Seasonal Dynamics and Food Web Interactions of Planktonic Organisms in Platte Lake, Benzie Co., Michigan.

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Objectives:

- Describe the plankton composition and seasonal dynamics of plankton populations in Big Platte Lake, MI during 2005.
- Compare plankton composition and seasonal dynamics in 2005 with composition and dynamics in 2002, 2003, and 2004.
- Describe the planktonic food web of Big Platte Lake, MI, including major feeding pathways.
- Discuss likely cause of late summer foam event in Big Platte Lake.

Methods:

Phytoplankton and zooplankton samples were collected from Big Platte Lake every two weeks in 2005 unless ice conditions made sampling unsafe. Only one set of samples was collected in January, February, March, and October. No samples were collected in December.

MDNR technicians sampled epilimnetic phytoplankton with a 2-cm diameter silicone tube dropped vertically through the upper 30 feet of water where algae are most abundant. The tube sampler was outfitted with a one-way foot valve on the lower end to facilitate sample collection. As the tube was withdrawn from the water, its contents were released into a clean container. Three 250-mL epilimnetic samples were collected from separate locations near the deep hole. MDNR personnel also collected discrete samples from 45, 60, 75 and 90 feet at one location on each sampling date. All algal samples were preserved with Lugol's solution.

MDNR technicians collected zooplankton samples with a 30-cm diameter, 64-µm mesh net. Three vertical net tows were collected from 1 m above the sediments to the surface at separate locations near the deep hole. The net was hauled no faster than 1 m/sec. The contents of each net tow was washed into separate, labeled 250-mL bottles and preserved with formalin.

Phytoplankton samples were examined by placing 10 ml of well-mixed sample into a settling chamber for 24 hours. Algal species were enumerated at 200-400x magnification using a Zeiss inverted compound microscope. All colonial and large solitary algal species in the sampling chamber were enumerated at 200x magnification (Table 1). Cell counts for large algal species were multiplied by 100 to get cells/liter. Small algal species in the sampling chamber were enumerated at 400x magnification using a sub-sampling technique (Table 1). All algae were counted within a rectangular field of view. Multiple fields of view were examined until the total algal count for all dominant species exceeded 100. Cell counts for small algal species were divided by the proportion of the sampling chamber examined (area of all rectangular fields/area of chamber) and multiplied by 100 to get cells/liter. For some colonial and filamentous species (Table 1), it was easier to measure colony length or area and apply a correction formula to estimate the number of cells.

Table 1: Counting procedures used for algal types and genera found in Big Platte Lake, Benzie Co., Michigan.

Algae type	**Counting Procedure**	**Algal Genera**
Large/Colonial	magnification = 200 count entire chamber cells/L = counts * 100	*Stephanodiscus, Cyclotella, Cocsinodiscus, Cymatopleura, Amphipora, Asterionella, Diploneis, Pleuro/Gyrosigma, Rhizosolenia, Cymbella, Tabellaria, Pediastrum, Coelastrum, Mugeotia, Zygnema, Spirogyra, Gymnodinium, Peridinium, Chrysophaerella, Ceratium*
Small	magnification = 400 count fields cells/L = counts ÷ prop. chamber * 100	*Synedra, Achnanthes, Navicula Hantschia, Nitschia, Pinnularia, Mastigloia, Scenedesmus, microgreens, Golenkinia, Closterium, Mallamonas, Cryptomonas, Dinobryon, Epipyxis*
Filament	magnification = 200 count entire chamber counts = length * 5.5 cells/L = counts * 100	*Fragilaria*
Filament	magnification = 200 count entire chamber counts = length * 1.0 cells/L = counts * 100	*Melosira*
Colony	magnification = 200 count entire chamber counts = area * cells/area cells/L = counts * 100	*Microcystis*

Table 2: Shapes and geometric formulas for select algal taxa found in Big Platte Lake, Benzie Co., Michigan. Symbols: D = diameter, L = length, W = width, H = height.

	Fragilaria	*Melosira*	*Scenedesmus*	*Microcystis*	*Dinobryon*
Cell shape	elliptic prism	cylinder	prolate spheroid	sphere	ellipsoid
Formula	$L*W^*H*\pi/4$	$H*D^2*\pi/4$	$L*W^2*\pi/6$	$D^3*\pi/6$	$\frac{1}{2}(\frac{2}{3}L*W*T)*\pi/6$ + $\frac{1}{2}(\frac{1}{3}L*W*T)*\pi/6$

Algal biovolume was calculated as the product of cell density and average cell volume. Average cell volume was determined by measuring length, width, and depth of 20 randomly selected cells from 2003 samples and applying a published geometric formula that closely approximated the shape of each taxon (Table 2). The biovolume of colonial green algae was calculated as the product of colony density and average colony volume. Cell volumes (μm^3) were multiplied by 10^{-9} to give biovolume (μl). If one assumes that algal cell density is approximately 1.0 g/ml, biovolume (µl) is equivalent to dry biomass (mg). This assumption is good for green algae and cyanobacteria. It severely underestimates diatom biomass.

Zooplankton species were enumerated by counting 5-ml sub-samples in a Bogorov tray at 25x magnification using a Leica stereomicroscope. Zooplankton biomass was calculated as the product of species density and average individual dry weight. Average individual dry weights of copepod (calanoid, cyclopoid) and cladoceran (*Bosmina*, *Daphnia*, and *Holopedium*) species was determined by measuring 30 individuals of each taxon and applying a published length-weight regression to the average length (Culver et al. 1985). Average individual dry weights of rotifer species (*Polyarthra*, *Keratella*) found in Lake Michigan (Makarewicz et al. 1994) were used to estimate average individual dry weights in Big Platte Lake. Average individual dry weights of *Alona* and *Chydorus* in Lake Michigan (M. Edwards, unpublished data) were used estimate dry weight of animals found in Big Platte Lake. Average individual dry weight of *Leptodora* in Big Platte Lake was estimated by applying a published length-weight regression (Manca et al. 2000) to a 6 mm animal.

Results:

Phytoplankton:

Small green algae, flagellates, and diatom species dominated the phytoplankton in the epilimnion of Big Platte Lake in 2004. The most common green algae were *Scenedesmus* and unidentified colonial and single-celled microgreens. The most common flagellates were *Dinobryon*, a colonial chrysophyte, and two cryptomonads (*Cryptomonas*, *Chroomonas*). In past years, the large *Cryptomonas* was referred to as a "Euglenoid." Common diatoms included *Asterionella* in the winter, spring and fall; *Melosira, Fragilaria,* and *Navicula* (and similar taxa) during spring and fall mixing; and centrics during the summer. Blue-green algae were represented by the colonial genera *Microcystis* and *Merismopedium*.

Planktonic algae were most abundant in June and August 2005 when peak cell counts were 3.8 and 4.8 million cells per liter, respectively (Fig. 1c). Spring and summer phytoplankton abundance maxima have been a consistent feature of Big Platte Lake since 2002, even though the dates of peak abundance have varied slightly from year to year. In 2003, spring and summer maxima occurred during the same months as in 2005; whereas in 2004, the spring maximum occurred in April rather than June (Fig. 1). In 2002, the spring abundance peak occurred in early June but the summer peak was delayed until early September.

Average epilimnetic cell counts were 3 times higher in 2005 (1,560,000 cells per liter) than in past years (2003: 470,000 cells per liter; 2004: 550,000 cells per liter). In part, high cell counts in 2005 can be attributed to increased lake productivity. Mean chlorophyll *a* concentration has increased 25% between 2003 and 2005 (Fig. 2). It is also likely that cell counts increased in 2005 as a result of improved resolution and technical precision during the counting process. In 2005, small cells were counted at 200x magnification rather than 100x magnification.

There was a distinct seasonal succession of algal taxa in Big Platte Lake during 2005. Small flagellates were numerically dominant under the ice in winter (Fig. 1c). Small green algae shared dominance with growing populations of flagellates and diatoms in the spring, and became numerically dominant in June and August. Colonial blue-green algae were present in modest abundance between July and October. The seasonal succession in 2005 differed from that in 2003 and 2004 when diatoms were numerically dominant in April, August, and October (Fig. 1).

Although small green algae were numerically dominant in Big Platte Lake during 2005, diatoms contributed substantially to algal biomass (Fig. 3c). Diatom cells are much larger than the cells of most other algal taxa in Big Platte Lake. Only the dinoflagellate *Ceratium* has larger cells. Diatoms comprised greater than 50% of algal biomass in the epilimnion (0-30 ft.) during winter, spring and mid-summer (Fig. 3c). Flagellates and green algae were so abundant in the epilimnion during most of the year that their contribution to total algal biomass was significant despite their small size. Because we disregarded the glass frustule (cell wall) when calculating diatom biomass, we underestimated the contribution of diatoms to total biomass.

In 2005, algal biomass in the epilimnion of Big Platte Lake ranged from 0.09 to 2.74 mg/L, and mean annual algal biomass was 0.82 mg/L. Algal biomass was low (< 0.5 mg/L) during winter, spring, and fall 2005 (Fig. 3c). Centric diatom blooms were responsible for algal biomass peaks in late July. Microgreens were responsible for biomass peaks in late July and November. In 2003 and 2004, mean algal biomass was much lower (0.25, 0.22 mg/L, respectively) than in 2005. Diatoms dominated algal biomass during spring, summer and fall except during August 2003 when algal biomass was dominated by blue-green algae (Fig. 3).

The distribution of algal biomass with depth reflects the mixing status and thermal properties of Big Platte Lake. In January, algal biomass was greatest near the surface indicating that the lake was not mixing (Fig. 4). A layer of ice most likely covered Big Platte Lake restricting mixing and light levels so that only small, mobile green algae could grow under the ice. Between April and June, Big Platte Lake alternated between periods of mixing and stratification. During mixing periods, algal biomass was similar at all depths (Fig. 4, April 28-May 25), and heavy diatoms were brought to the surface by the moving water. During stratified periods, algal biomass varied with depth (Fig. 4, June 8). Small green algae and flagellates become abundant in the warm epilimnion and heavy diatoms and colonial blue-greens sink toward the bottom. On June 22, it is likely that Big Platte Lake became mixed after a period of stratification. Algal biomass was similar throughout the water column. Between July and September, algal biomass was greatest near the surface indicating that the lake was stratified (Fig. 4). Green algae, flagellates and blue-green algae grew well in the warm surface waters. In late July, there was a *tremendous* centric diatom bloom after which the diatoms settled toward the bottom (see diatom peak at 75 ft.). In November, algal biomass was similar at all depths, indicating that Platte Lake had once again become mixed.

Zooplankton:

The zooplankton community of Big Platte Lake includes 5 copepod taxa (*Diacyclops thomasi*, *Mesocyclops edax*, *Diaptomus* spp., *Epischura lacustris*, and harpacticoids), 9 cladoceran taxa (*Bosmina*, *Eubosmina*, *Ceriodaphnia*, *Diaphanosoma*, *Daphnia*, *Holopedium*, *Sida*, *Chydorus*, *Leptodora*) and many rotifer species. Cyclopoid copepods (both naupliar and copepodid stages) and the cladoceran *Bosmina* were the most common microcrustaceans in 2005. *Polyarthra* and *Keratella* were the most common rotifers.

Planktonic crustaceans and rotifers were most abundant during summer 2005 (Fig. 5c). Peak crustacean and rotifer densities were 73 and 121 animals per liter, respectively, on 22 June. Rotifers were 2-3 times as abundant as crustacean plankton in 2005. Large numbers of copepod nauplii were present in early June and early August (Fig. 5c). Juvenile and adult copepods were most abundant after the first nauplii peak in June. Cladocerans and rotifers exhibited a single dominant abundance peak in June.

Zooplankton abundance and season dynamics have changed during the past 3 years. Crustaceans were most abundant in 2002 (peak = 166 per liter) and 2003 (peak = 142 per liter) and least abundant in 2004 (peak = 35 per liter). Crustaceans exhibited a single period of high abundance in all years; however, that period began one month earlier (May) in 2002 and 2003 than in 2004 and 2005 (Fig. 5). Rotifers were also most abundant in 2002 (peak = 939 per liter) and 2003 (peak = 552 per liter) and least abundant in 2004 and 2005 (peak = 122 and 121 per liter). Rotifers exhibited three abundance peaks (April, June, and October) and in 2002, two abundance peaks (May and August) and in 2004, but only one abundance peak (June) in 2003 and 2005.

There was a distinct seasonal succession of zooplankton taxa in Platte Lake in 2005. Cyclopoid copepods (nauplii and copepodids) dominated the crustacean plankton in the winter and spring but shared dominance with the cladocerans between June and October (Fig. 5c). *Daphnia* replaced *Bosmina* as the dominant cladoceran in July, but *Bosmina* became dominant once again in August. Rotifers were numerically dominant throughout the year, but particularly in June.

In 2005, zooplankton biomass in Big Platte Lake ranged from 2.3 to 164 μg/L, and mean annual zooplankton biomass was 33.0 μg/L. Zooplankton biomass was lowest (< 20 μg/L) in the winter, spring, and fall (Fig. 6c). Although rotifers and copepod nauplii were numerically dominant during most of the year, they only comprised a small portion of total zooplankton biomass in 2005. Juvenile and adult copepods dominated zooplankton biomass in winter, spring and fall, whereas large-bodied cladocerans dominated zooplankton biomass during the summer (Fig. 6c).

The mean abundance and seasonal pattern of biomass varied between years in Big Platte Lake. Mean zooplankton biomass was higher in 2003 (64 mg/L) than in 2004 and 2005 (34 and 33 mg/L, respectively). Zooplankton biomass exhibited two dominant peaks in 2003 and 2004, but only one dominant peak in 2005 (Fig. 6). In all 3 years, cladocerans were responsible for a biomass peak in June. In 2003, juvenile and adult copepods created a second biomass peak in May. In 2004, cladocerans created a second biomass peak in July.

Discussion:

Plankton Food Web

Planktonic organisms in Big Platte Lake include bacteria, protozoans, algae, rotifers, and crustaceans. Bacteria and protozoans interact closely in a "microbial food web". Bacteria ingest organic molecules dissolved in lake water and protozoans eat the bacteria. Algae, rotifers, and crustacean plankton interact with one another, and with larger invertebrates and fish, in a traditional grazing food web (Fig. 7). The Big Platte Lake food web has remained unchanged since 2002. No unique or exotic plankton species were discovered in 2005.

Algae (phytoplankton) constitute the basis for the grazing food web in Big Platte Lake (Fig. 7). Algae use photosynthetic pigments to acquire energy from the sun. They use this energy to create sugars, which are eventually stored as starch or oil. Heavy algal taxa such as the diatoms are abundant during spring and fall overturn when the lake is mixed, top to bottom, by the wind. If the overturn period is long, diatoms can become quite abundant. Overturn lasted until late May 2003 but was over in early May 2004. Consequently, diatoms exhibited a prominent abundance and biomass peak in 2003 but not in 2004 (Figs. 1,3). In 2005, mixing was delayed until late May, and consequently, diatoms did not become abundant until early June.

Periods of strong mixing are often indicated by the presence of bottom-dwelling (benthic) diatoms in plankton samples. Large benthic diatoms such as *Cymatopleura* and *Gyrosigma* are often present in surface and mid-water samples collected during spring and fall mixing periods (May, November). Interestingly, these large benthic diatoms are also present in water samples collected in mid-summer (late July-early August). This suggests that Big Platte Lake undergoes significant mixing in mid-summer and may be considered a polymictic lake.

When Big Platte Lake is not mixed, it stratifies into warm surface and cool deep-water layers. Heavy diatoms sink into the hypolimnion and lighter phytoplankton taxa such as green algae and flagellates become abundant (see Fig. 4, July 13 and July 27). Small green algae and flagellates thrive during the spring and early summer when epilimnetic nutrients (nitrogen and phosphorus) are plentiful. During calm periods in late summer, epilimnetic nitrogen concentrations become low. Colonial blue-green algae become abundant because they can tolerate low nitrogen concentrations and have gas vacuoles that allow them to float near the surface. Added phosphorus during the late summer can enhance the growth of blue-green algae.

When diatoms, flagellates and green algae are abundant in Big Platte Lake, populations of herbivorous zooplankton (rotifers, copepod nauplii, and cladocerans) increase. Nauplii and rotifers are small (80-300 μm) and can only ingest single celled or small colonial green algae and flagellates (Fig. 7). Cladocerans such as *Bosmina* and *Daphnia* are large (400-2500 μm) and can ingest diatoms as well as small green algae and flagellates. Because they can eat a wider range of food sizes, cladocerans may out-compete rotifers and nauplii for food in June when all algal types are abundant.

Planktonic herbivores in Big Platte Lake are most abundant when densities of green algae and flagellates are high. Peak rotifer abundance coincided with green algae densities during each year of this study (compare Figs. 1 and 5). Peak cladoceran abundance coincided green algae peaks in 2003 and 2005 but also with a June flagellate peak in 2004. Rotifers and cladocerans reproduce asexually and their populations can increase quickly when food is abundant. Copepods reproduce sexually and rarely produce more than three sets of nauplii in a year. The copepods in Big Platte Lake produced nauplii in late May and August when edible algae were most abundant (Fig. 4a).

Among the cladocerans, the temporary replacement of *Bosmina* by *Daphnia* in July can be explained by species-specific growth rates and feeding ability. *Bosmina* is smaller than *Daphnia* and grows more quickly in the cool epilimnion early in the summer. As water temperature increases, so do *Daphnia* populations. By July, the large herbivore is abundant and feed heavily on green algae thereby reducing its abundance. In August, the blue-green alga *Microcystis* becomes abundant. *Microcystis* can be toxic to *Daphnia* and is difficult to ingest. *Bosmina*, however, can avoid the blue-green colonies and feed on green algae and flagellates. A growing *Bosmina* population soon surpasses the stagnant *Daphnia* population.

Abundance of planktonic crustaceans and rotifers was lower in 2004 than in 2002 and 2003 because the density of edible green algae was low in 2004. Densities of green algae exceeded 1,000,000 cells/ml in the epilimnion during April, May, June, and late September 2002 and June 2003. Abundant green algae fueled fast-growing populations of rotifers and cladocerans. Green algal counts were never more than 400,000 per ml in 2004. Crustacean and rotifer abundance was also low in 2005 even though the density of edible green algae was at its highest in the past 4 years. It is not clear why zooplankton populations did not respond to increased algal production in 2005. High proportions of colonial green algae may be resistant to ingestion. Alternatively, herbivores may be feeding on algae, but may in turn be eaten by planktivorous fish.

Predators in Platte Lake include cyclopoid copepods and planktivorous fish (Fig. 7). Cyclopoid copepods feed on protozoans and rotifers during all juvenile and adult (copepodid) life stages. Larval and juvenile fish are visual predators that actively select large prey such as adult copepods and cladocerans. Some fish species such as alewife, yellow perch, and sunfish also feed on plankton as adults. If fish predation is intense, small-bodied taxa (ex: rotifers, nauplii) will dominate the zooplankton.

Late Summer Algal Bloom and Foaming Event

Unlike other oligotrophic lakes, Big Platte Lake exhibits a large epilimnetic phytoplankton bloom in late summer. The algal bloom was composed primarily of diatoms in 2004 and green algae in 2005 (Fig. 1). Diatoms and blue-green algae (*Microcystis*) dominated the bloom in 2003. Reasons for the bloom are unclear; however, it is likely that strong epilimnetic mixing is responsible. During the summer, there are two water masses in Big Platte Lake: 1) a large volume of epilimnetic water in contact with shallow sediments across a large portion of the lake, and 2) a small volume of hypolimnetic water restricted to a single basin near the outlet of the lake. The deep basin is a sink for nutrients and algae (especially diatoms) during stratified periods. The rest of the lake is a source for nutrients and algae, particularly when the water is mixed by strong winds. Benthic diatoms (*Cymatopleura* and *Gyrosigma*) present in plankton samples confirm that well mixed epilimnetic water was scouring shallow sediments in mid-August 2003-2005.

In late August, the surface of Big Platte Lake near shore becomes covered with dense foam. The foam was more abundant and persisted longer in 2003 than in 2004 and 2005. Though not analyzed chemically, the foam was most likely composed of surfactants released from dead algae. In mid-August, the diatom *Fragilaria* and the blue-green *Microcystis* are abundant in the epilimnion of Big Platte Lake. Diatoms are a likely source of surfactant because they store photosynthetic product as oil (triglycerides). The gelatinous polysaccharide matrix that encases colonial *Microcystis* cells could also be a source of surfactant. It is likely that an extended wind event stirred epilimnetic water which eventually disturbed shallow sediments thereby entrained decomposing diatoms into the epilimnetic water. Diatom and/or blue-green cell membranes burst, releasing stored oils and other organic molecules. The oils and other hydrophobic surfactants were then transformed into foam by turbulent mixing. Because epilimnetic blue-green biomass and foam quantity were higher in 2003 than 2004-2005, it is likely that the decomposition of blue-green algae during high wind events is primarily responsible for foam on Big Platte Lake.