Title: Zooplankton population dynamics in the Upper Mississippi River-Lake System

Abstract:

River-Lake chains are very complex systems found in nature, and these systems are greatly influenced by physical surroundings and the organisms that live within them. In order to better understand these interactions, we sampled seven different riverine sites along a 70 mile stretch of the upper Mississippi River-Lake chain. Zooplankton were collected. Our results indicated that zooplankton population density was greater on average at the effluent sites (28.45 Ind L^{-1}) than at the influent sites (1.36 Ind L^{-1}). The species content was similar during the months of June and August with high densities of *Bosmina,* Cyclopodia, and Calanoida.

Introduction:

River-lake systems such as those found in Northern Minnesota are fundamentally different than most river systems. These differ in the fact that the rivers flow through a series of lakes causing different interactions among organisms and the changing environment. However, these river-lake systems are still believed to function in a dynamic equilibrium. Because these systems are so different from commonly found river systems, they often diverge from commonly accepted riverine theories.

The Riverine Productivity Model (RPM) suggests that autochthonous primary production supports secondary production by biota in large rivers despite the large allochthonous inputs into the system (Thorp et. al. 1994). The Flood Pulse Concept proposes that the main contributing factor for the existence, productivity, and interactions of the river-flood plain system and the biota that lives within it are periodic flooding (Junk et. al. 1989). The Serial Discontinuity Concept (SDC) suggests that the disruption of the river causes large shifts in biotic and abiotic processes and patterns both upstream and downstream of the dams (Stanford and Ward 1988). The extent to which the shifts occur greatly depends on where, how large, and what kind of dam is located in that system.

The River Continuum Concept (RCC) is the most widely accepted current model for river systems, and proposes that there is a predictable progression of organisms along a river gradient that correlates directly to the physical parameters and the biological factors (Vannote et. al. 1980). This gradient occurs from the headwaters of a river system continuously to the mouth where downstream communities capitalize on the production of fine particulate organic matter (FPOM) from course particulate organic matter (CPOM) and life cycles of upstream communities. The RCC divides a river into three major components, the headwaters, mid-reaches, and lower reaches. The headwaters are normally narrower with a large amount of shore vegetation. This results in allochthonous organic matter entering the system in a much greater quantity than autochthonous material because the sunlight for photosynthesis is greatly reduced. However, the mid-reaches of the system are more susceptible to penetrating light allowing for more photosynthesis in the system creating a greater amount of autochthonous organic material. The lower reaches of the river system tend to be influxed with large amounts of FPOM that has drifted downstream which causes a decrease in photosynthesis (Vannote et al. 1980). The RCC also describes a continually changing production to respiration (P/R) ratio along the river gradient and states that there is a P/R ratio <1 at the headwaters due to the lack of photosynthesis. However, as the mid-reaches of the system are reached, this P/R ratio becomes >1, but decreases again to <1 at the lower reaches of the system.

Invertebrates are by far the most abundant and diverse group of animals found in rivers and two main types of invertebrates are found within these systems. Benthic organisms exist as a part of the species population that lives in or on the sediment at the bottom of the lake/river, whereas plankton are organisms that live in the pelagic zone. Benthic organisms in the system break down course particulate organic matter (CPOM) such as leaves creating both fine particulate organic matter (FPOM) and dissolved organic matter (DOM) (Cummins et. al. 1974). Benthic organisms play an integral role in creating the dynamic equilibrium by species adaptation and population changes down the continuum in correspondence with the available plant material used for feeding (Vannote et. al, 1980). It is suggested that shredders feed on

CPOM breaking it down to FPOM which travels downstream, collectors then feed on the FPOM in the system, and grazers feed on associated periphyton. Because of the large amounts of CPOM in the upper reaches of a river, the benthic population largely consists of shredders and collectors. In the mid reaches of the river system, this changes to mostly grazers because of the increased plankton populations and collectors (Vannote et al. 1980). When approaching the lower reaches of a river system, the population consists primarily of collectors due to the increased presence of FPOM (Stanford and Ward 1979). Plankton inhabits the pelagic zone of these systems when sufficient water depth is found. These plankton exists in three different forms, phytoplankton, bacterioplankton, and zooplankton. Most plankton are unable to move independently and is mainly moved through a system by currents.

Of the three types of plankton, zooplankton are the most conspicuous and the focus of this study. Commonly, these microscopic organisms are termed the animal plankton and exist in both marine and freshwater aquatic systems. Zooplankton are free-floating organisms that depend on river flow for dispersal. They can be classified by their size and are often designated as 2-20 μm (nanoplankton), 20-200 μm (microplankton), 0.2-20 mm (mesoplankton) (Harris et al. 2005). The species of zooplankton typically found in freshwater environments are rotifers, cladocerans, and copepods and most commonly live in lentic systems. Zooplankton play an integral part in river systems as they are the intermediate trophic level between producers and secondary consumers. They also hold a major role in the food web contributing to the biological productivity of the system (Harris et al. 2005). Zooplankton are a heterotrophic species and can be classified as carnivorous, herbivorous, or detritorous (Harris et al. 2005).

The Mississippi River system is one of the major systems in the United States with the fourth largest watershed in the world measuring about 1,837,000 square miles. The headwaters of the Mississippi River is unique in that the river flows through several large body lakes. This research will examine the zooplankton populations both upstream and downstream of seven lakes in the upper Mississippi River system during the months of June and August 2009.

Methods:

Study Area: A 70 mile stretch of the Upper Mississippi River surrounding the Bemidji area in Northern Minnesota was sampled during the months of June and August 2009. This sample area begins upstream of Lake Irvine in Beltrami County to approximately twenty miles downstream of Lake Winnibigoshish in Cass County. In this seventy mile stretch, seven sites were selected in conjunction with the inflows and outflows of the Mississippi River through three lake groups. These lake groups encompass the following lakes; Lake Irvine, Lake Bemidji, Wolf Lake, Lake Andrusia, Cass Lake, and Lake Winnibigoshish. Table 1 depicts these lake groups along with the seven particular sites. Zooplankton will be collected at each of these seven sites.

Zooplankton Sampling: Duplicate samples were collected at each of three quadrates in each of the seven locations located within a close distance of the inflow/outflow of the river through the current lake. Zooplankton was collected along each bank and from the main channel of the river using a 63-150 micrometer zooplankton net. After collection, zooplankton were placed in a 70% ethanol solution for preservation (Harris et al 2005). The zooplankton were then identified and counted through the use of a dissecting microscope and classified to the lowest taxonomic level possible.

Results:

The species of zooplankton found in the Mississippi river-lake system during the months of June and August were similar. *Bosmina*, Cyclopodia, and Calanoida were the three most prevalent species in June and August (Fig. 1A and 1B). There were also significant numbers of *Daphnia* in June and *Ceriodaphnia* and *Chydorus* in August. (Fig. 1A and 1B)

Results would also indicate that there are greater zooplankton densities at the effluent of the lake as opposed to the influent (Figures 2A and 2B). These lake groups can be identified in Table 1. In both June and August, Lake Group 1 showed a significant difference in the effluent and influent zooplankton densities with p values of 0.017 and 0.015 respectively. However, in Lake Groups 2 and 3, the differences were only significantly in June, not in August.

Comparisons were also made between the zooplankton densities in June and August. Average results would show that zooplankton in June were generally in a greater amount that in

August (Figure 3). However, a significant difference was only found at sites 2, 4, and 6. The significant difference at site 2 was one in which the zooplankton densities in August exceeded the densities in June.

Discussion:

The species distribution was similar during the months of June and August. This is because these are the species that are expected to be found in a temperate aquatic system in Northern Minnesota. Although the abiotic parameters may fluctuate increasing or decreasing these zooplankton densities, the species are expected to stay the same.

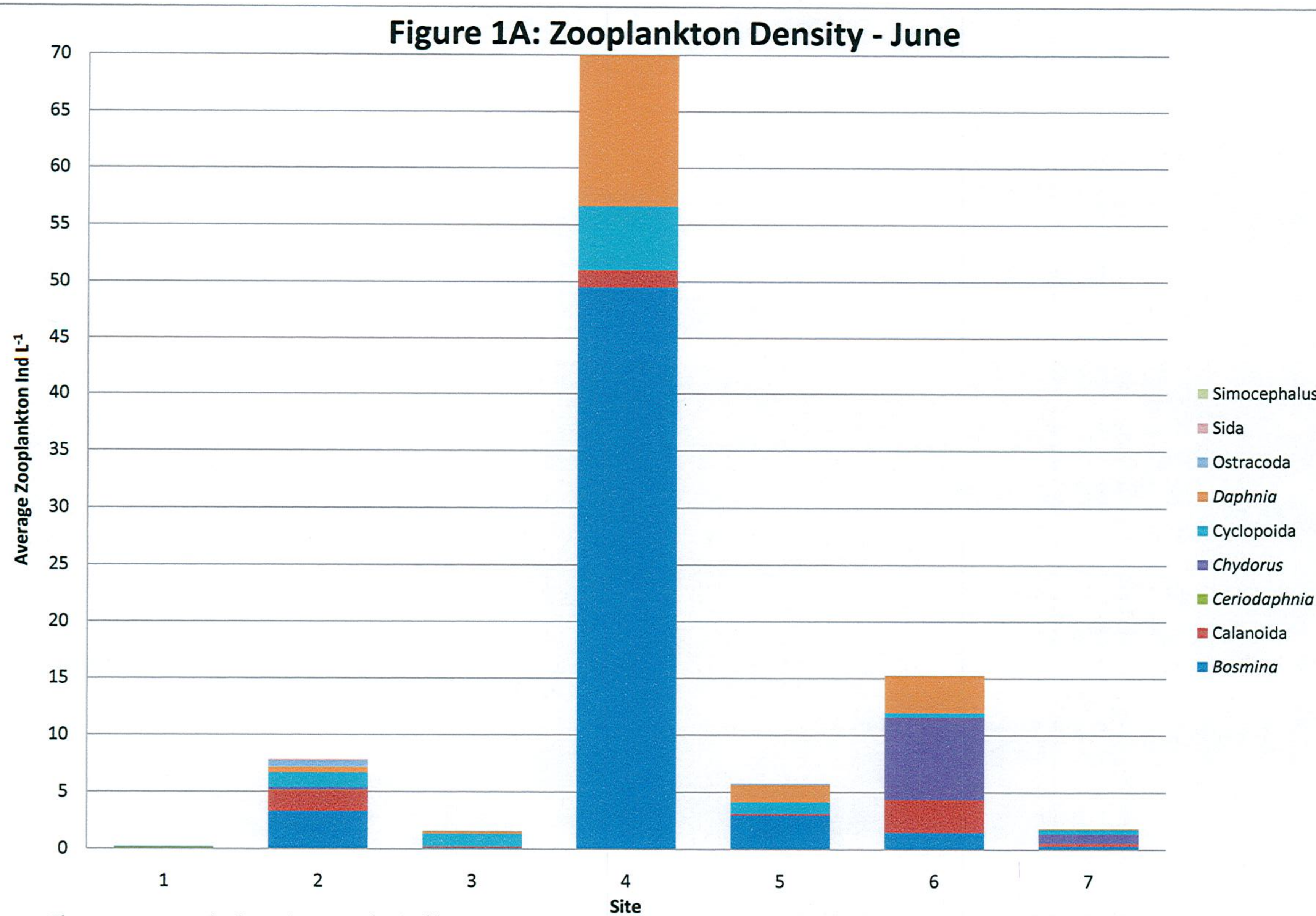
The results suggested that zooplankton densities were greater at the effluence of the lake as opposed to the influence. The average numbers show that there is always a greater number at the effluence. However, statistical tests would show that only four of the six differences are statistically significant. The increased densities at the effluences could be due to several factors. In the literature, we found that zooplankton reside in deep, non-turbulent waters. At the effluence of a lake in a system, the water is slowing outpouring from the lake and tends to be a deeper area of the river system. This is in opposition to the influence of a lake system which tends to have fast currents and shallow waters where the river water is pouring into the lake system. Thus, the zooplankton would be expected to be found at the effluence of the lake. The densities may also be higher at the effluence because of the accumulation of organic matter that the zooplankton use as a major food source. This organic matter is streamed out of the lake back into the river where it can accumulate or continue to flow down the river. The Mississippi river-lake system was concurrent with this previous research. During sampling, the river tended to be shallower with much faster currents at the influence as opposed to the increasing depth, slower moving currents, and collection of organic material at the effluence.

The results concluded very little significant difference between zooplankton densities in June and August. The differences that were found could be at attributed to the higher water levels in the river during the month of June. The increasing dept is usually an ideal habitat for zooplankton. The indifference could be attributed to the environmental weather patterns which stayed relatively the same between the month of June and August. The temperatures never dramatically increased which is usually a factor of growth in the later summer months.

River-Lake systems are a unique attribute to the Northern Minnesota environment. By studying zooplankton, one of the smallest organisms in these systems, we can begin to understand the complex associations. Current Riverine Systems theories do not fully or accurately describe these river-lake systems. However, future research will continue to examine these organisms along with the multitude of other organisms and factors intricately involved in these systems.

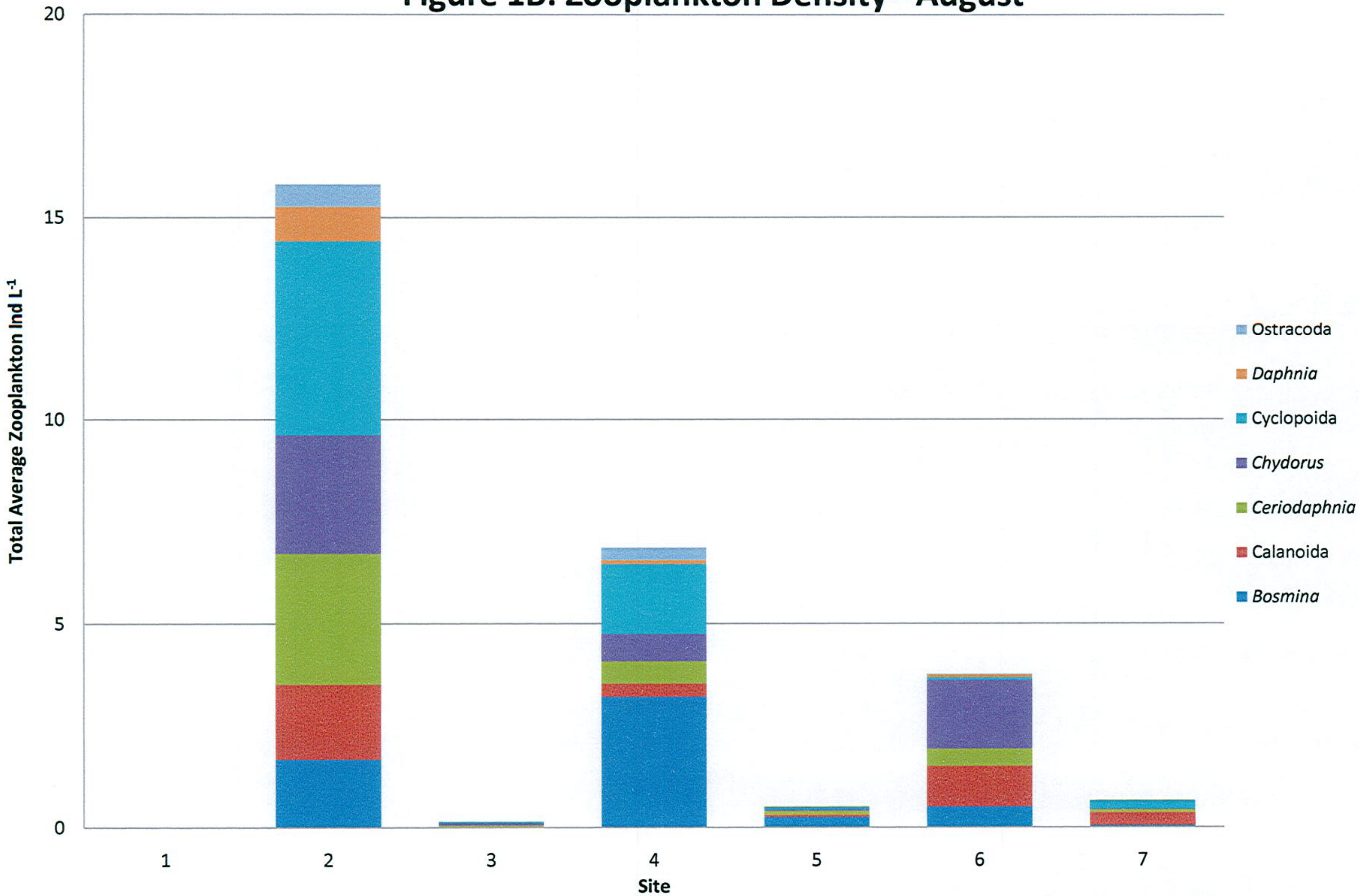
(Physical and chemical parameters such as turbidity, hydrologic forcing(flow), ambient light, temperature, dissolved oxygen (DO), pH, and depth were collected at each site. In addition, chlorophyll a, partial CO_2, and nutrients were collected. These were collected at the same time for a related study. These parameters could be applied to the data results in further studies of this project.)

Table 1				
Site Number	**Group System**	**Lake Group**	**Location**	**River Mile**
1	Lake Irvine and Lake Bemidji	1	Before Lake Irvine and Lake Bemidji	1288
2	Lake Irvine and Lake Bemidji	1	After Lake Irvine and Lake Bemidji	1282
3	Wolf Lake, Andrusia Lake, and Cass Lake	2	Before Wolf Lake, Andrusia Lake, and Cass Lake	1272
4	Wolf Lake, Andrusia Lake, and Cass Lake	2	After Wolf Lake, Andrusia Lake, and Cass Lake	1257
5	Winnibigoshish	3	Before Lake Winnibigoshish	1253
6	Winnibigoshish	3	After Lake Winnibigoshish	1233
7	Unaffected by Lake System	4	Mississippi River	1218

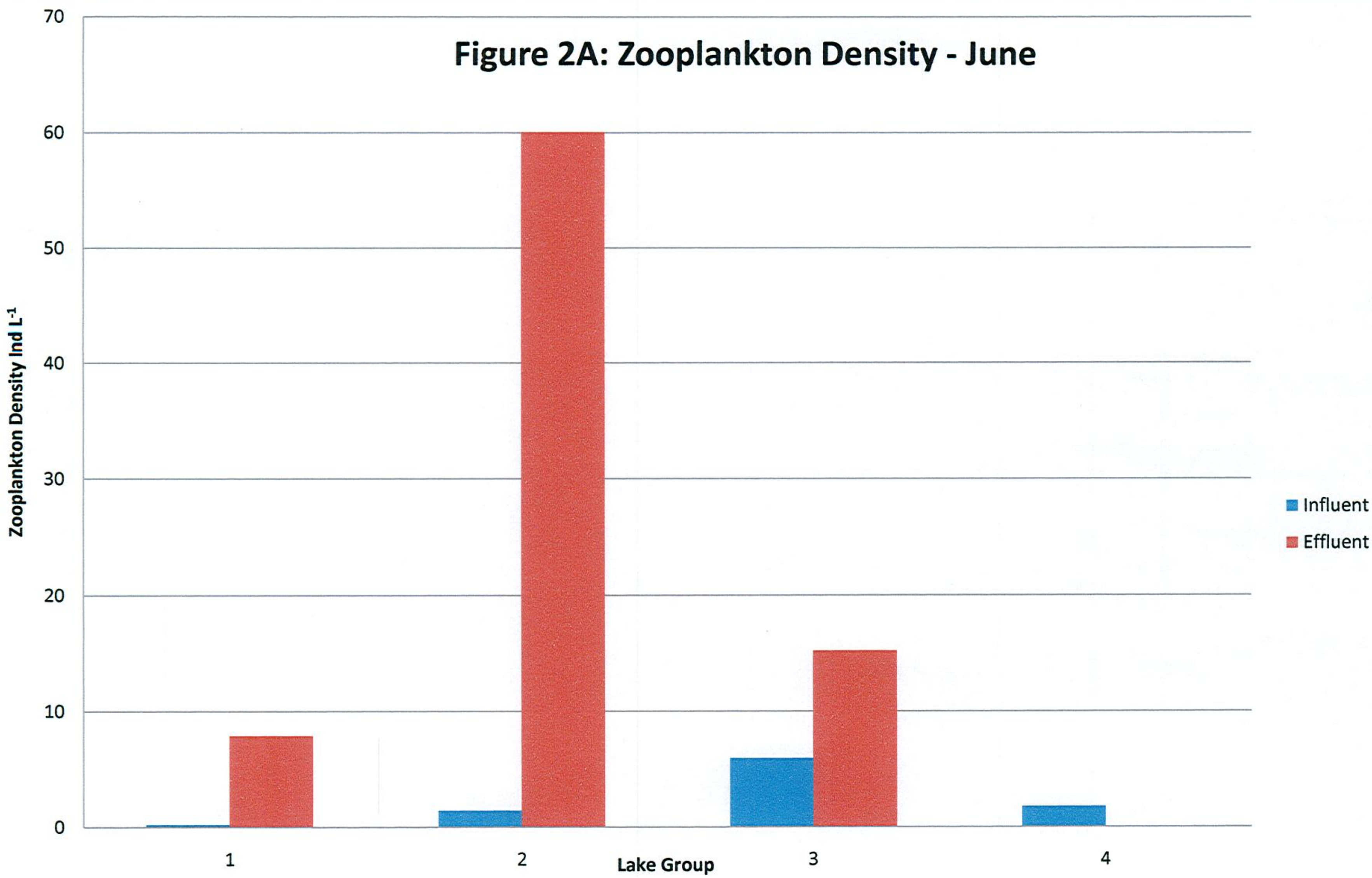


The average zooplankton densities (Ind L^{-1}) in the month of June. The seven sites listed below can be identified using Table 2.

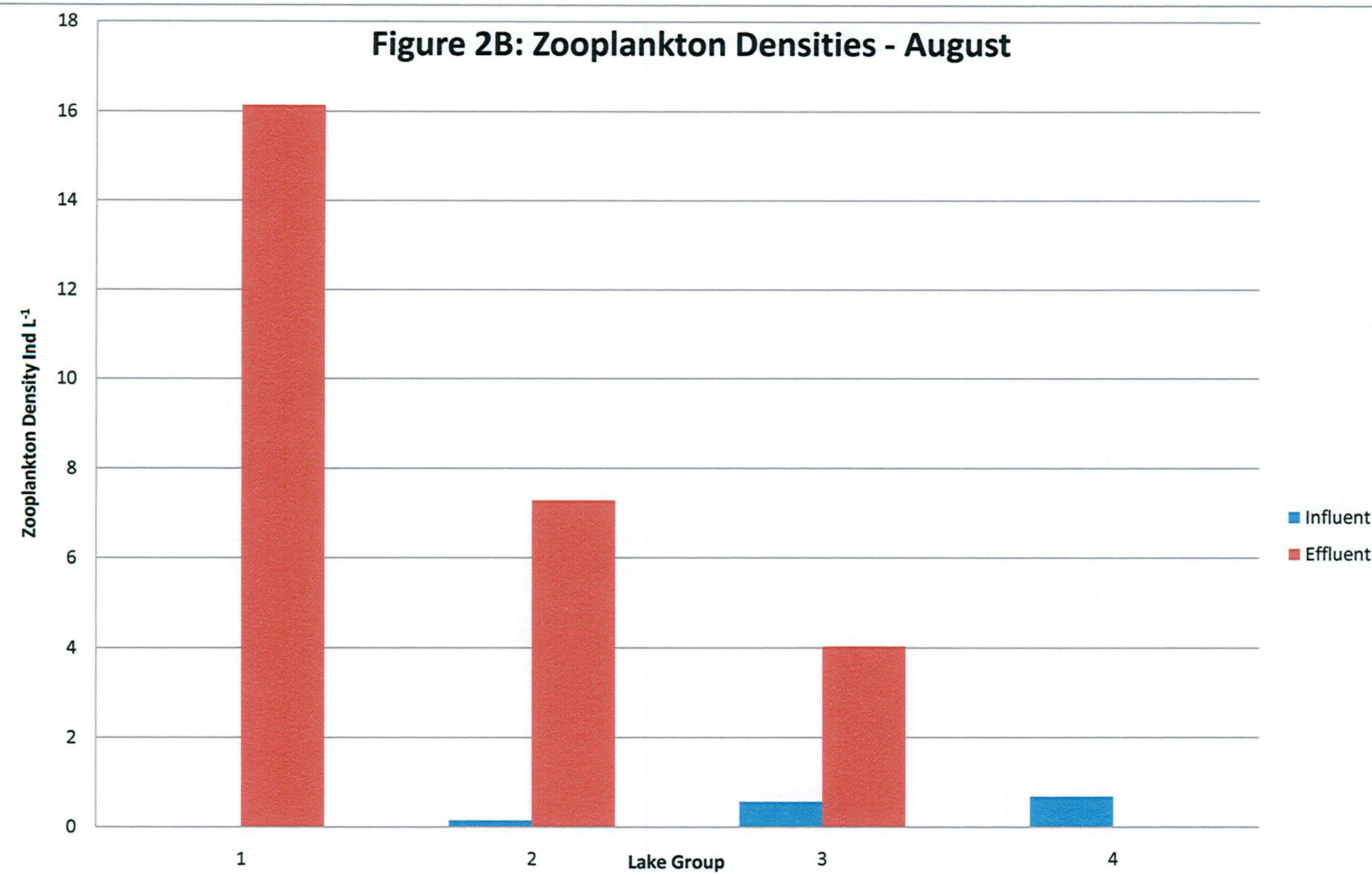
Figure 1B: Zooplankton Density - August



The average zooplankton densities (Ind L^{-1}) in the month of August. The seven sites listed below can be identified using Table 2.

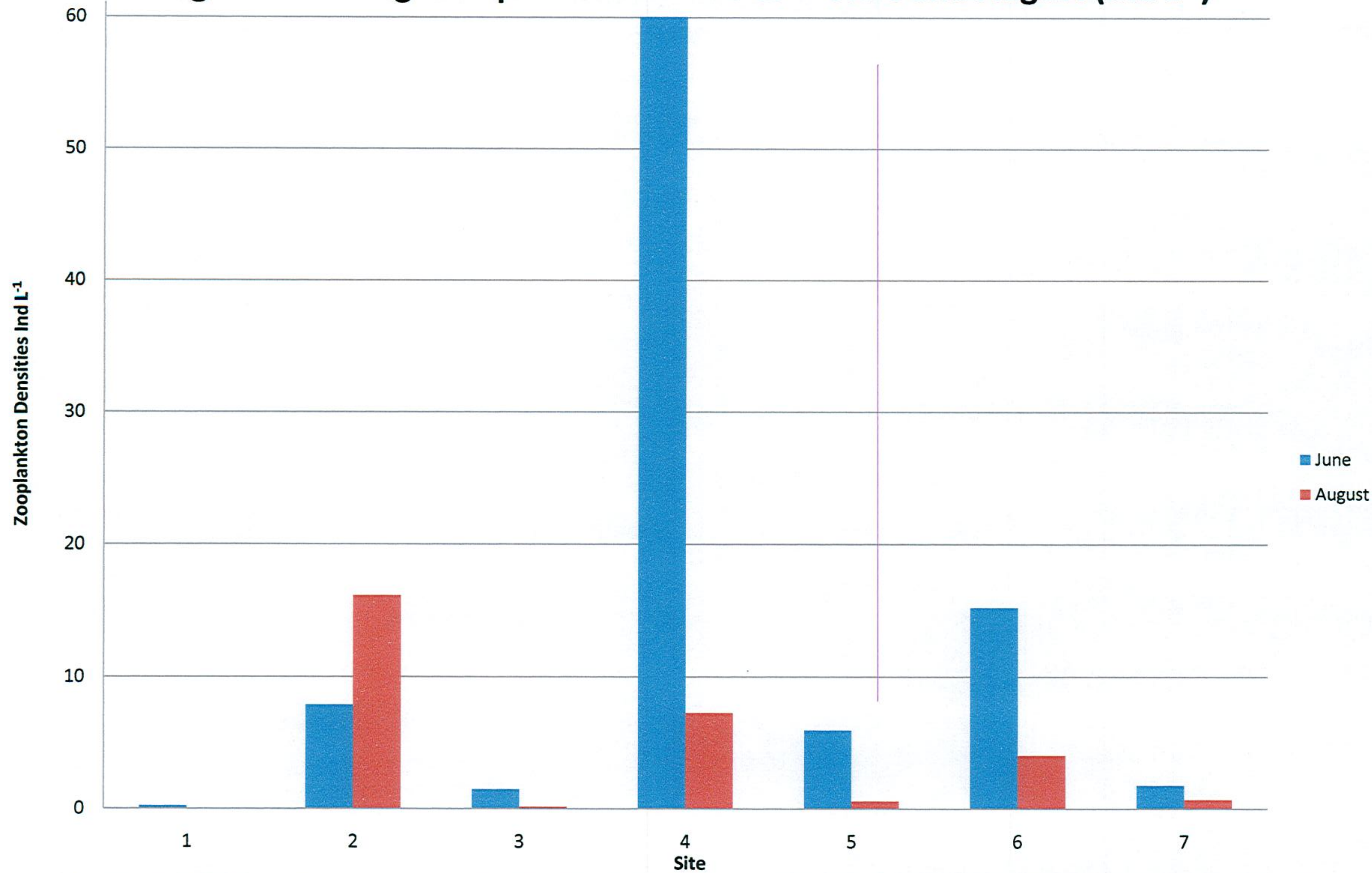


Zooplankton density in Ind L^{-1} during the month of June. The statistics are grouped by the influence and effluence of the Lake Group they are associated with (Table 2).



Zooplankton density in Ind L^{-1} during the month of August. The statistics are grouped by the influence and effluence of the Lake Group they are associated with (Table 2).

Figure 3: Average Zooplankton Densities in June and August (Ind L^{-1})



A comparison between the average zooplankton densities (Ind L^{-1}) in June and August. The June site 4 data has been divided by 2 and is actually 120.12 Ind L^{-1}.

Work Cited

Arhonditsis, G., Stow, C., Peral, H., Valdes-Weaver, L., Steinberg, L., & Reckhow, K. (2007). Delineation of the role of nutrient dynamics and hydrologic forcing on phytoplankton patterns along a freshwater-marine continuum. Ecological Modeling, 208, 230-246.

Banaszuk, P., & Wysocka-Czubaszek, A. (2005). Phosphorus dynamics and fluxes in a lowland river: The Narew Anastomosing River System, NE Poland. Ecological Engineering, 25, 429-441.

Cummins, K.W. "The structure and function of stream ecosystems." Bioscience 24 (1974): 631-641

Garnier, J., & Billen, G. (2007). Production vs. Respiration in river systems: An indicator of an "ecological status". Science of The Total Environment, 375, 110-124.

Harris, R.P., Wiebe, P.H., Lenz, J., Skjoldal, H.R., & Huntley, M. (Eds.). (2005) Zooplankton Methodology Manual. San Diego, CA: Academic Press

Junk, W.J., Bayley, P.B., Sparks, R.E., (1989). The Flood Pulse Concept in River-Floodplain Systems, p. 110-127. In D.P. Dodge [ed.] Proceedings of the International Large River Symposium. Can. Spec. Pulb. Fish. Aquat. Sci. 106

Lawler, D.M., Petts, G.E., Foster, I.D.L., & Harper, S. (2006). Turbidity dynamics during spring storm events in an urban headwater river system: The Upper Tame, West Midlands, UK. Science of the Total Environment, 360, 109-126.

Stanford and Ward, Serial Discontinuity Model

Thorp, The Riverine Productivity Model: an heuristic view of carbon sources and organic processing in a large river system

Vannote, R. L., Minshall,G. W., Cummins, K.W., Sedell,J.R., & Cushing, C.E. (1980). "The River Continuum Concept." Canadian Journal of Fisheries and Aquatic Science 37, 130-137.

Encyclopedia of Aquatic Life, Facts on File Publications, NY, NY Edited by Dr. Keith Banister and Dr. Andrew Campbell, 1985, pgs 154 and 155 Drifters and Wanderers The ecology of Zooplankton

Magill's Encyclopedia of science, Animal Life, Volume 4, Salem Press, Inc., Pasadena CA, editor = carl w. hoagstrom, Ph. D. 2002, Pgs. 1713-1715 Zooplankton