbed river. I experienced the loss of several anchors (but not sondes) during flow pulses in 2008. Also, it can be cost prohibitive to conduct dissolved oxygen measurements concurrently in the main channel and in lateral habitats. Finally,

because estimates of R are so variable, P/R calculations are unreliable (Rosenfeld and Mackay 1987, Mulholland et al. 2001, Thorp and Delong 2002). Therefore, stable isotope or lipid studies may be better measures of the algal contribution to the food web. Lipid studies may be particularly enlightening because each algal group has its own profile (Arts and Wainman 2012). Therefore, it is possible to determine whether the algal groups are being consumed in the same proportion as they occur in the algal community. Diatoms and green algae are the most nutritious algal groups (Arts and Wainman 2012); their dominance of the algal community in the Kansas River suggests there is likely a significant autochthonous contribution to the food web.

My studies examined the structure and function of the phytoplankton community in the Kansas River, but it is possible that the benthic community also contributes to the food web. This community is limited by a lack of stable substrate and high turbidity values. It might be valuable to measure the amount of benthic habitat available around the edges of the backwaters and sandbars. These occur at scales too small to be captured via satellite, but small format aerial photography has been successfully used in archaeological and agricultural studies for some time. I have some preliminary images captured during low flow using a kite and remote controlled camera. Quadracopters and drones have become more affordable in the past few years and could be used to both quantify the amount of benthic habitat available at various water stages and to quantify the amount of bar movement that occurs during a year.

Although there is more work to be done, these studies have contributed to the understanding of the phytoplankton community in sand bed rivers, particularly the Kansas River. The composition of the phytoplankton community appears similar to that of other large rivers across the globe, with diatoms and green algae generally dominating the community and exhibiting seasonal changes in abundance. It also appears to be a potamoplankton community, rather than an extension of the reservoir communities. However, it is apparent that more needs to

be done to fully understand the impact of flow variability on both the structure and function of this community.

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APPENDIX A: FIGURES

FIGURE 1. 2007 taxa richness. Sites on x-axis: BW = backwater, MC = main channel, SC = side channel.

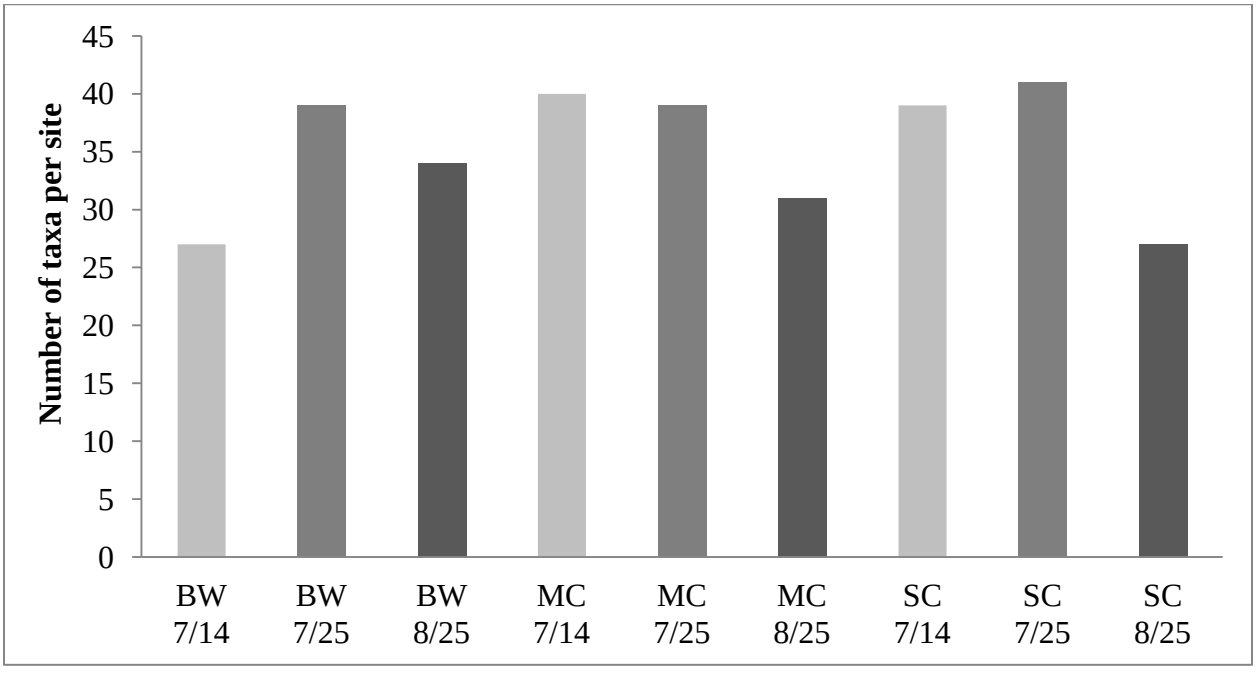


FIGURE 2. 2007 community composition calculated using number of cells counted.

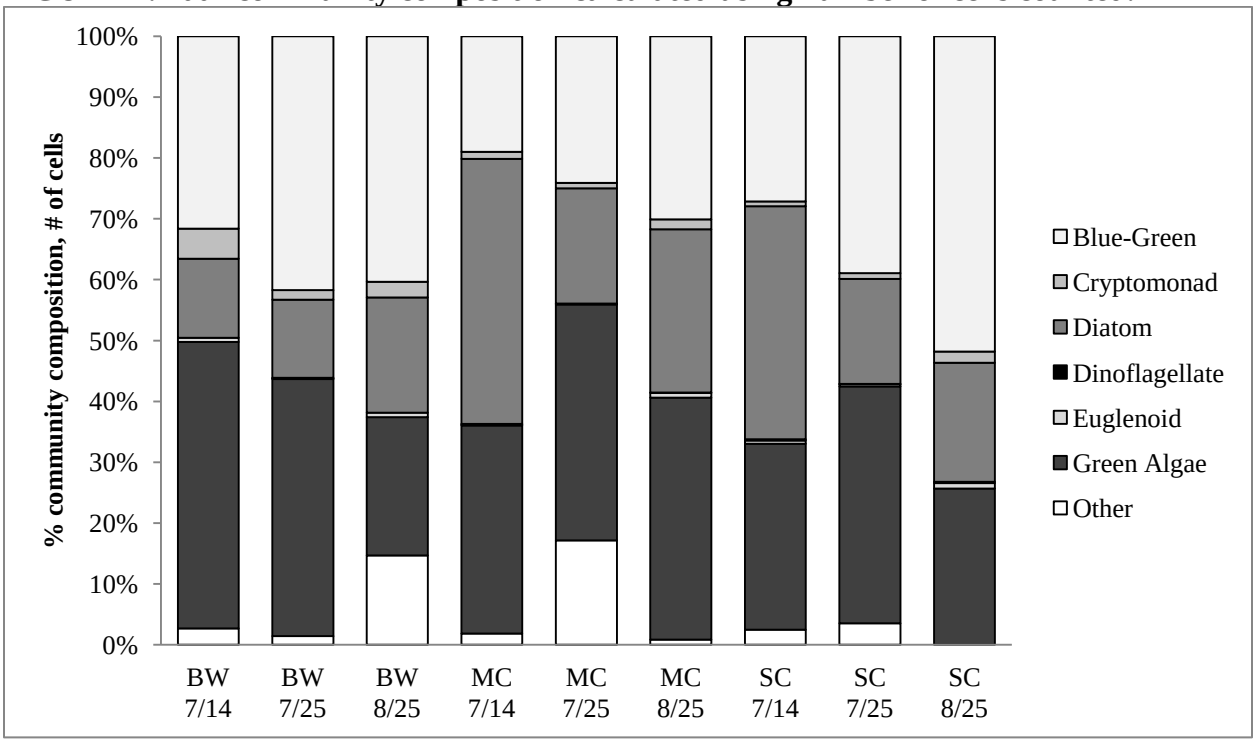


FIGURE 3. 2007 community composition by biovolume.

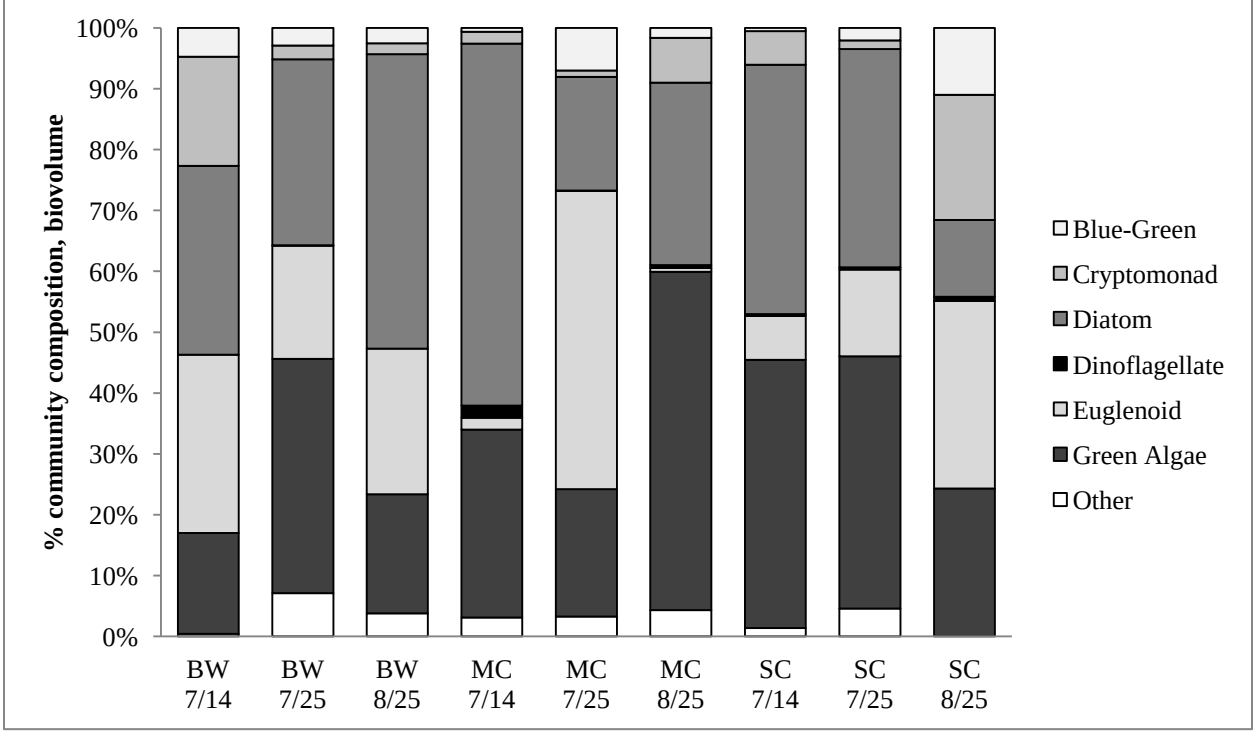


FIGURE 4. 2007 centric vs. pennate diatoms by count.

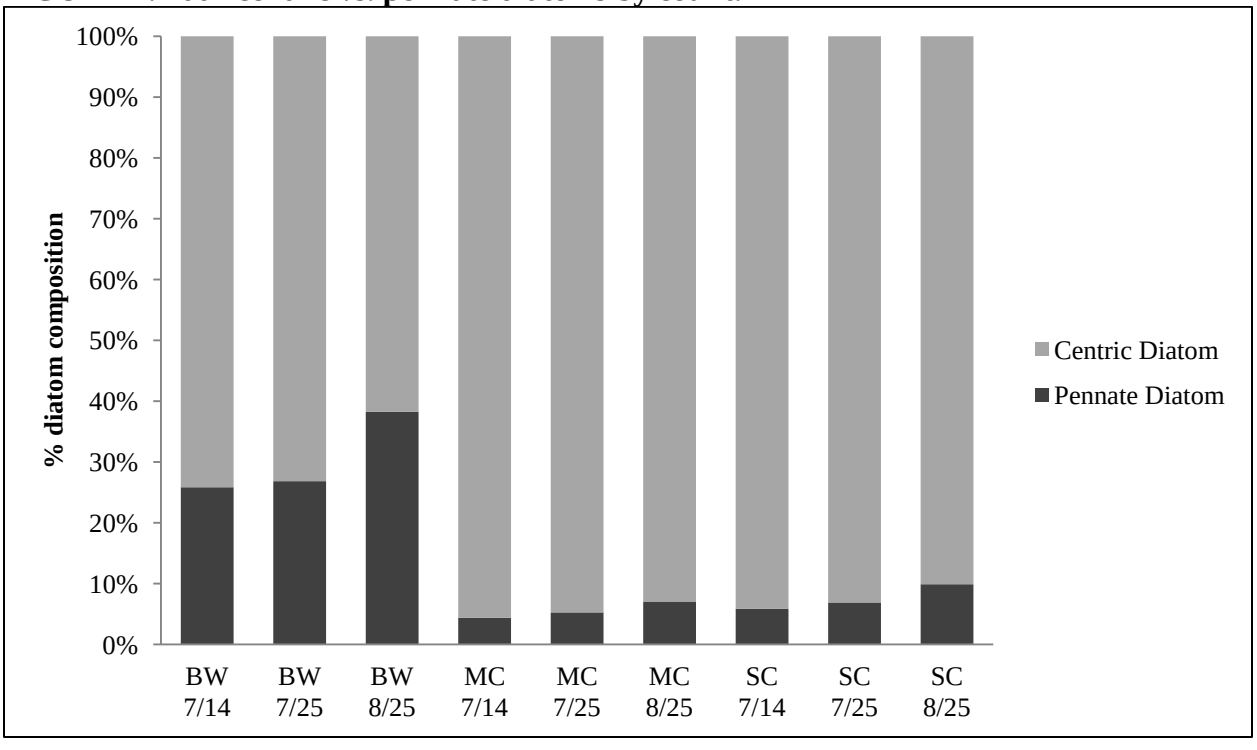


FIGURE 5. 2007 centric vs. pennate diatoms by biovolume.

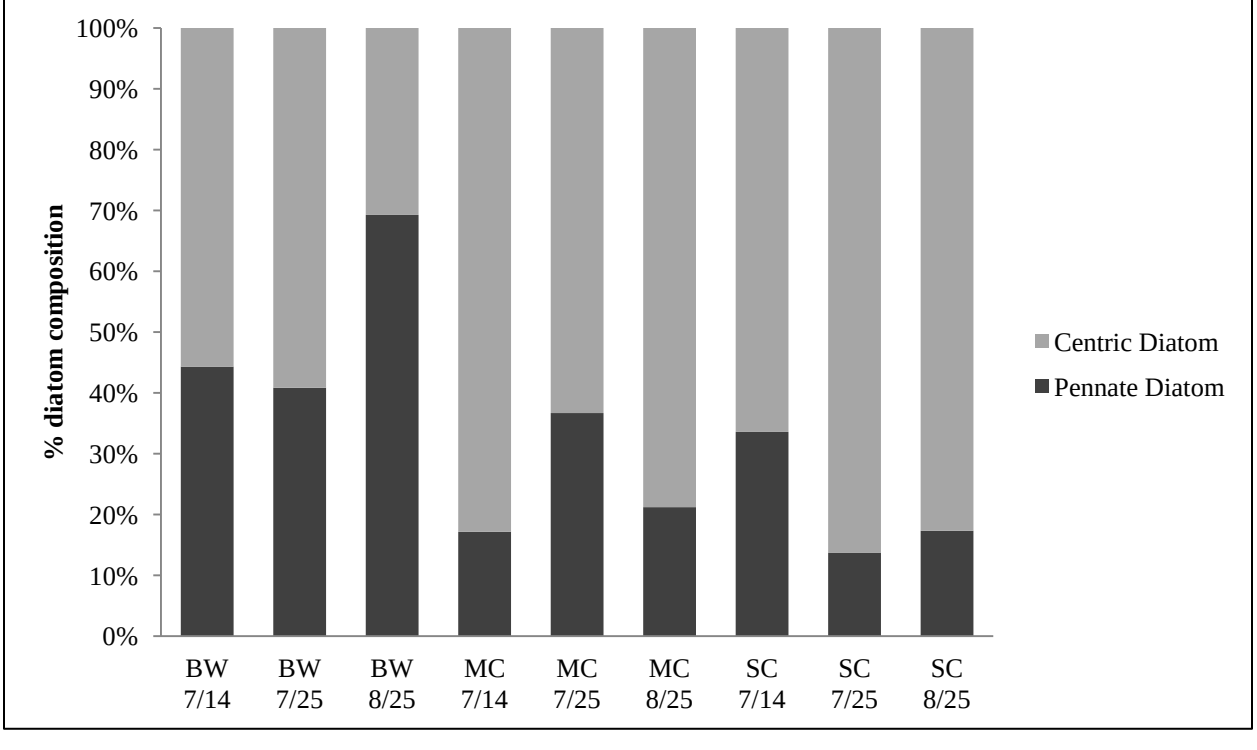


FIGURE 6. 2009 taxa richness by date for main channel sites.

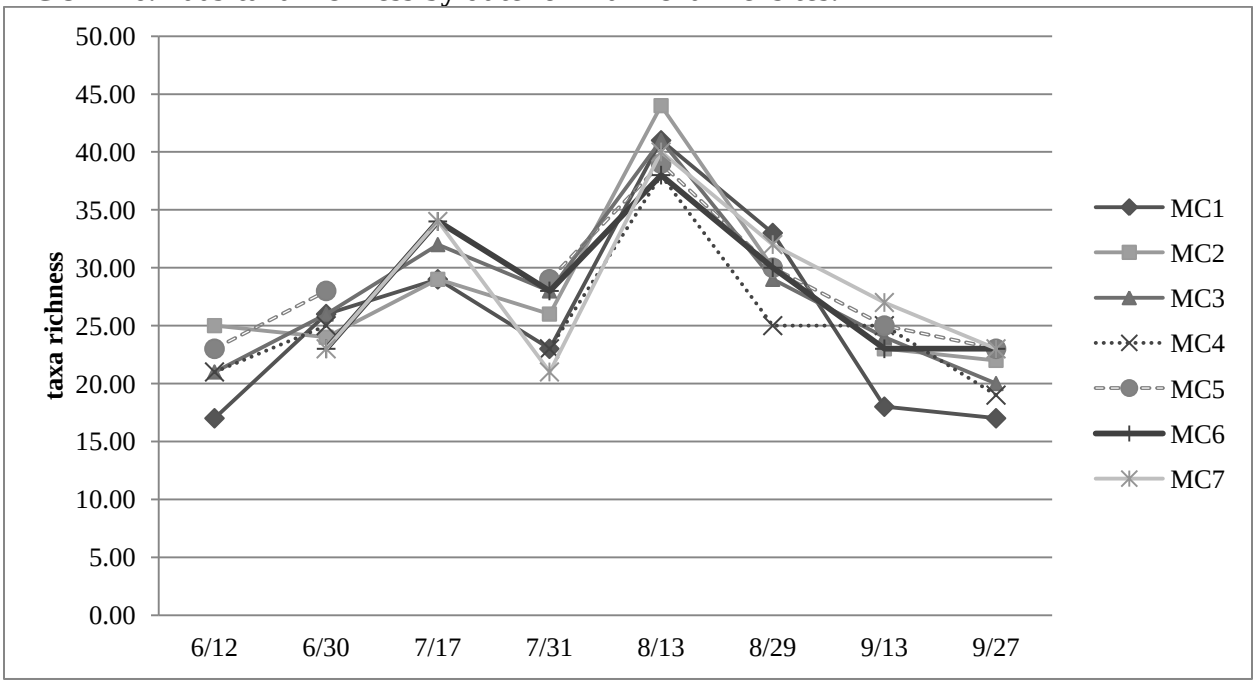


FIGURE 7. 2009 taxa richness by date for side channel and backwater sites.

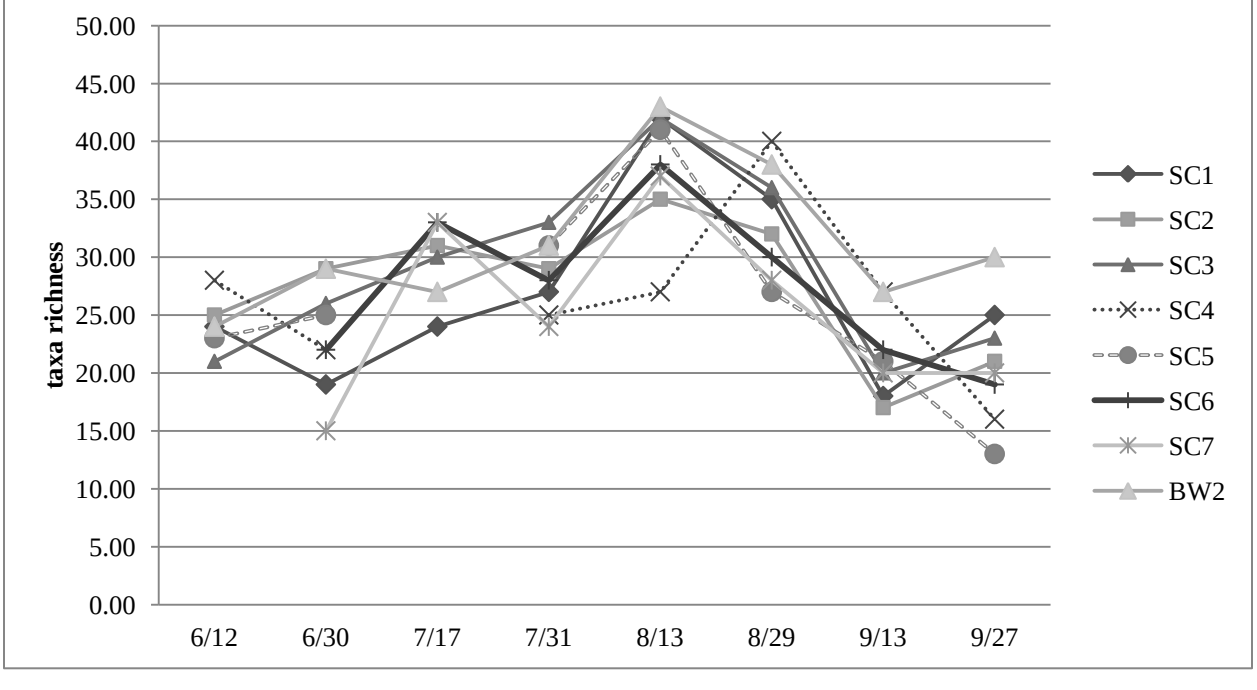


FIGURE 8. June 13, 2009 algal community composition by cell count.

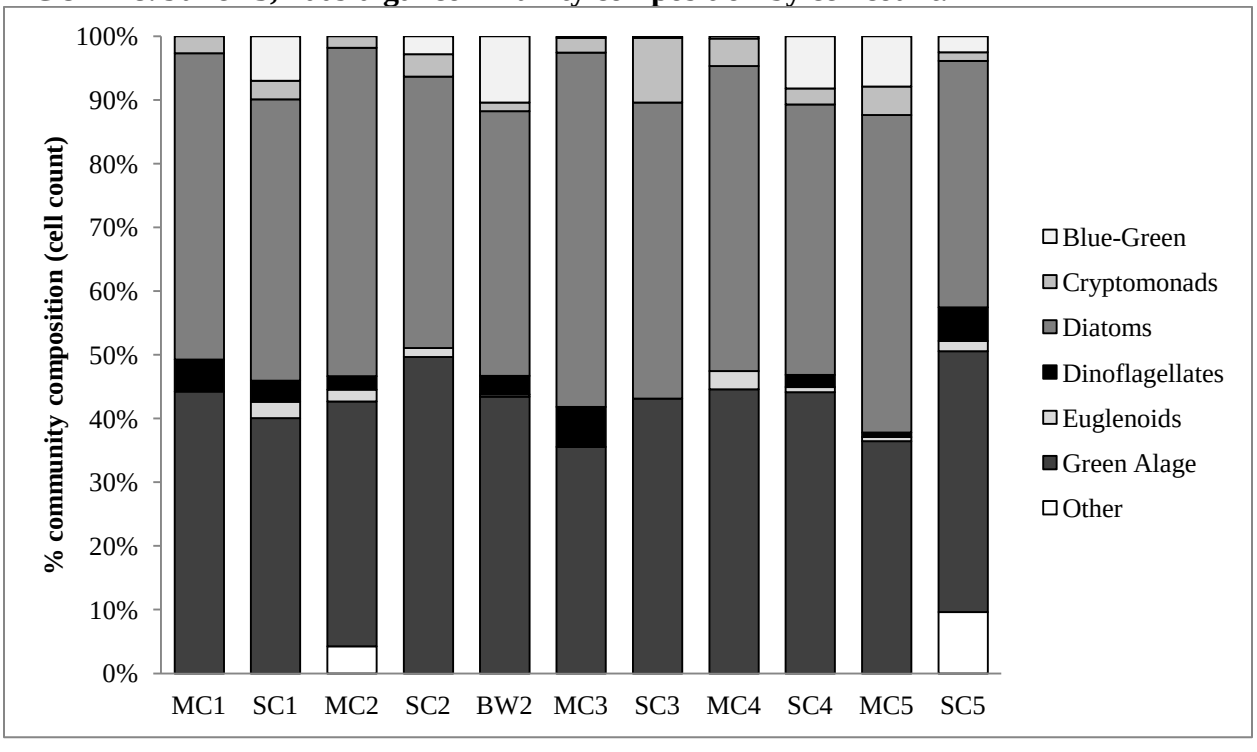


FIGURE 9. June 13, 2009 algal community composition by biovolume (µm3).

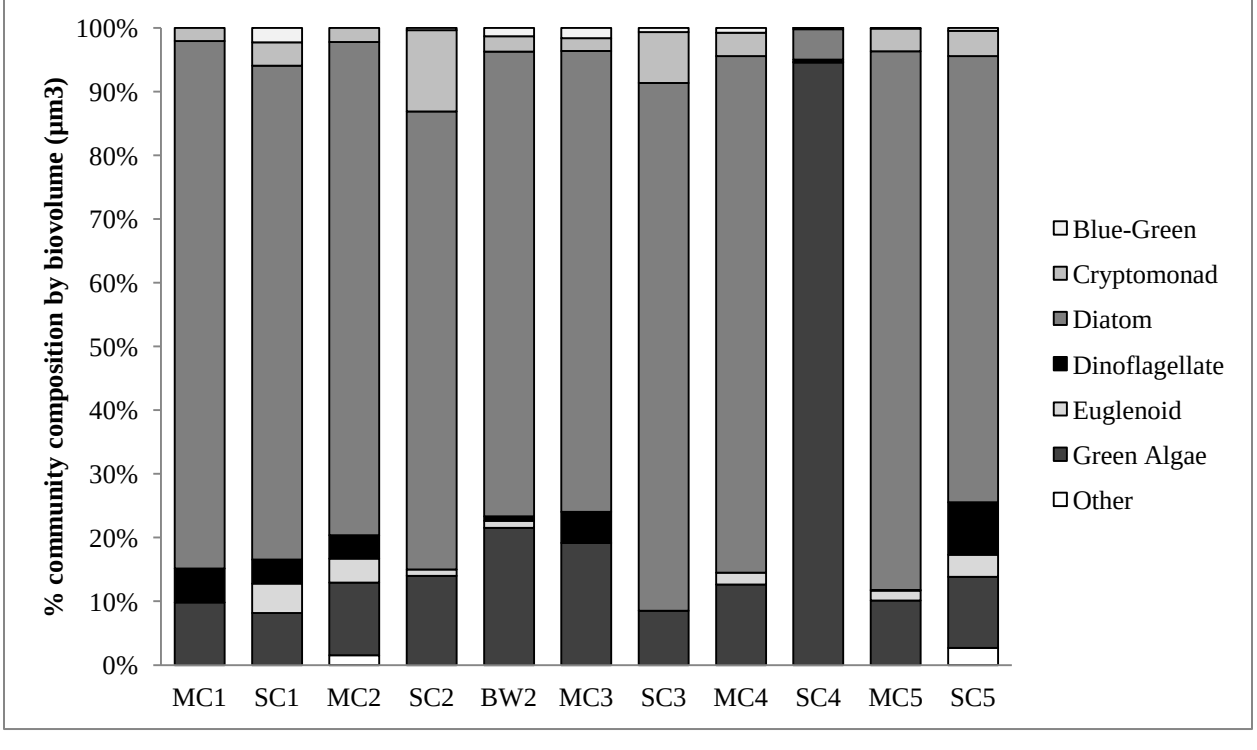


FIGURE 10. July 1, 2009 algal community composition by cell count.

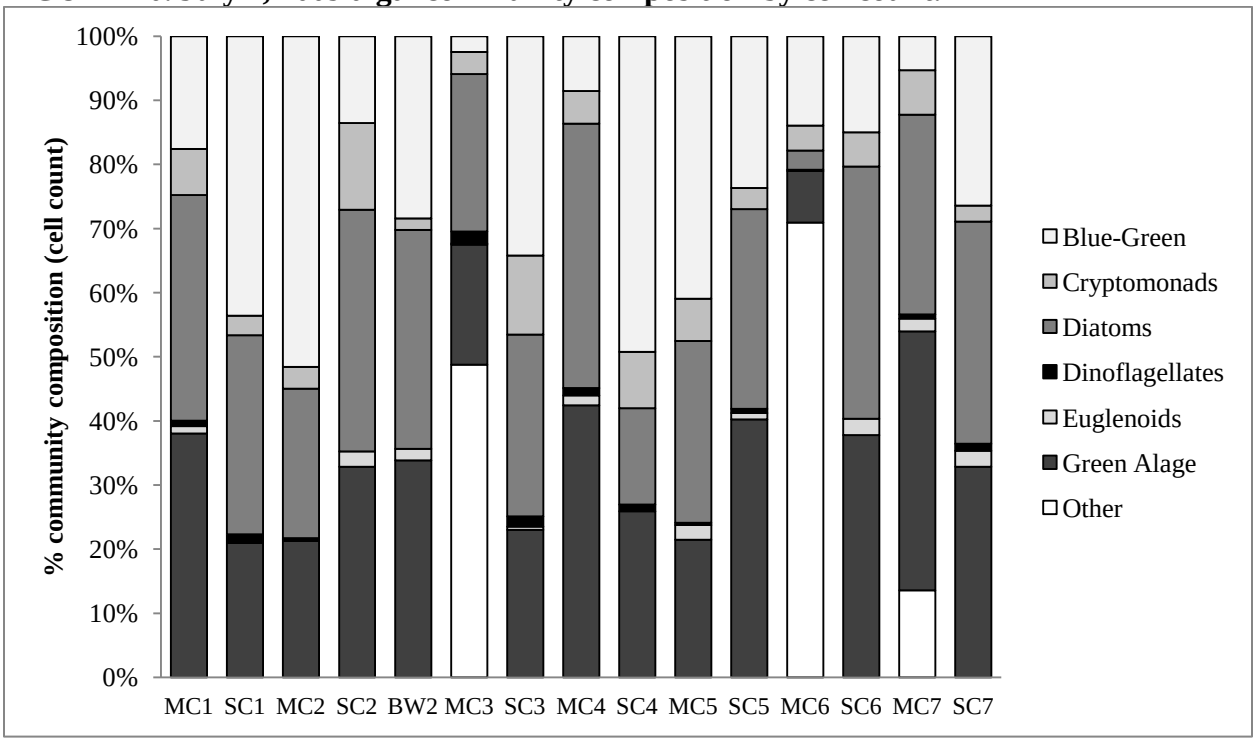


FIGURE 11. July 1, 2009 algal community composition by biovolume (µm3).

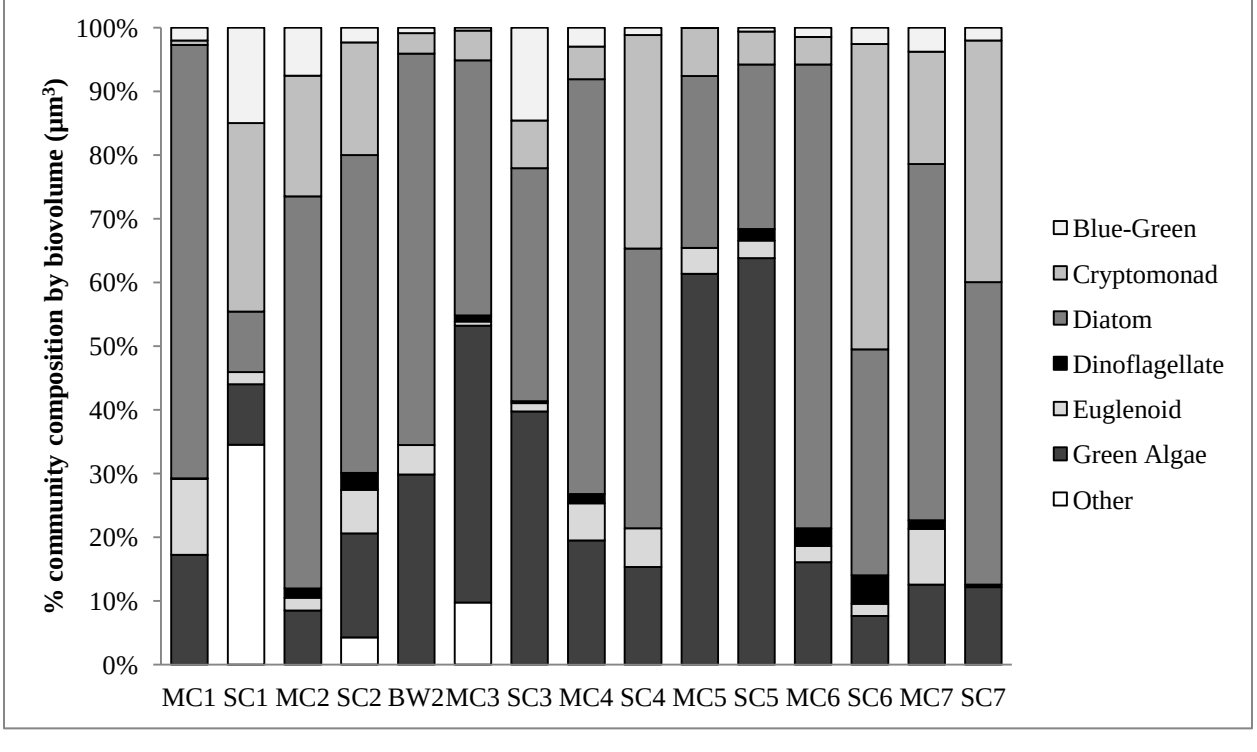


FIGURE 12. July 18, 2009 algal community composition by cell count.

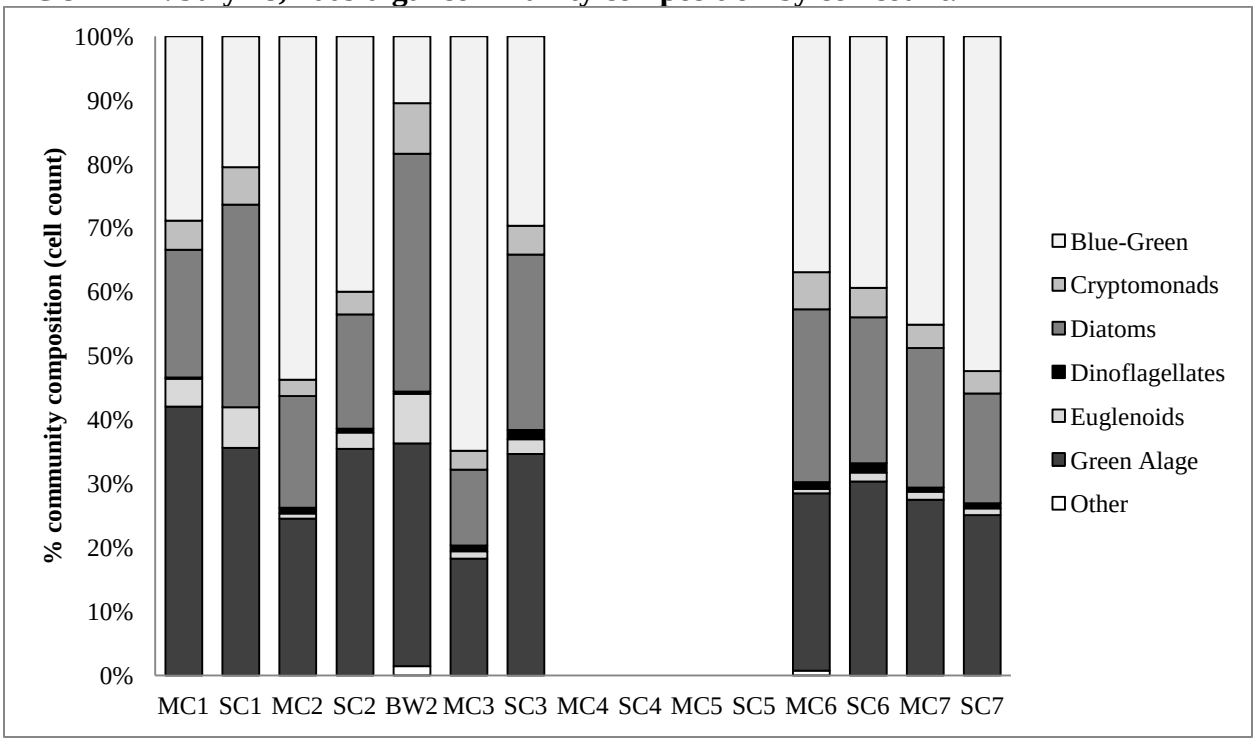


FIGURE 13. July 18, 2009 algal community composition by biovolume (µm3).

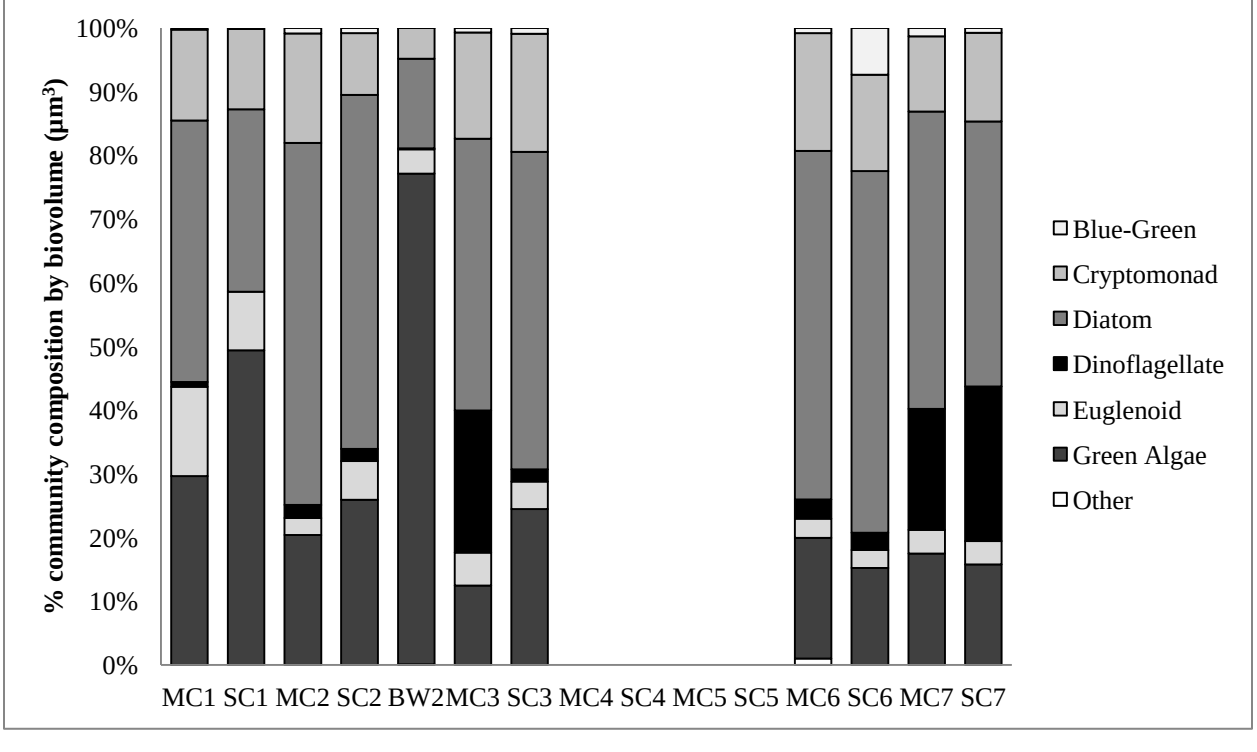


FIGURE 14. August 1, 2009 algal community composition by cell count.

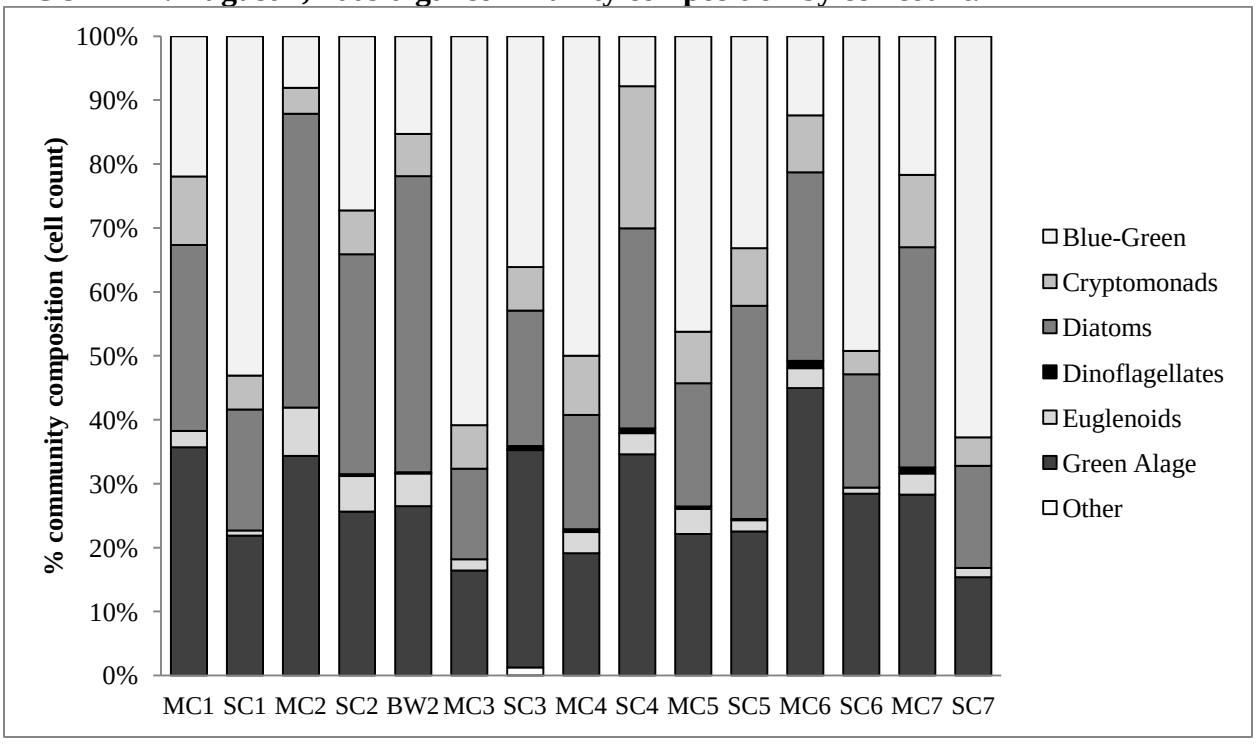


FIGURE 15. August 1, 2009 algal community composition by biovolume (µm3).

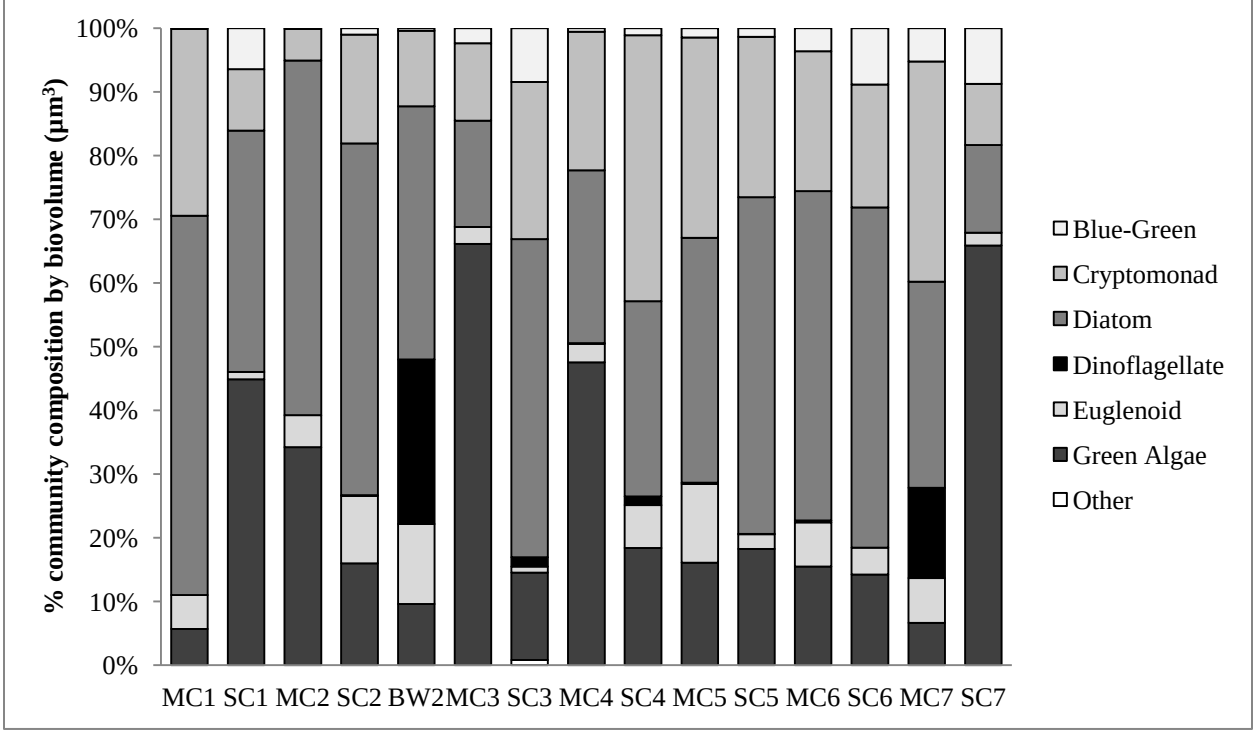


FIGURE 16. August 14, 2009 algal community composition by cell count.

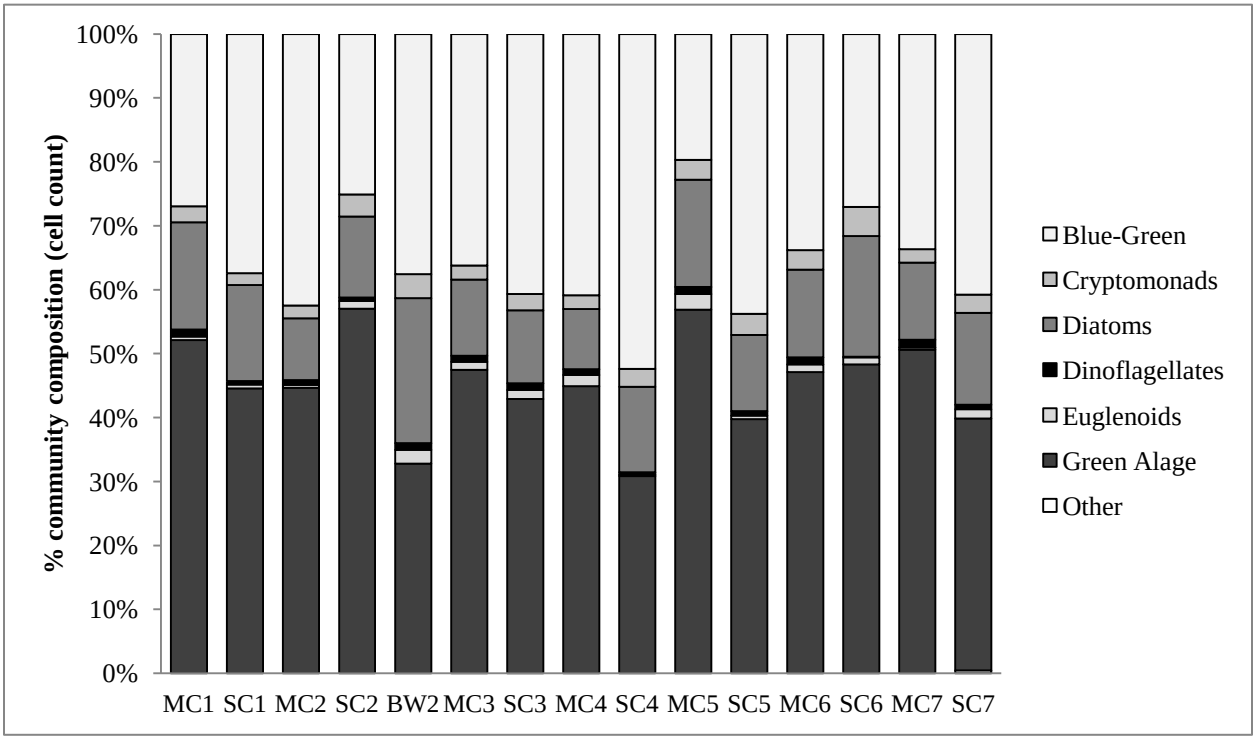


FIGURE 17. August 14, 2009 algal community composition by biovolume (µm3).

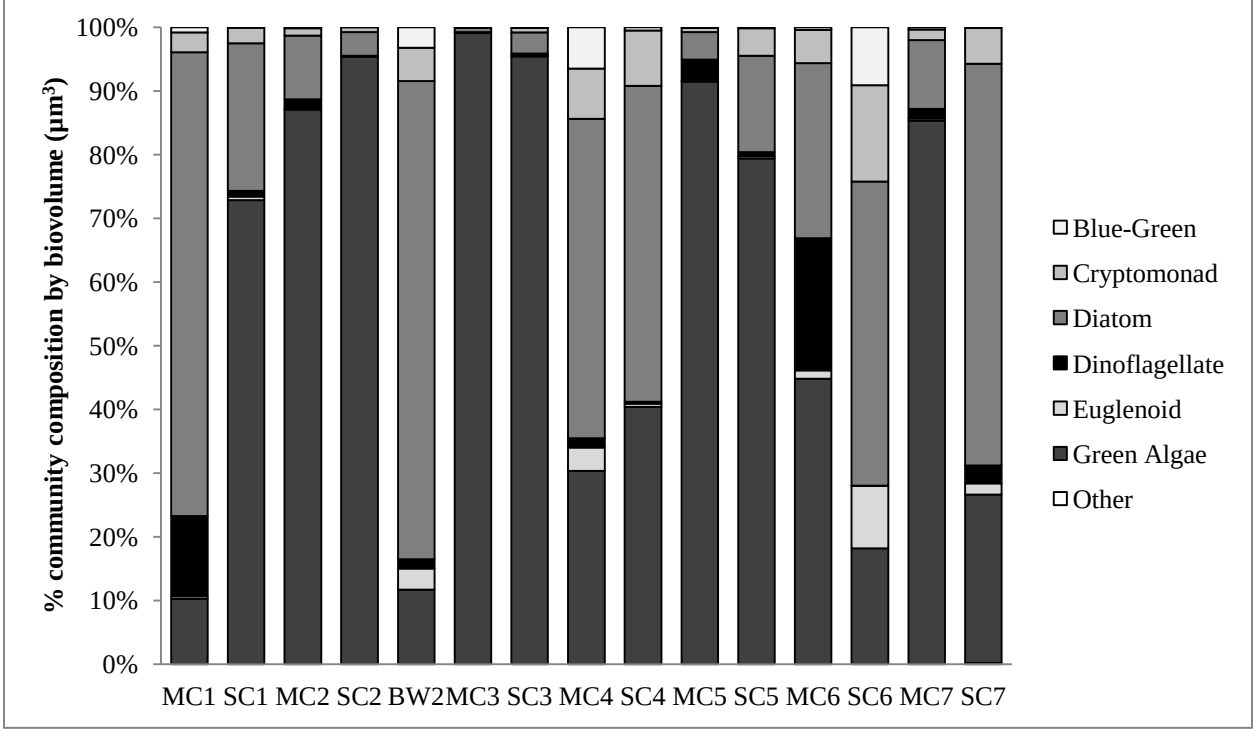


FIGURE 18. August 30, 2009 algal community composition by cell count.

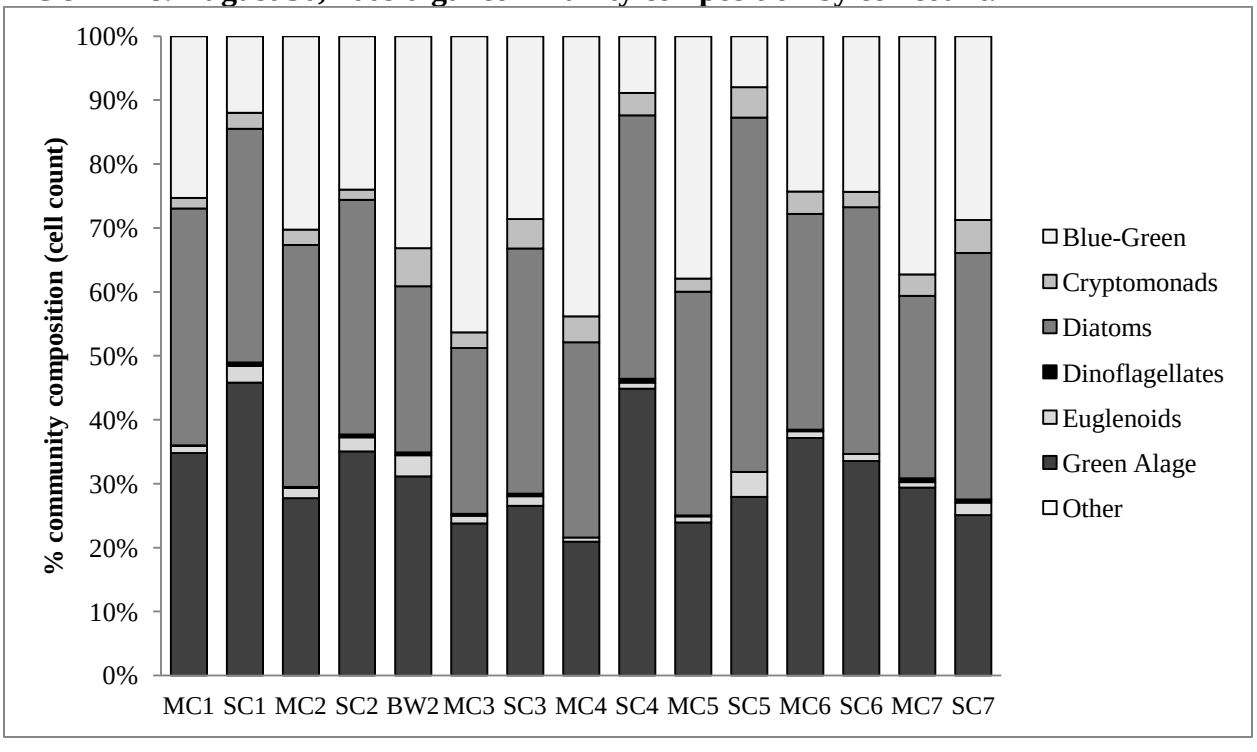


FIGURE 19. August 30, 2009 algal community composition by biovolume (µm3).

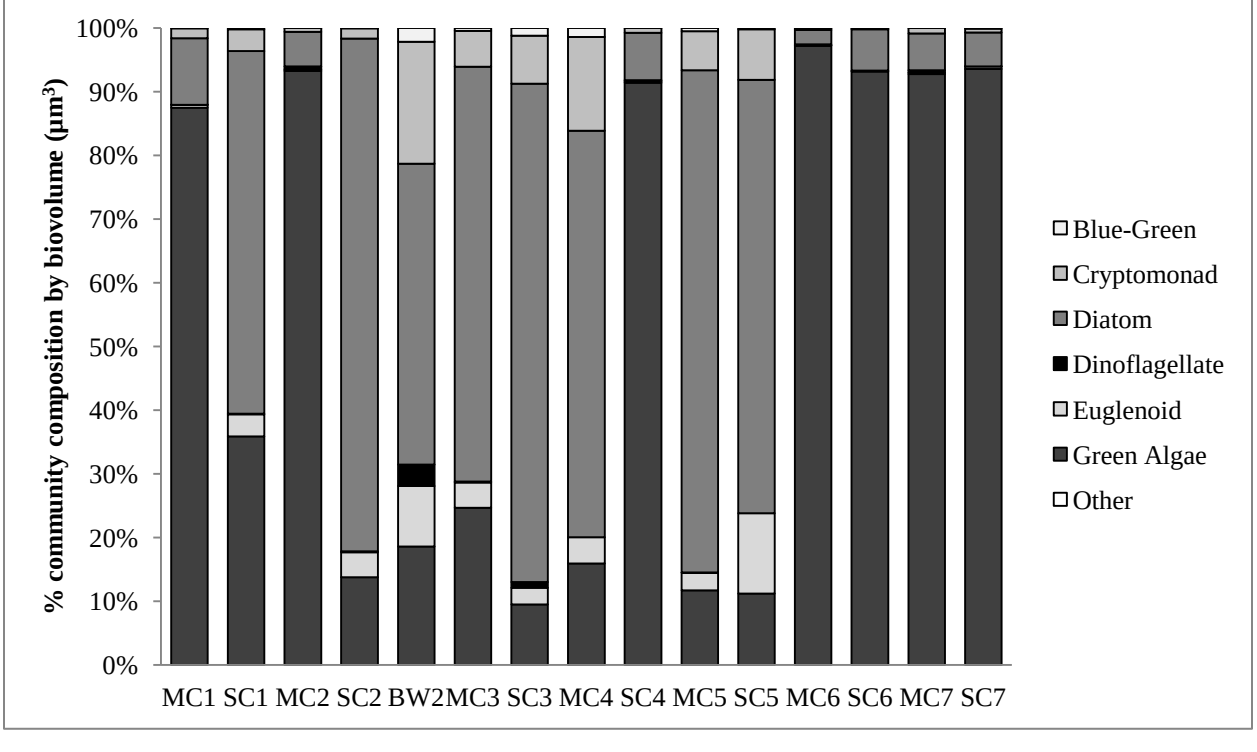


FIGURE 20. September 14, 2009 algal community composition by cell count.

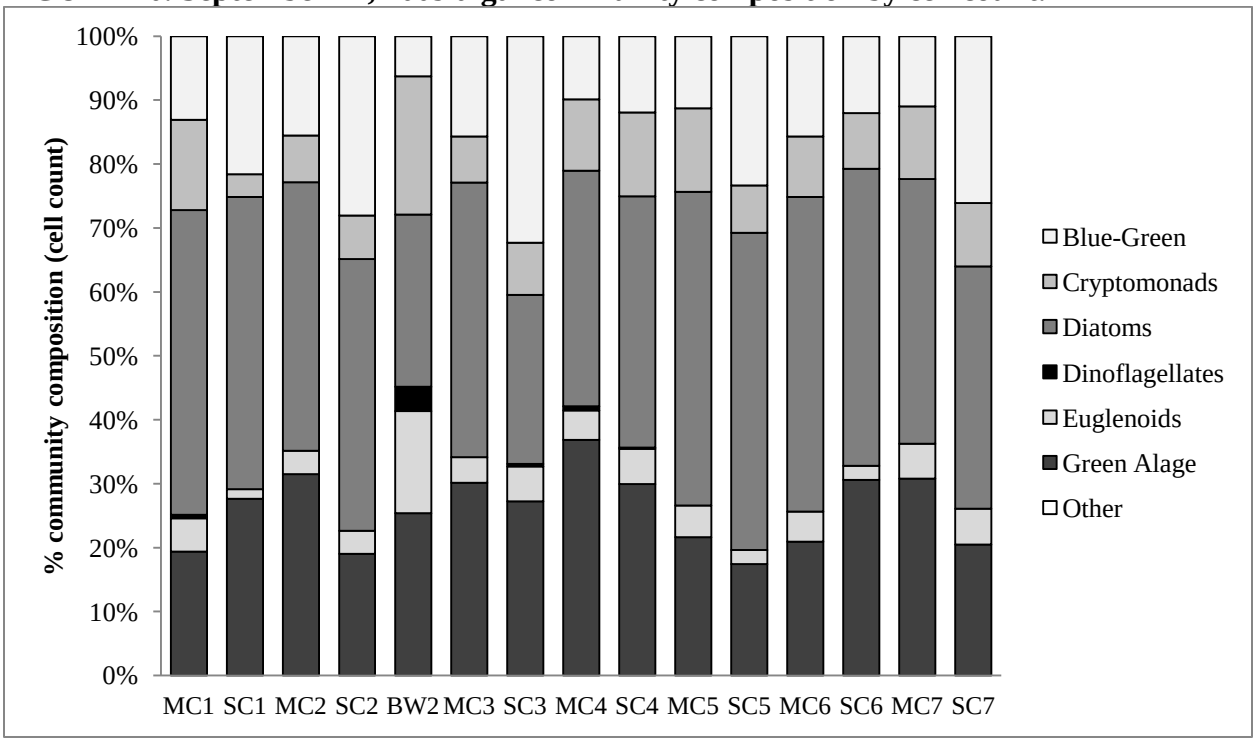


FIGURE 21. September 14, 2009 algal community composition by biovolume (µm3).

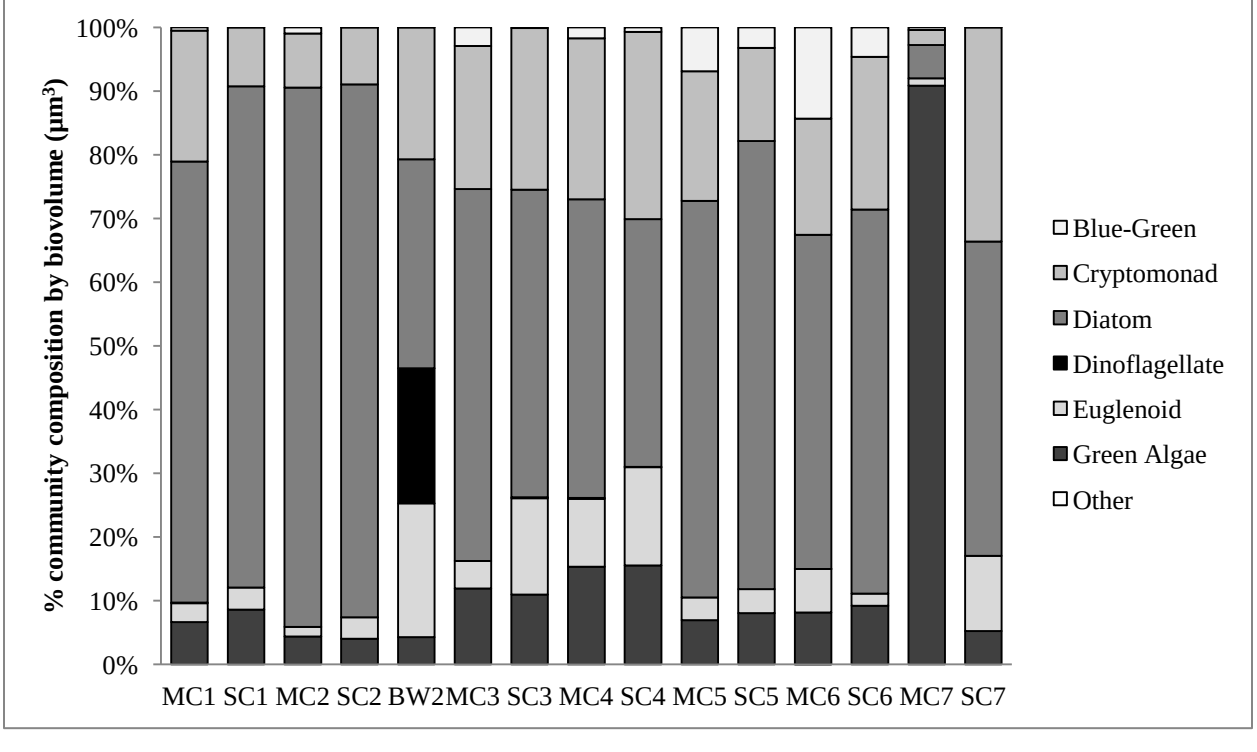


FIGURE 22. September 28, 2009 algal community composition by cell count.

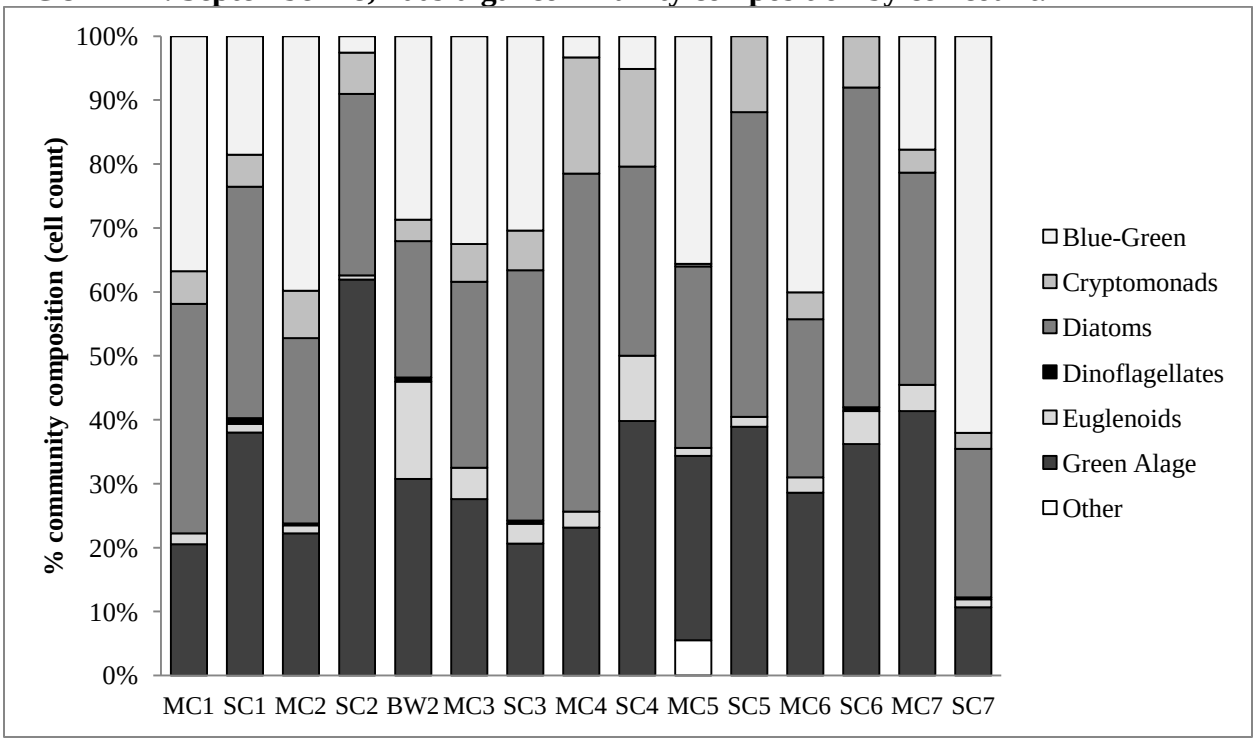


FIGURE 23. September 28, 2009 algal community composition by biovolume (µm3).

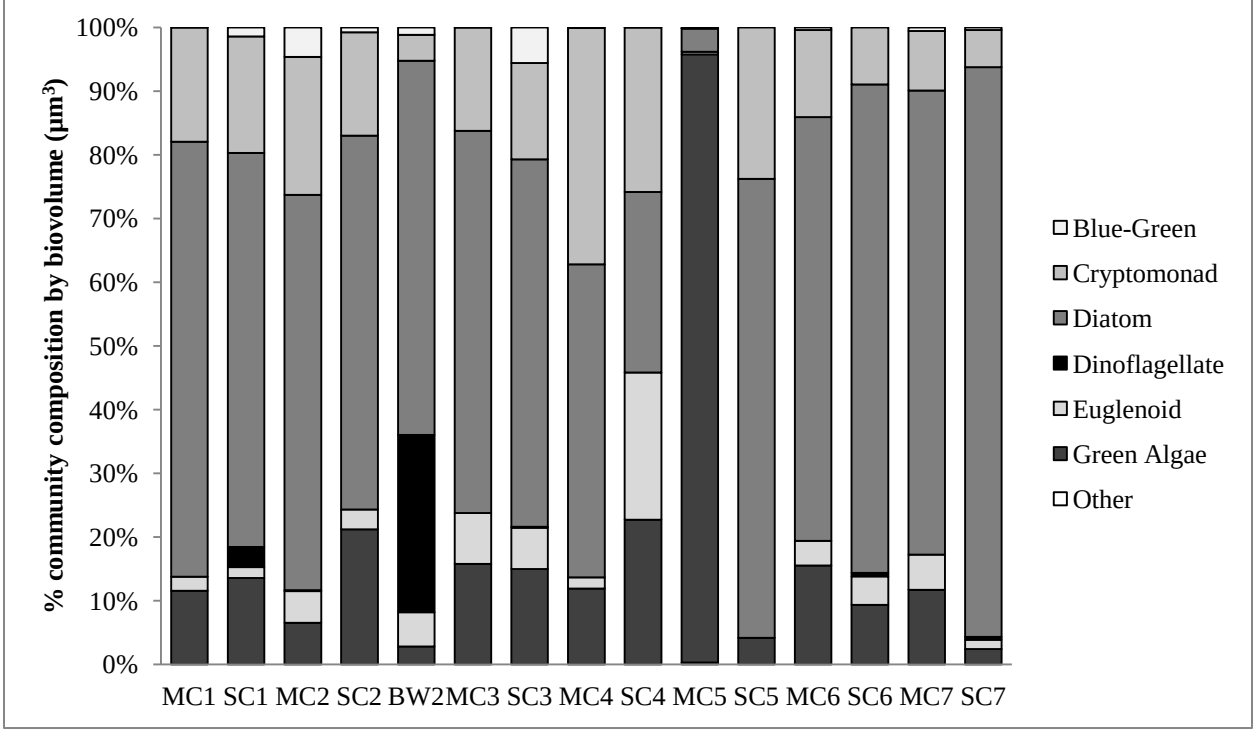


FIGURE 24. Centric vs. pennate diatom counts June 13, 2009.

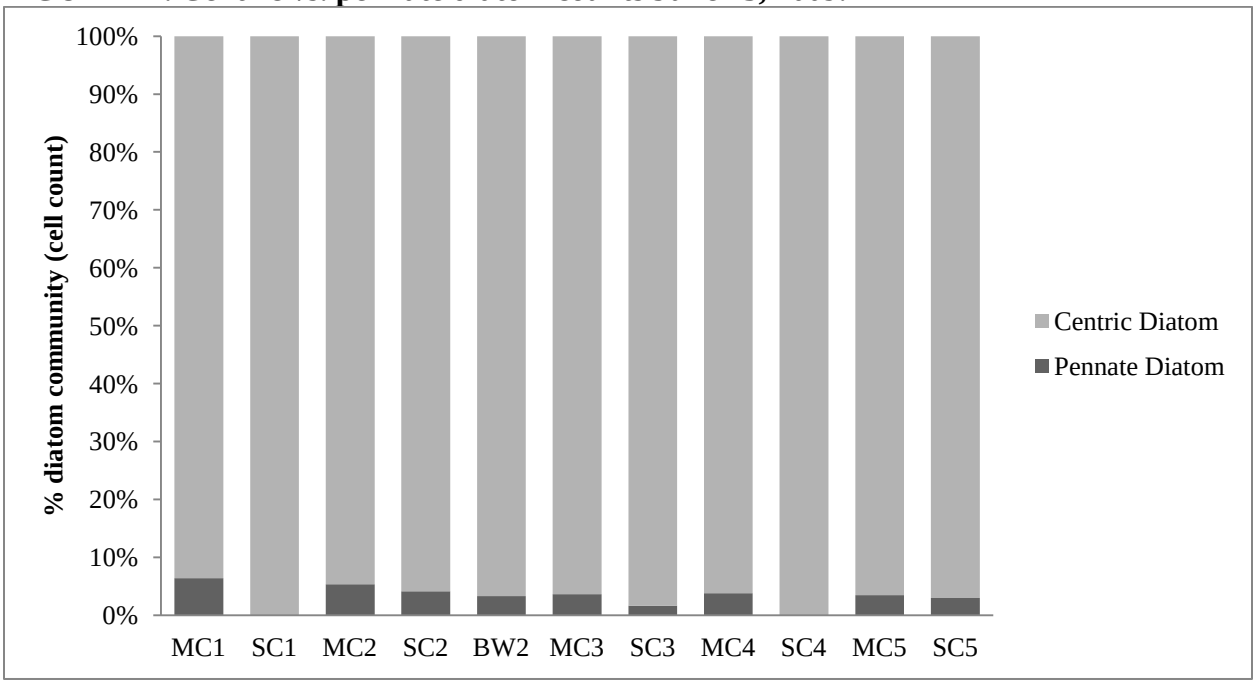


FIGURE 25. Centric vs. pennate diatom counts July 1, 2009.

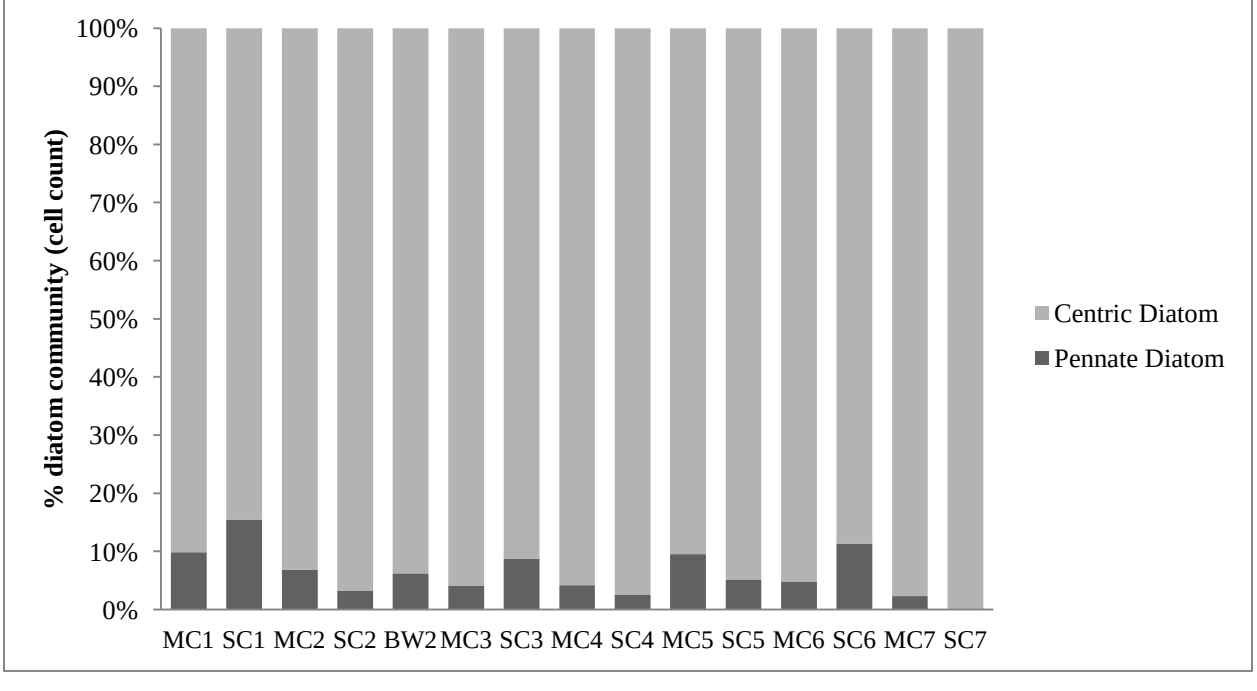


FIGURE 26. Centric vs. pennate diatom counts July 18, 2009.

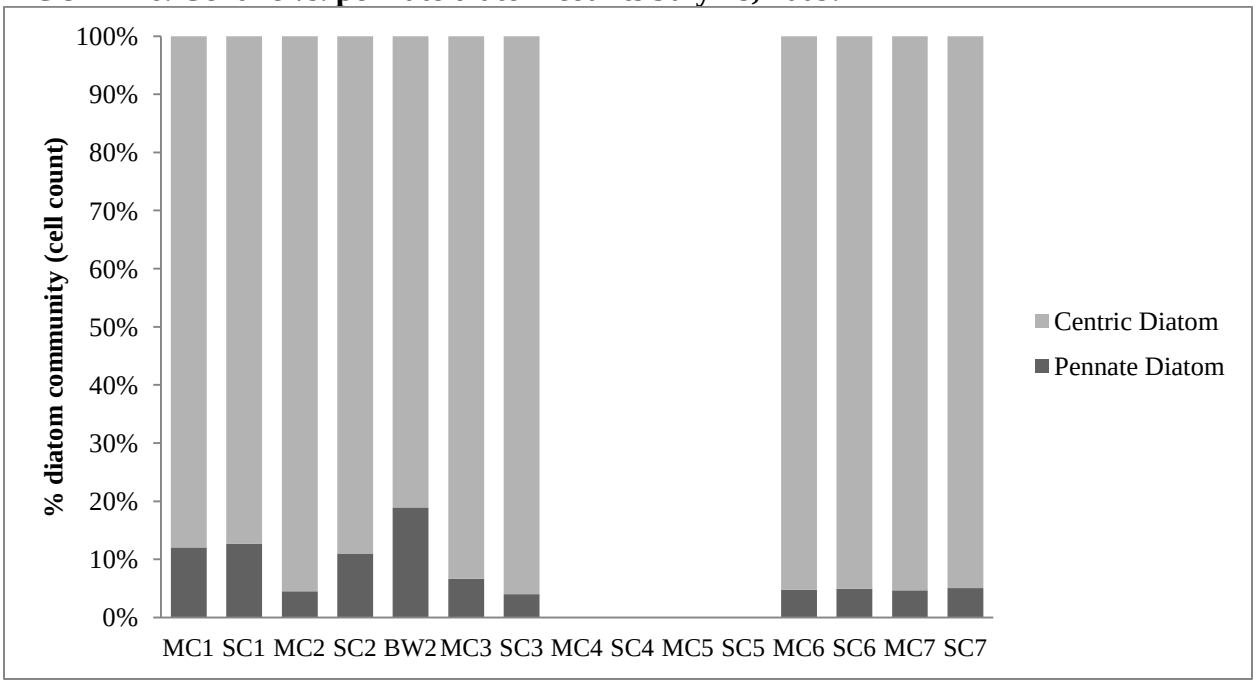


FIGURE 27. Centric vs. pennate diatom counts August 1, 2009.

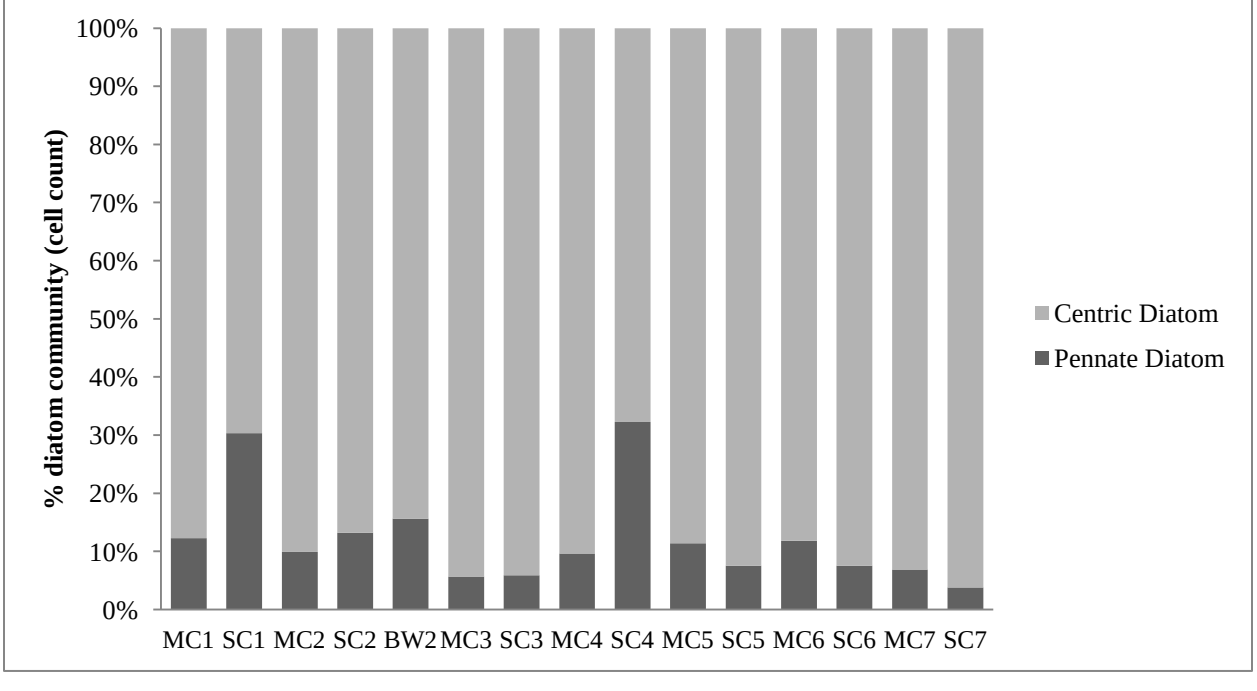


FIGURE 28. Centric vs. pennate diatom counts August 14, 2009.

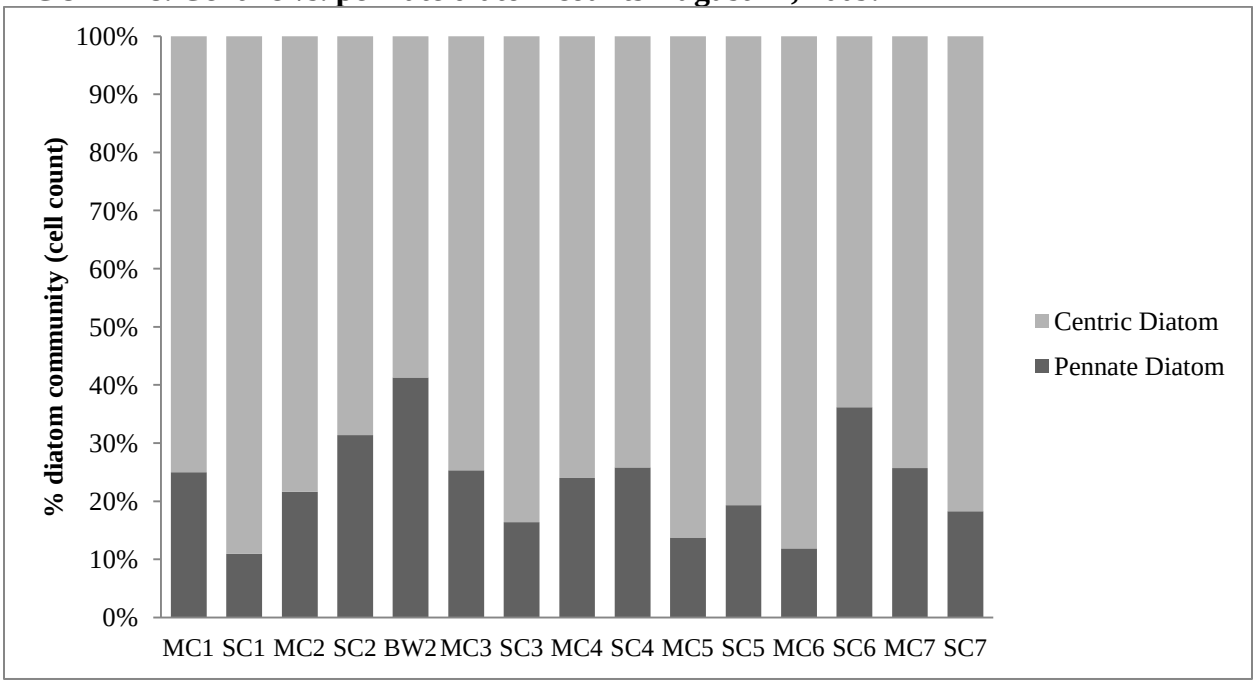


FIGURE 29. Centric vs. pennate diatom counts August 30, 2009.

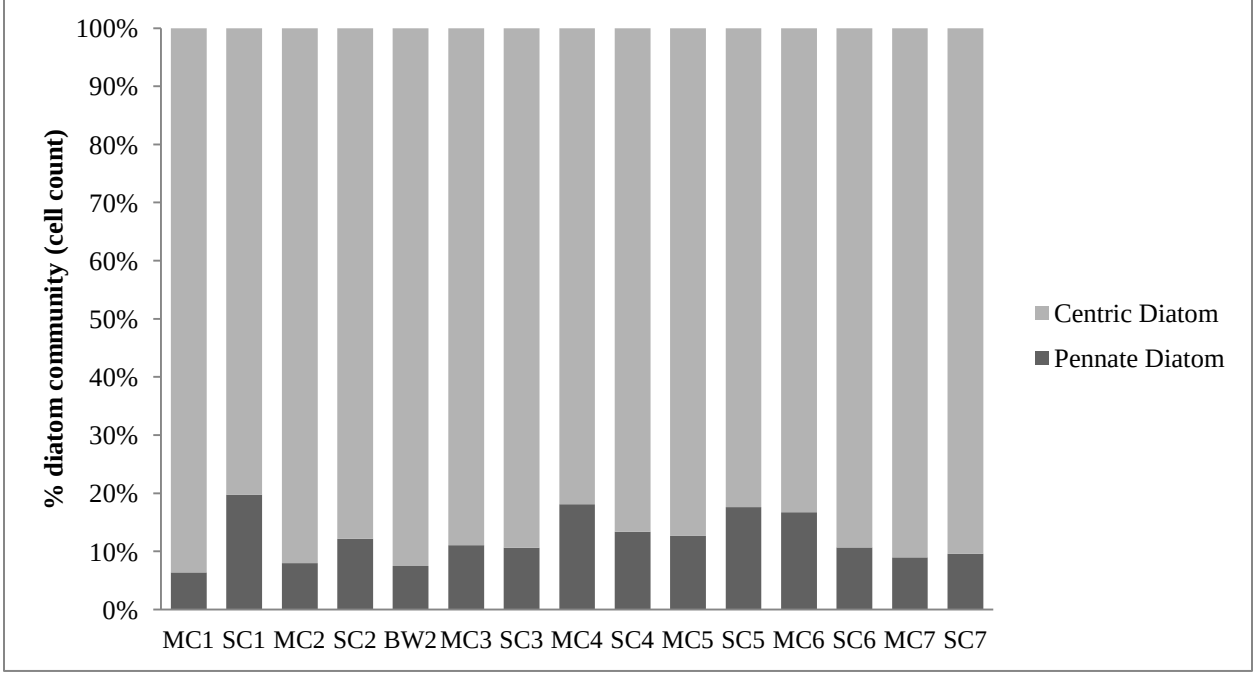


FIGURE 30. Centric vs. pennate diatom counts September 14, 2009.

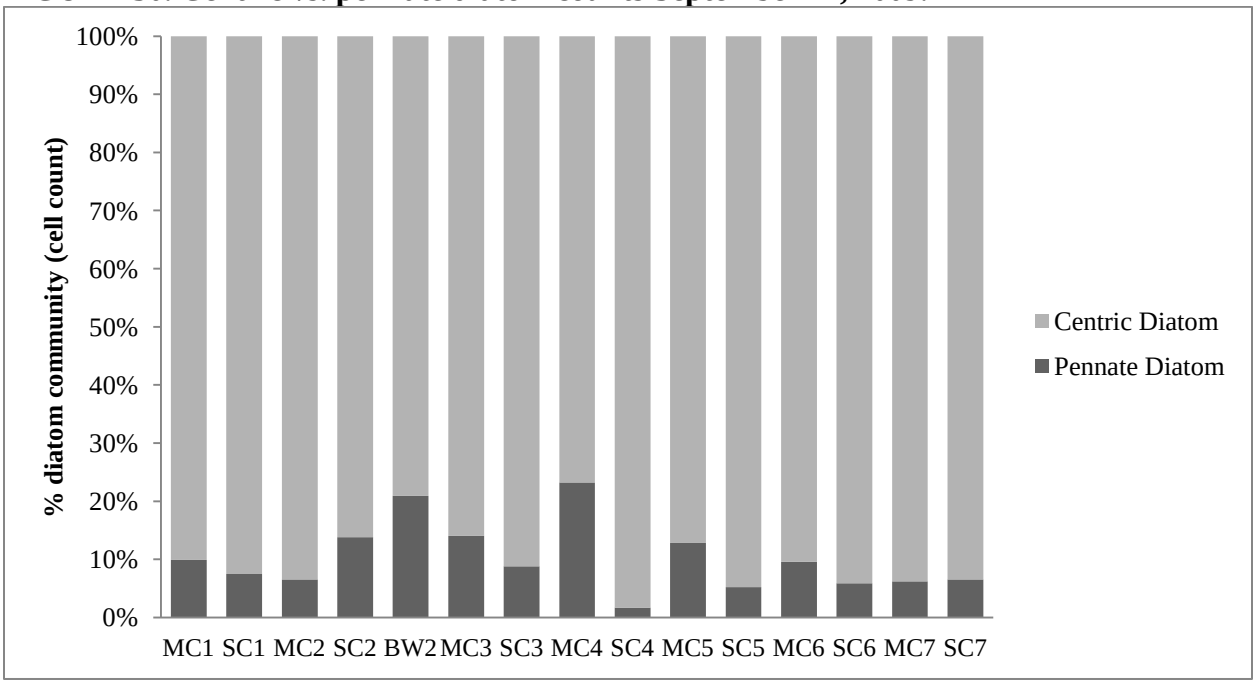


FIGURE 31. Centric vs. pennate diatom counts September 28, 2009.

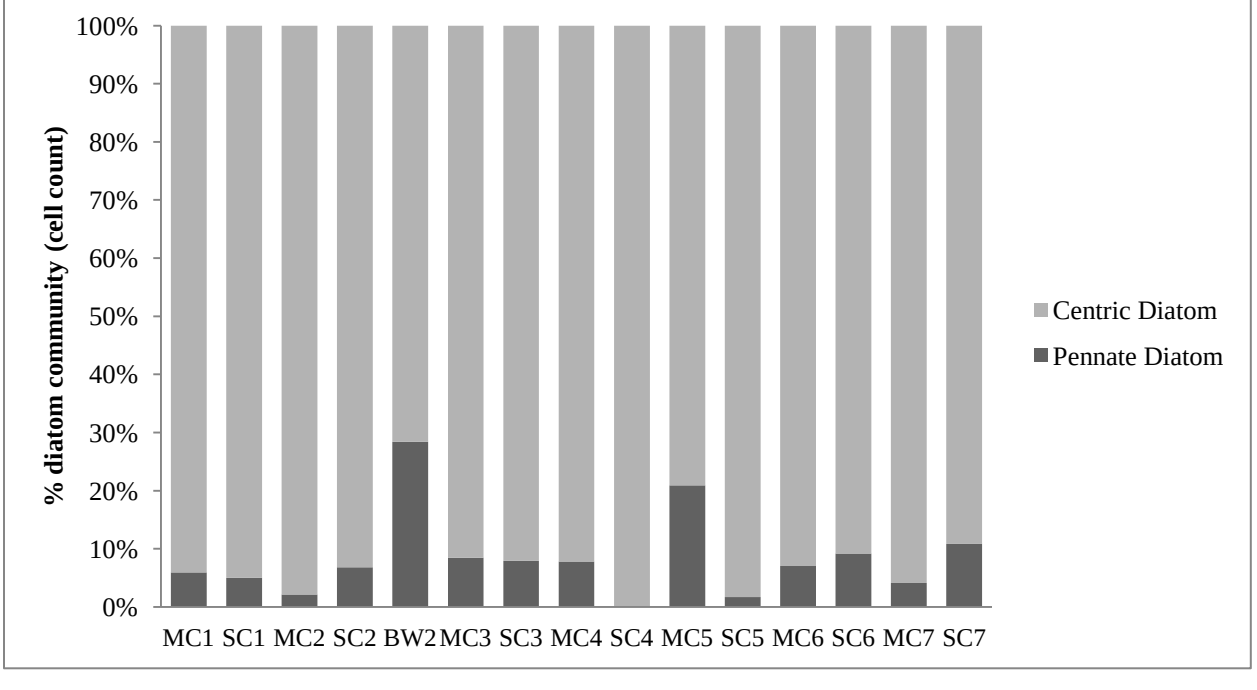


FIGURE 32. Centric vs. pennate diatom biovolume (µm3) June 13, 2009.

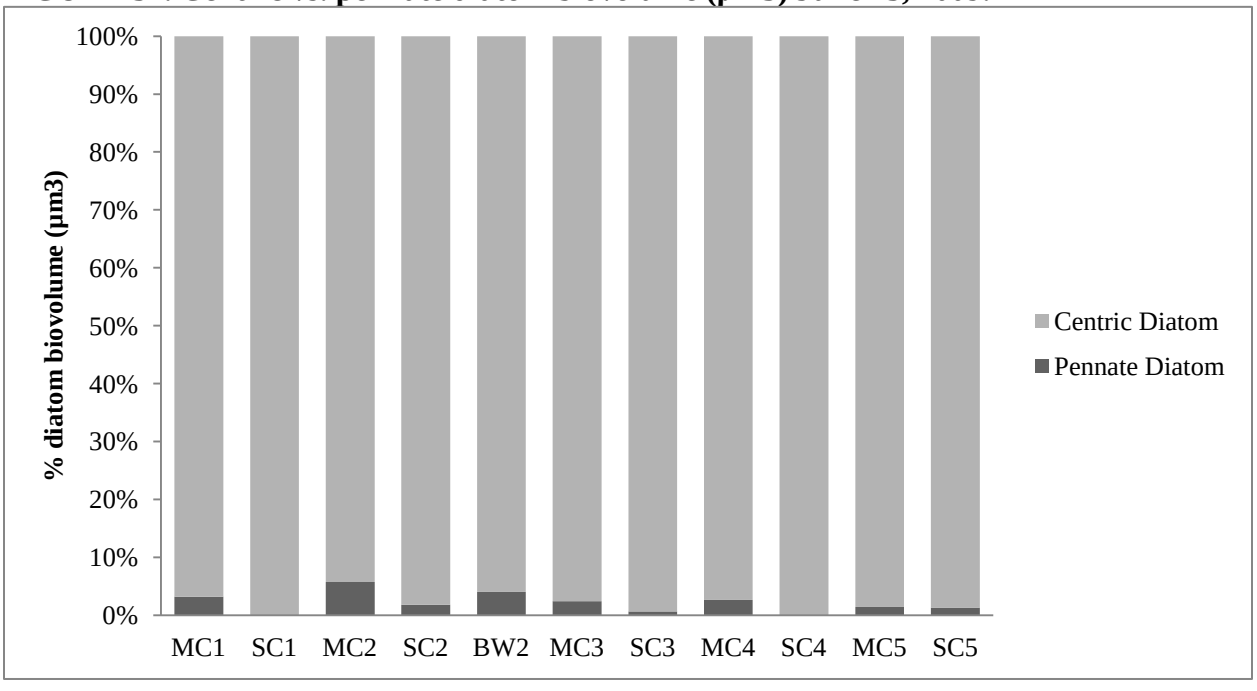


FIGURE 33. Centric vs. pennate diatom biovolume (µm3) July 1, 2009.

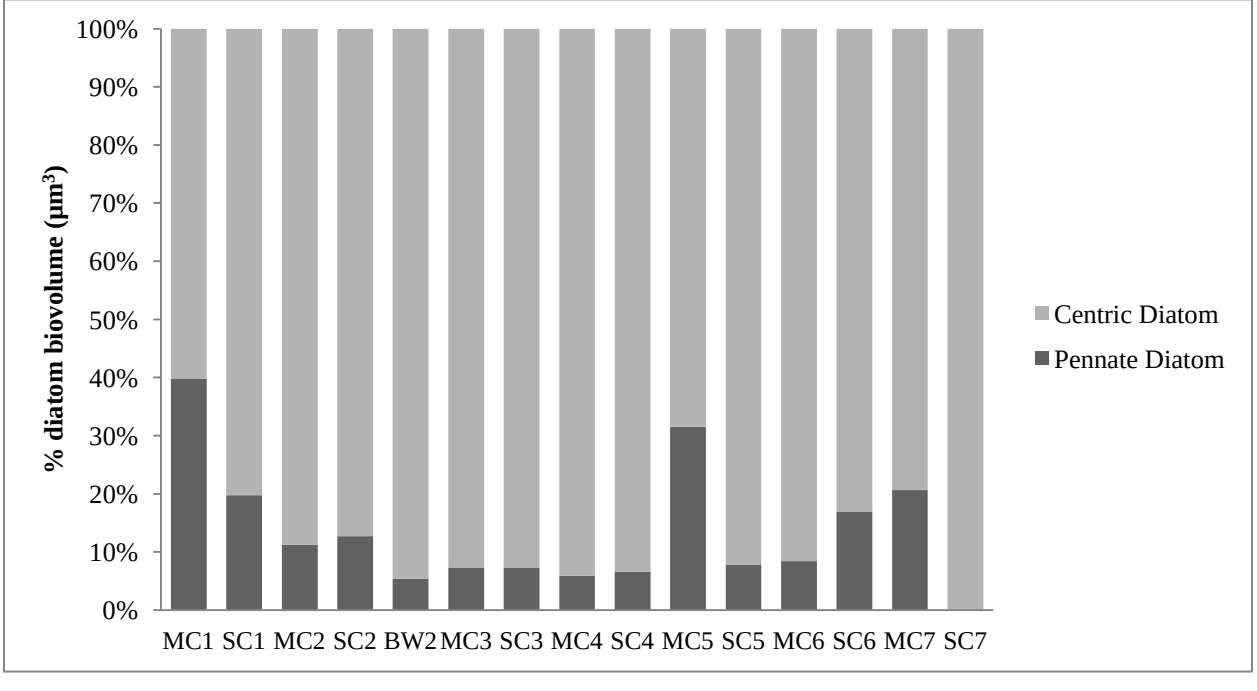


FIGURE 34. Centric vs. pennate diatom biovolume (µm3) July 18, 2009.

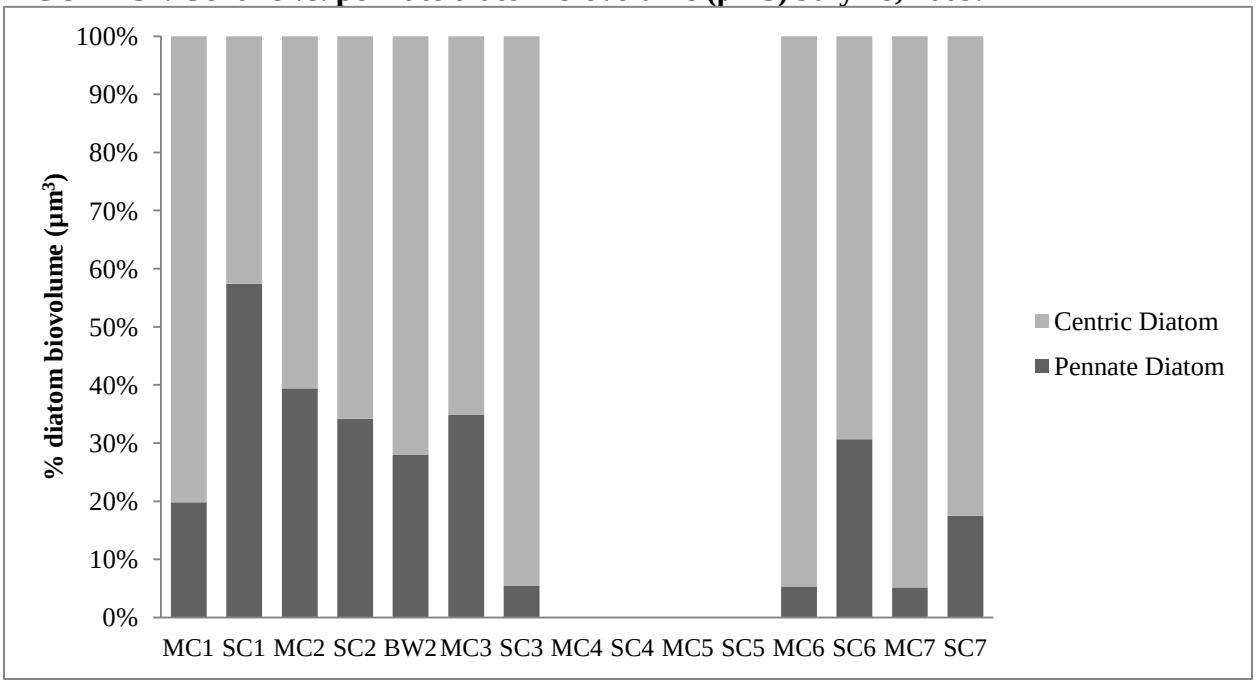


FIGURE 35. Centric vs. pennate diatom biovolume (µm3) August 1, 2009.

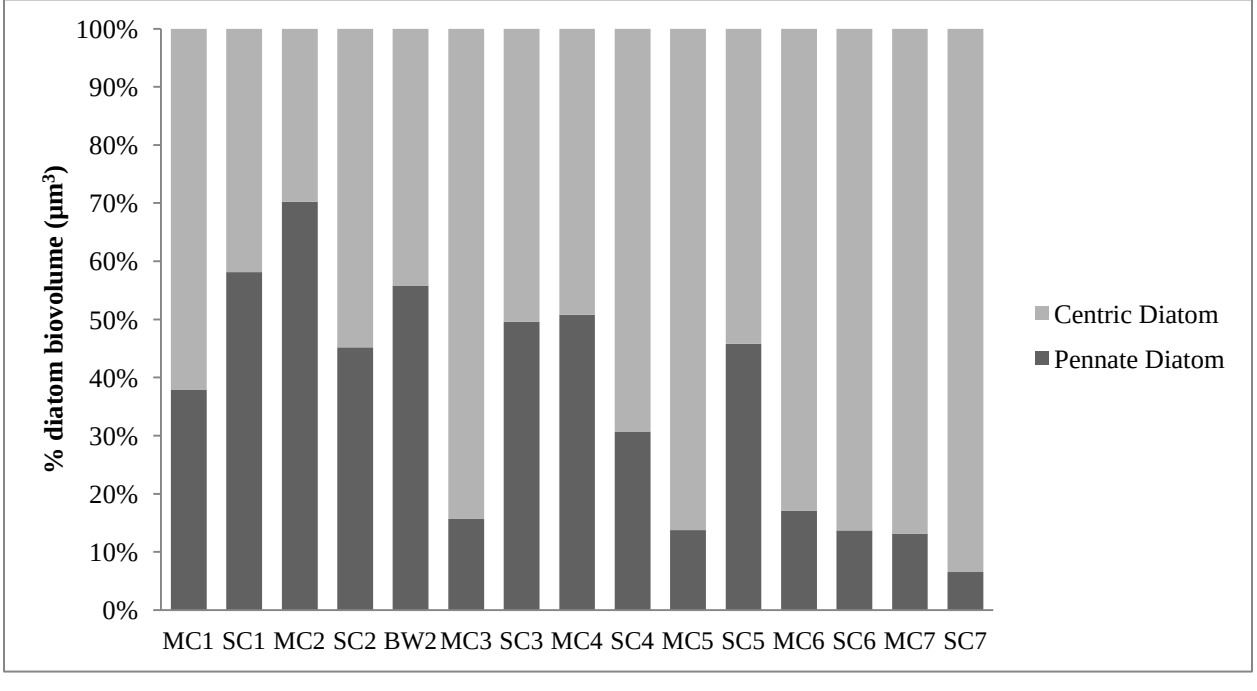


FIGURE 36. Centric vs. pennate diatom biovolume (µm3) August 14, 2009.

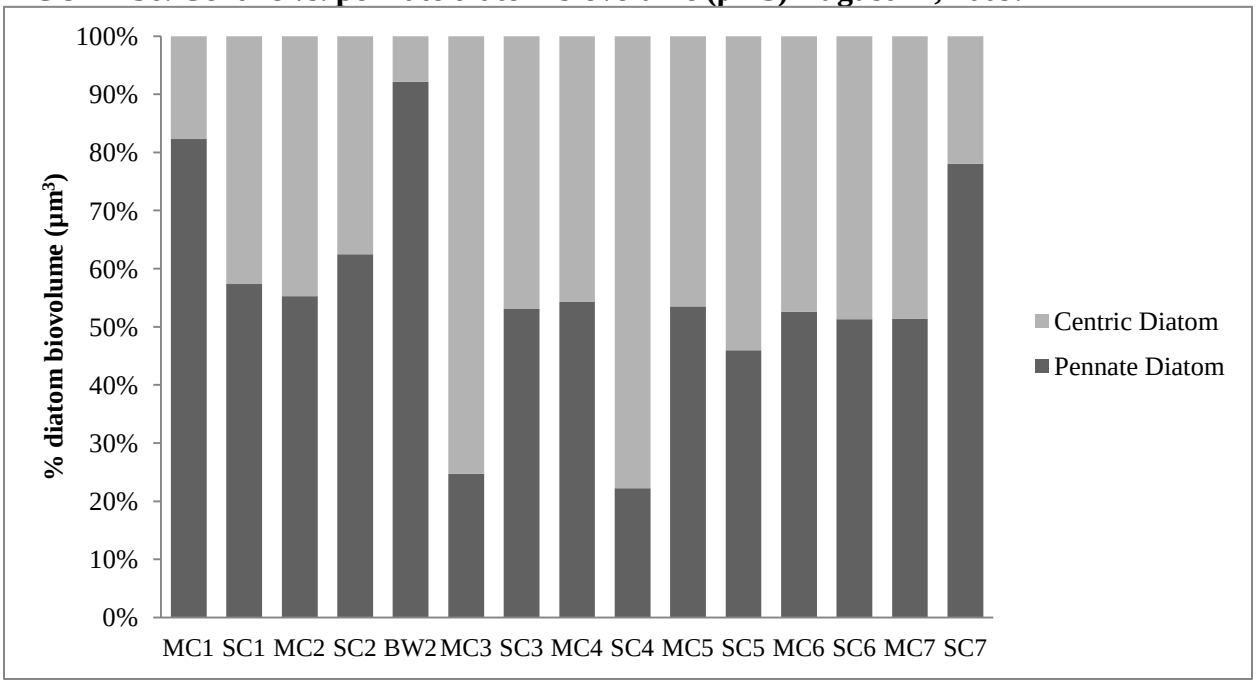


FIGURE 37. Centric vs. pennate diatom biovolume (µm3) August 30, 2009.

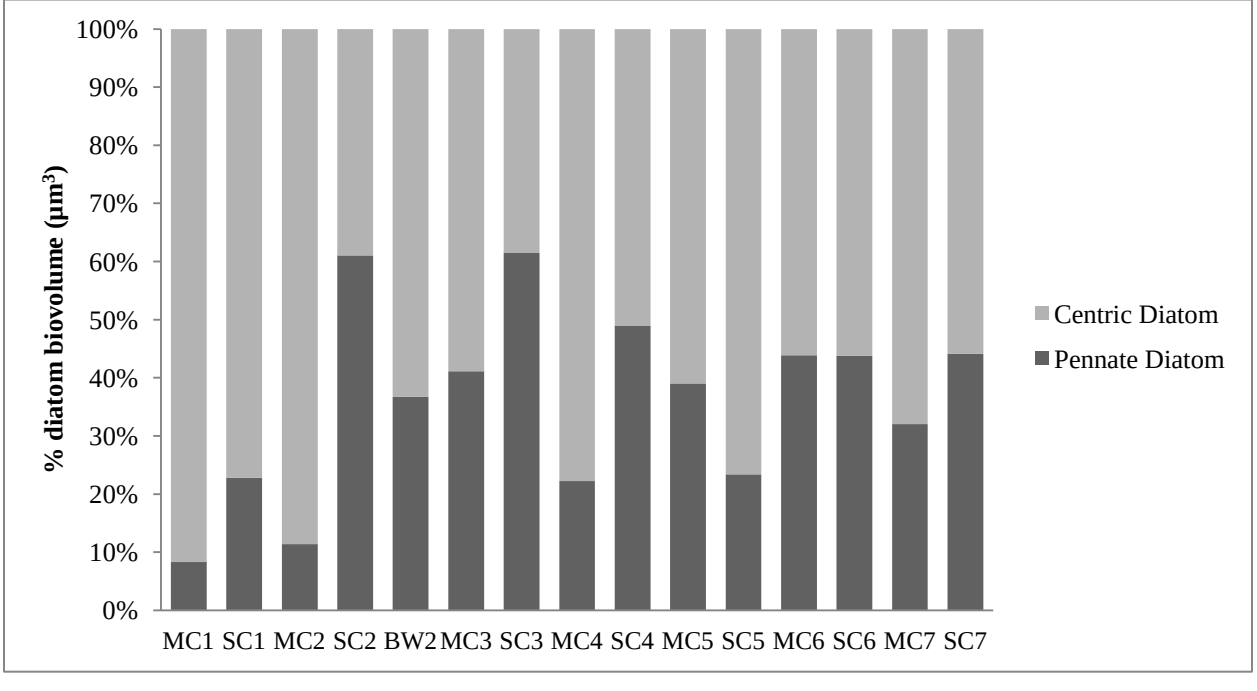


FIGURE 38. Centric vs. pennate diatom biovolume (µm3) September 14, 2009.

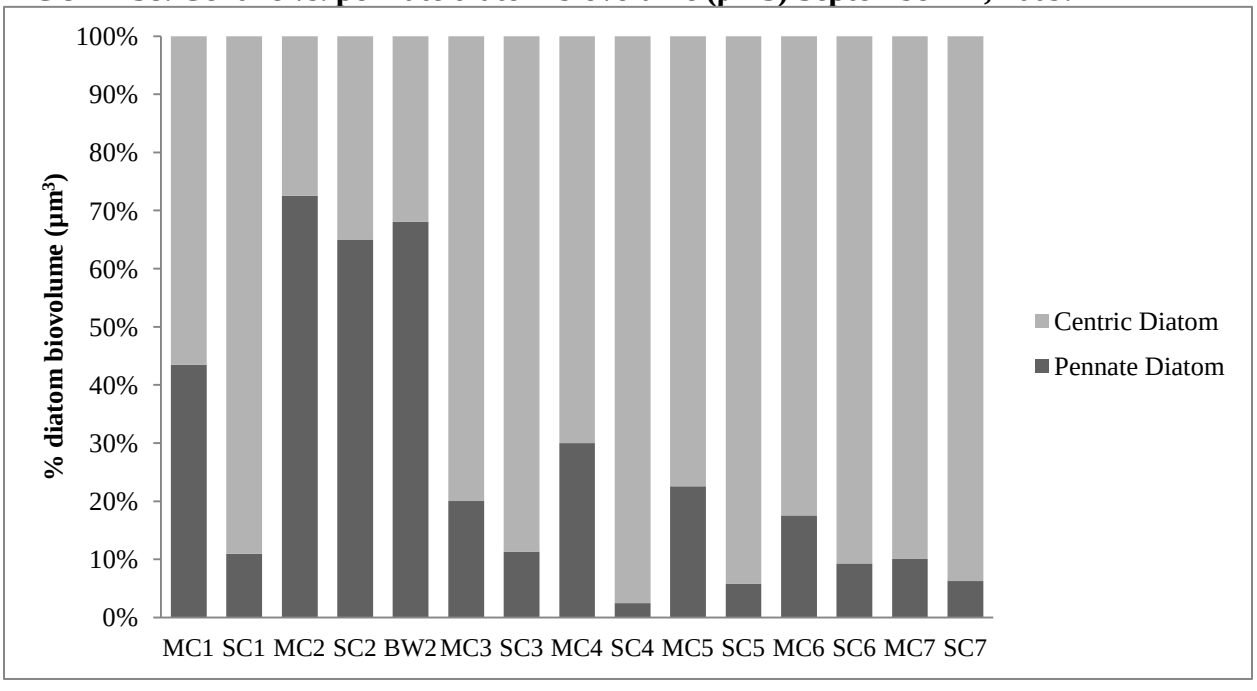


FIGURE 39. Centric vs. pennate diatom biovolume (µm3) September 28, 2009.

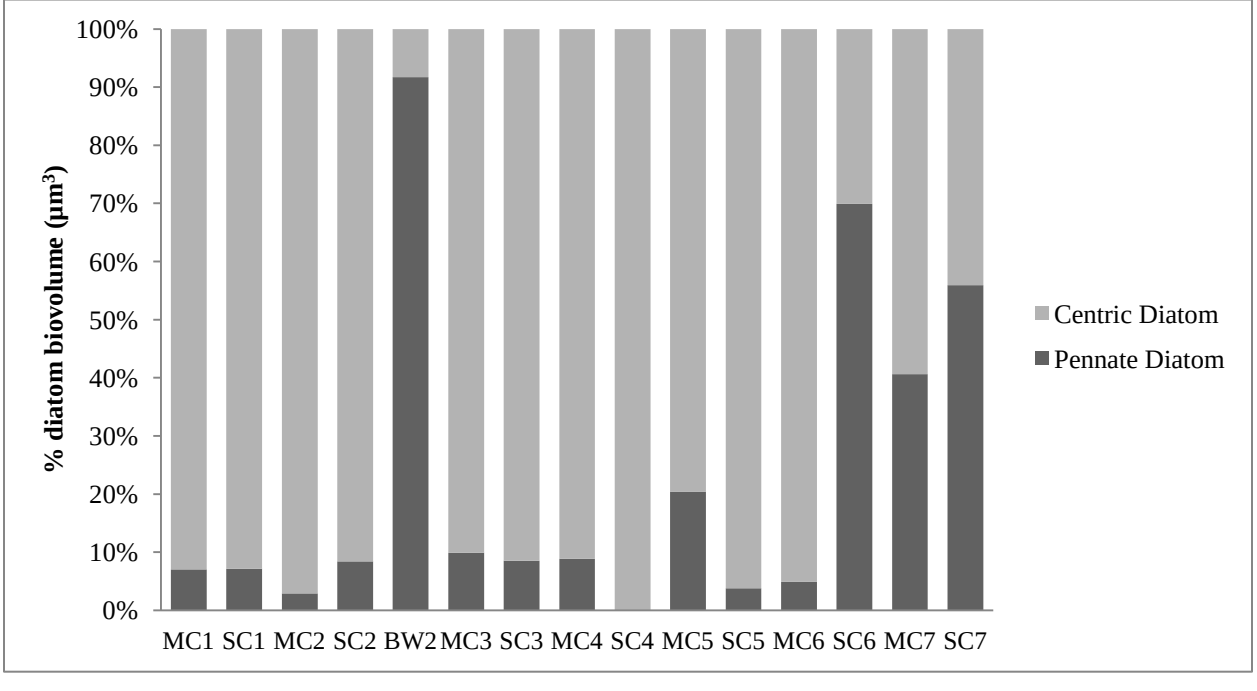


FIGURE 40. Algal community composition by date for 2009; calculated using cell counts.

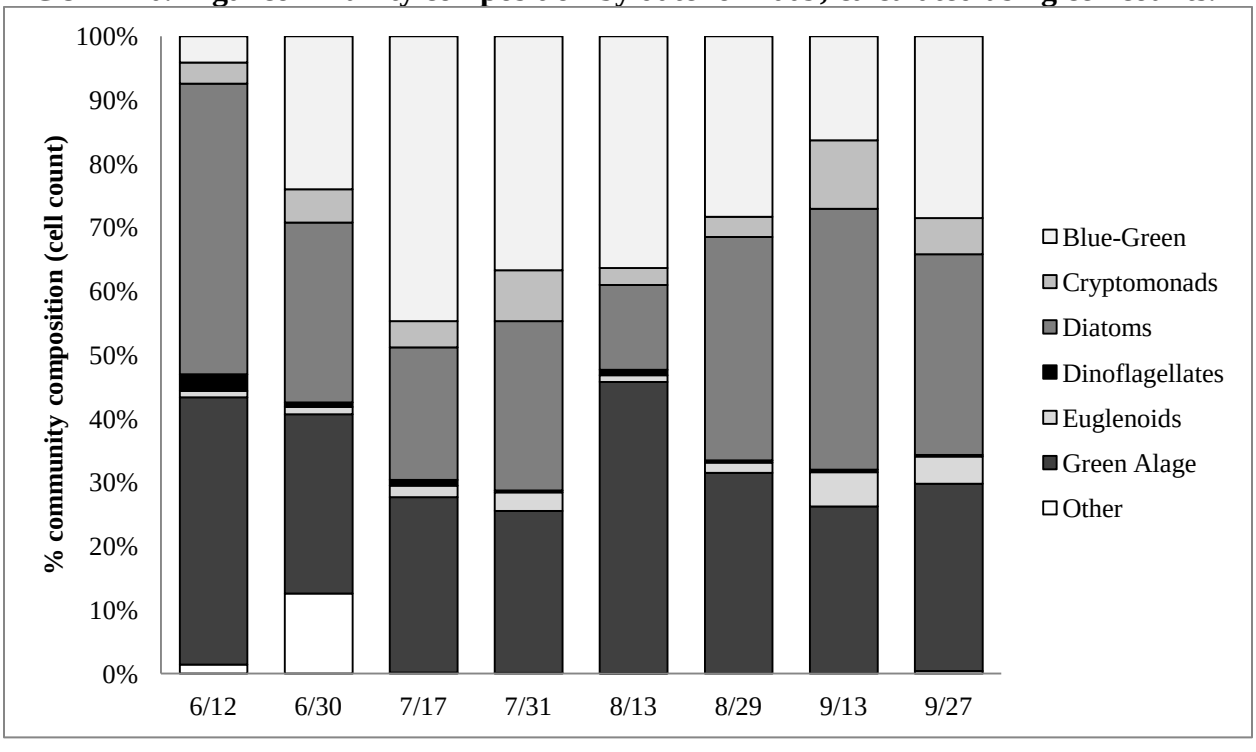


FIGURE 41. Algal community composition by date for 2009; calculated using biovolume (µm3).

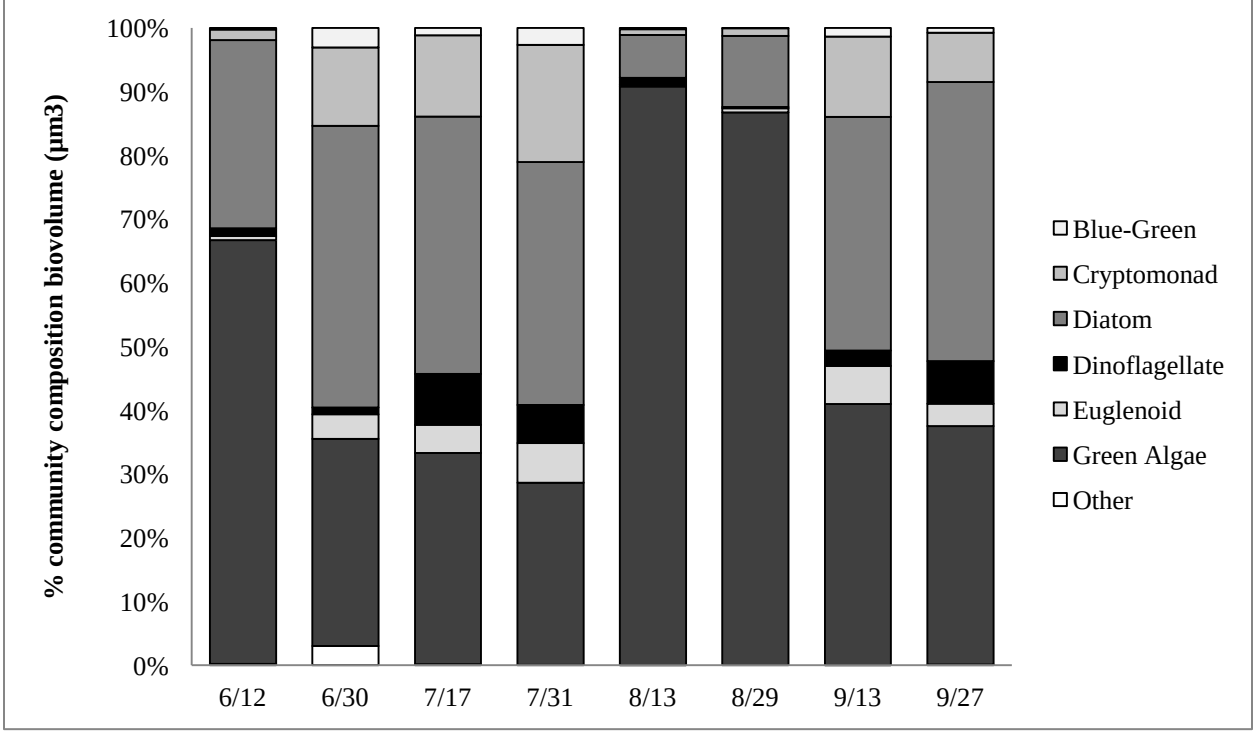


FIGURE 42. S-transformation of the 2007 hydrograph. A time-frequency analysis method called the S-transform was applied to the daily stage time series from 3-Jul to 16-Oct (106 days) for 2007. The line plot at the top of the figure shows the analyzed time series in red. The main plot below the line plot shows the resulting time-period power spectrum linearly scaled to make full use of the color palette. The marginal average of the power spectrum values across time provides the estimate for the periodogram shown to the right of the main plot, linearly scaled to have a maximum value of one for representational purposes. This analysis examines a window of time, with the maximum time period occurring in the middle. The time window is then decreased by one day step-wise, resulting in a triangular figure. Figure and caption provided by Jude Kastens.

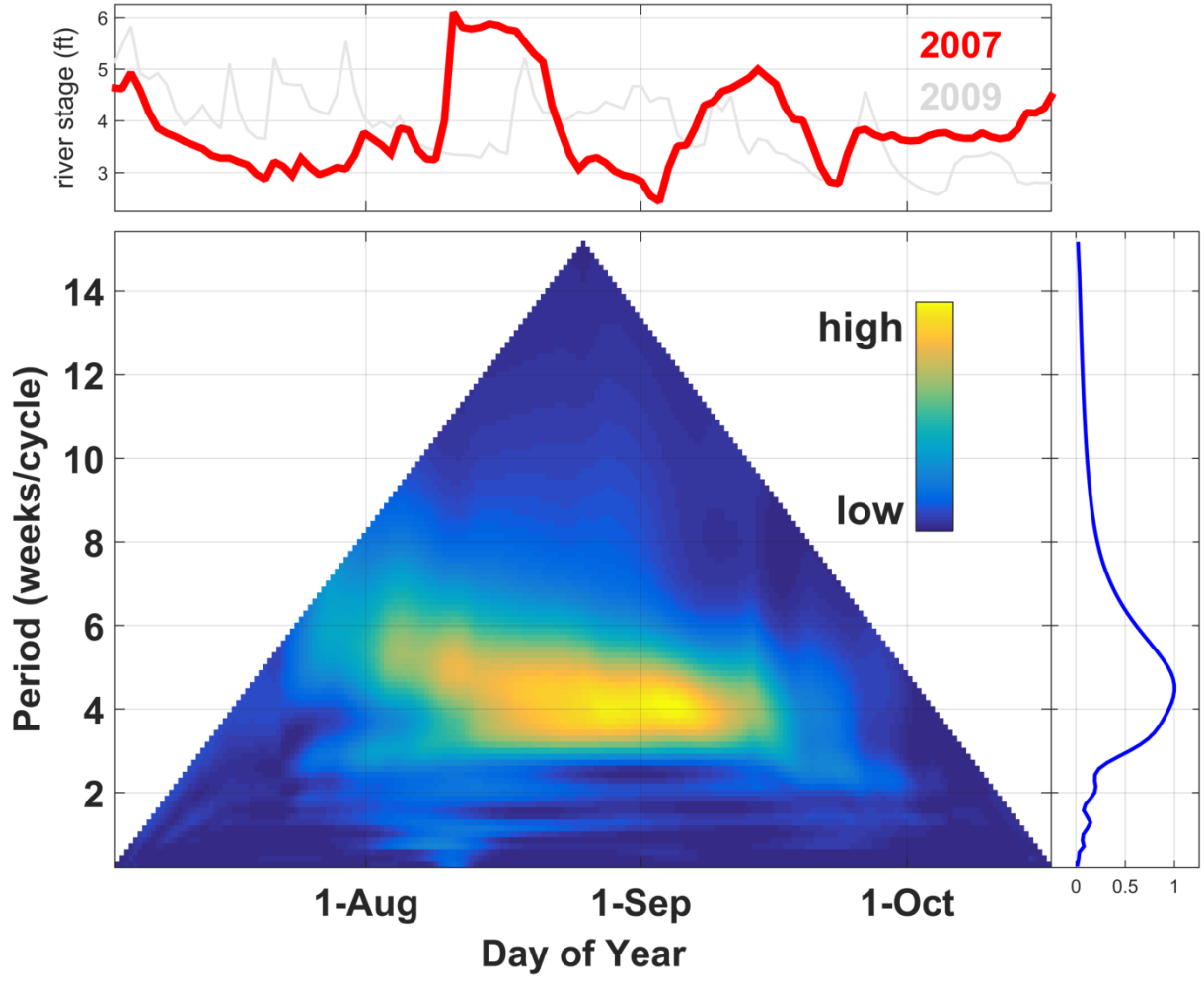


FIGURE 43. S-transformation of the 2009 hydrograph. A time-frequency analysis method called the S-transform was applied to the daily stage time series from 3-Jul to 16-Oct (106 days) for 2007. The line plot at the top of the figure shows the analyzed time series in red. The main plot below the line plot shows the resulting time-period power spectrum linearly scaled to make full use of the color palette. The marginal average of the power spectrum values across time provides the estimate for the periodogram shown to the right of the main plot, linearly scaled to have a maximum value of one for representational purposes. This analysis examines a window of time, with the maximum time period occurring in the middle. The time window is then decreased by one day step-wise, resulting in a triangular figure. Figure and caption provided by Jude Kastens.

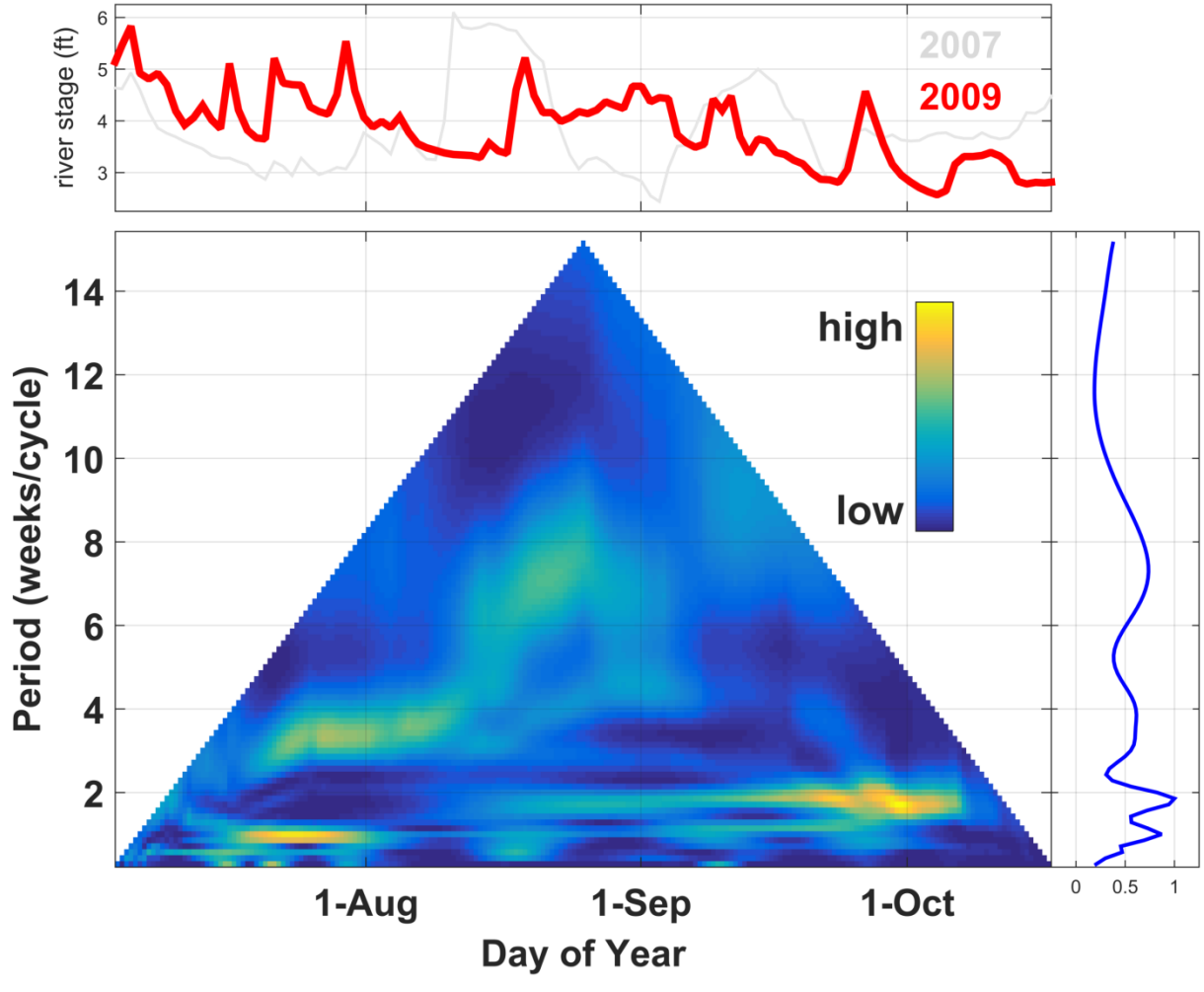


FIGURE 44. Net primary production for longitudinal sites by site and date.

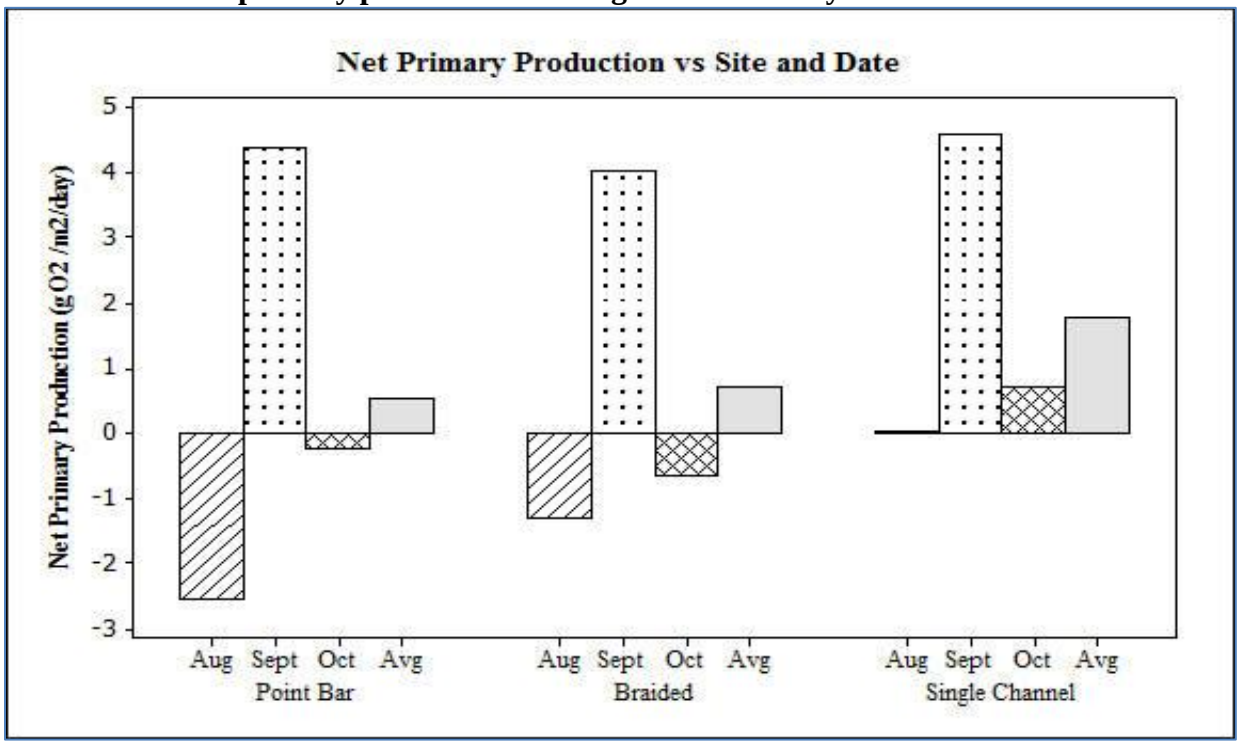


FIGURE 45. P/R values for longitudinal sites by site and date.

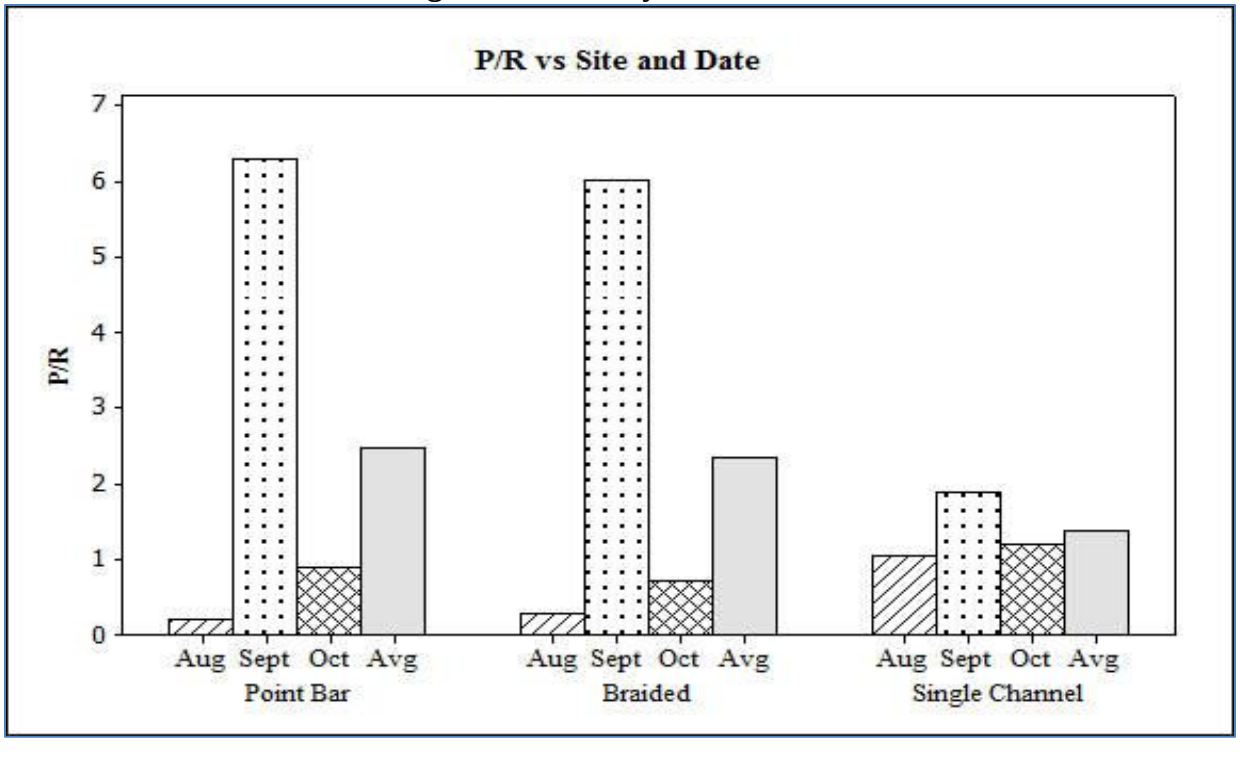


FIGURE 46. Boxplot of respiration for lateral sites by site and date. The bottom of the box is the 1st quartile, the line in the middle of the box is the median value, and the top of the box is the 3rd quartile.

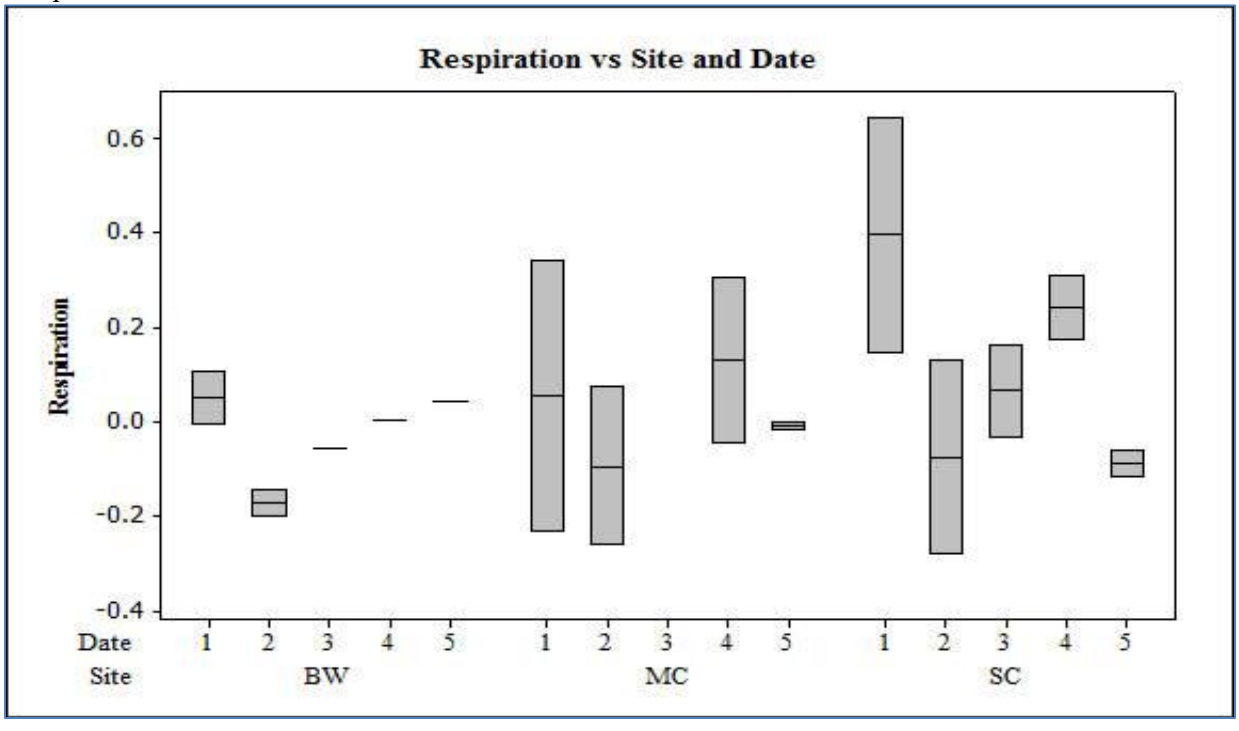


FIGURE 47. Boxplot of gross primary productivity for lateral sites by site and date. Refer to Fig. 46 for details.

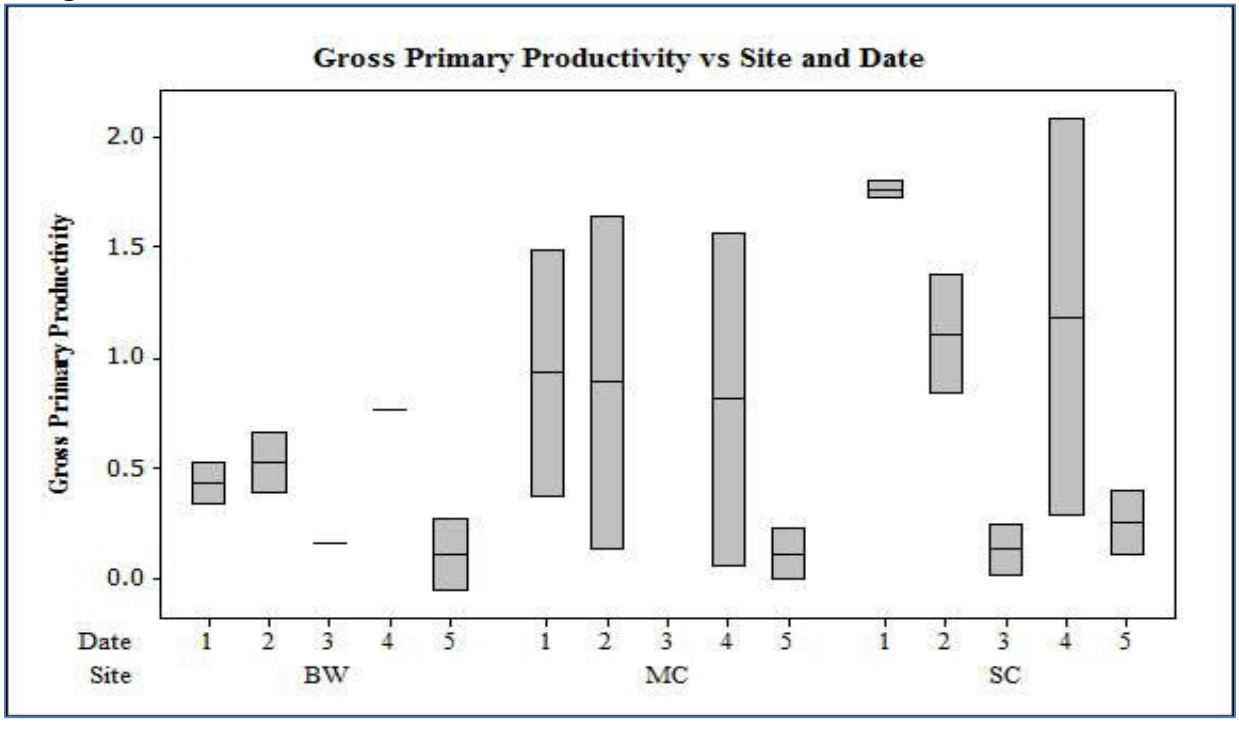
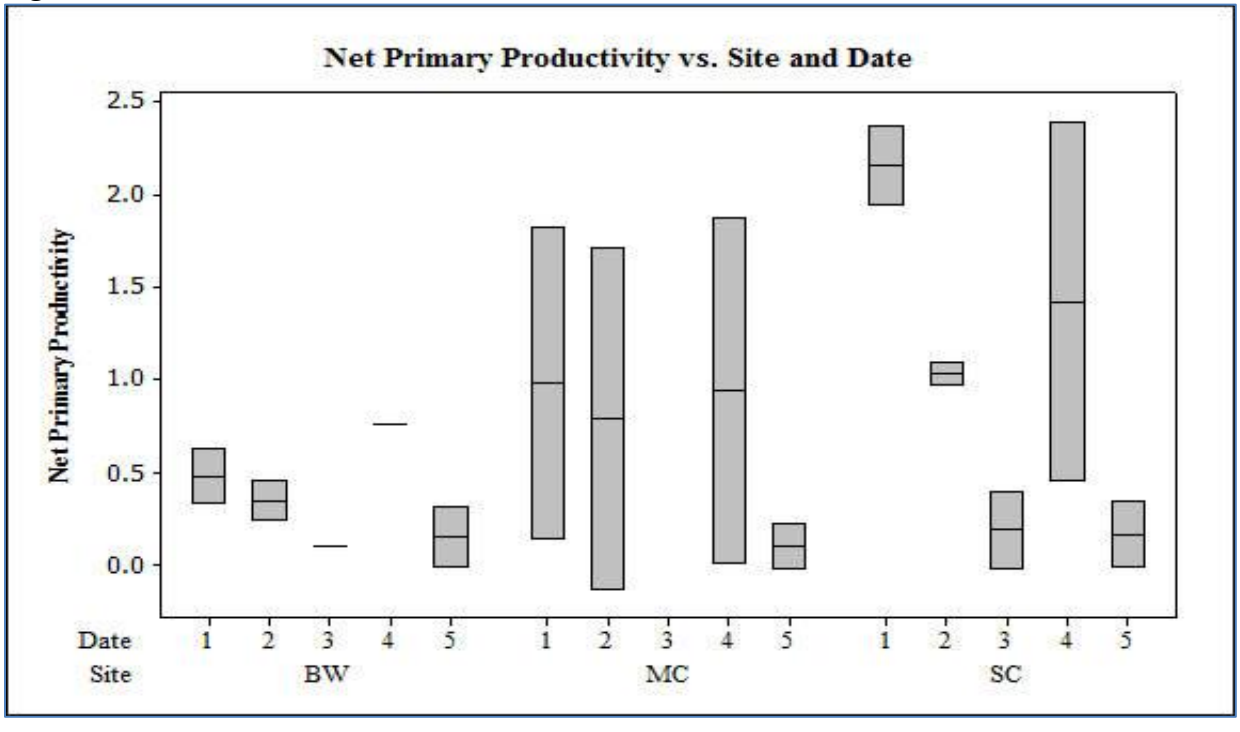


FIGURE 48. Boxplot of net primary productivity for lateral site by site and date. Refer to Fig. 46 for details.



APPENDIX B: TABLES

TABLE 1. 2007 dominant algal group by date and site; calculated by cell count.
BW = backwater, MC = main channel, SC = side channel

	BW	MC	SC
7/14	Green	Diatom	Diatom
7/25	Green/Blue-Green	Green	Green/Blue-Green
8/25	Blue-Green	Green	Blue-Green

TABLE 2. 2007 dominant algal group by date and site; calculated by biovolume (µm3). BW = backwater, MC = main channel, SC = side channel

	BW	MC	SC
7/14	Diatom/Euglenoid	Diatom	Green
7/25	Green	Euglenoid	Green
8/25	Diatom	Green	Euglenoid

TABLE 3. Averages for number of cells, biovolume (µm3), and number of taxa by site, date, and all samples, 2009. All columns value ± standard deviation.

	No. of Cells	Biovolume (μm^3)	No. of taxa
BW2	619 ± 259.4	644639 ± 358341	31 ± 6.31
MC1	524 ± 495	481439 ± 670867	26 ± 8.6
MC2	711 ± 782	1004200 ± 1480127	28 ± 7.08
MC3	846 ± 719	5025183 ± 1.3E+07	28 ± 6.74
MC4	523 ± 498	221409 ± 154900	27 ± 7.16
MC5	520 ± 381	1491567 ± 2982875	28 ± 5.55
MC6	655 ± 563	1670091 ± 3451804	28 ± 5.97
MC7	671 ± 538	1254971 ± 1523426	29 ± 7
SC1	527 ± 536	391046 ± 532656	27 ± 8.07
SC2	532 ± 450	987913 ± 2168769	27 ± 6
SC3	691 ± 629	1836452 ± 4463573	29 ± 7.79
SC4	413 ± 199.7	1415086 ± 2136143	26 ± 7.28
SC5	643 ± 798	513618 ± 754028	26 ± 8.47
SC6	517 ± 341	1117060 ± 2406310	27 ± 6.83
SC7	591 ± 485	670913 ± 969781	25 ± 7.83
6/13	359 ± 103.8	699042 ± 1441333	23 ± 2.879
7/01	314 ± 89.4	147362 ± 72176	25 ± 4.7
7/18	955 ± 533	451839 ± 284685	31 ± 3.142
8/01	467 ± 229.9	265499 ± 180927	27 ± 3.39
8/14	1499 ± 586	5359015 ± 9753662	39 ± 4.13
8/30	775 ± 227.1	2329616 ± 2740863	32 ± 4.13
9/14	247 ± 106.5	264804 ± 379328	22 ± 3.399
9/28	224 ± 91.5	219726 ± 300968	21 ± 3.91
ALL	601 ± 517.2	1262946 ± 4034507	28 ± 6.863

TABLE 4. Dominant algal group and combined diatom and green algae contribution to community composition by date, 2009.

	Cell count		Biovolume	
Date	Dominant group	% Diatom/Green	Dominant group	% Diatom/ Green
6/13	Green/Diatom	88	Green	96
7/01	Green/Diatom/Blue-Green	56	Diatom	77
7/18	Blue-Green	48	Diatom	74
8/01	Blue-Green	52	Diatom	67
8/14	Green	59	Green	98
8/30	Green/Diatom/Blue-Green	67	Green	98
9/14	Diatom	67	Green	78
9/28	Green/Diatom/Blue-Green	61	Diatom	81

TABLE 5. Ecosystem metabolism values for longitudinal sites by date.

Date	Site	Respiration g O_2 /m^2/day	Gross Primary Production g O_2 /m^2/day	Net Primary Production g O_2 /m^2/day	P/R
August	Point Bar	3.19	0.62	-2.57	0.19
September	Point Bar	0.83	5.19	4.37	6.29
October	Point Bar	1.96	1.73	-0.23	0.88
August	Braided	1.79	0.50	-1.29	0.28
September	Braided	0.80	4.84	4.04	6.01
October	Braided	2.14	1.50	-0.64	0.70
August	Single Channel	0.64	0.65	0.02	1.02
September	Single Channel	5.18	9.76	4.59	1.89
October	Single Channel	3.82	4.52	0.70	1.18

TABLE 6. Average ecosystem metabolism values for longitudinal site. All columns value ± standard deviation.

Site	Respiration g O_2 /m^2/day	Gross Primary Productivity g O_2 /m^2/day	Net Primary Productivity g O_2 /m^2/day	P/R
Point Bar	1.99 ± 1.180	2.51 ± 2.27	0.52 ± 3.53	2.46 ± 3.34
Braided	1.58 ± 0.695	2.28 ± 2.38	0.70 ± 2.91	2.33 ± 3.19
Single Channel	3.21 ± 2.33	4.98 ± 4.57	1.77 ± 2.47	1.36 ± 0.463