

DETERMINING THE EFFECTS OF A PLANKTIVORE BIOMANIPULATION IN
CAMPUS LAKE

By

Nicholas C. Wahl

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Approved by:

Dr. Gregory Whitley, Chair

Dr. James Garvey

Dr. Frank Wilhelm

Graduate School
Southern Illinois University Carbondale
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AN ABSTRACT OF THE THESIS OF

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Biomanipulations have often been used in small (<25 ha) shallow (<2.5 m mean depth) impoundments as a lake restoration technique. A biomanipulation was conducted on Campus Lake, a small southern Illinois impoundment, to improve water clarity. Specifically, 13,500 bluegill and 300 largemouth bass (30% and 15% of the estimated populations, respectively) were removed from the lake during fall 2006 and early spring 2007. Secchi depth, chlorophyll *a* concentration, zooplankton abundances, and total phosphorus (TP) were recorded as well as diet, annual growth rates, and size structure of bluegill, largemouth bass, and redear sunfish. Finally, bioenergetics models were used to determine the consumptive demand of bluegill and largemouth bass for prey. The biomanipulation did not significantly improve chlorophyll *a* or secchi depth due to high TP concentrations during the summer despite a significantly higher abundance of *Bosmina* after the removal. Diet analysis indicated that bluegill, largemouth bass, and redear sunfish feeding strategies were not altered due to the biomanipulation, and the annual growth rates of these fishes were not affected. However, the size structure of the bluegill population (proportional stock density (PSD)) was increased, and bluegill and largemouth bass population size structures (PSD) suggested a balanced predator-prey community. Bioenergetics modeling estimated that a bluegill removal of 75% would have been necessary to significantly reduce the consumptive demand of this species on

cladocerans. Using biomanipulation to improve water clarity in Campus Lake is limited due to internal TP loading, especially during the summer. However, biomanipulation does appear to be a feasible technique for increasing the size structures (i.e., PSD) of fish populations.

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INTRODUCTION

“Biomanipulation,” a term for the method of manipulating lake food webs to decrease phytoplankton blooms and increase water clarity, was coined by Shapiro et al. (1975), although the first recorded biomanipulation was conducted by Caird (1945) after stocking largemouth bass (*Micropterus salmoides*) into a Connecticut lake. Since then, biomanipulation has frequently been used as a lake restoration technique and has been most successful in small (<25 ha), relatively shallow (average depth <2.5 m) impoundments (Drenner and Hambright 1999, Meijer et al. 1999, Olin et al. 2006). The underlying principle behind a biomanipulation is that reductions in the density of zooplanktivorous fishes (through the removal of planktivorous fish and/or stocking of piscivores) will result in a top-down trophic cascade in which zooplankton density increases and phytoplankton abundance decreases (Carpenter et al. 1985). Decreased phytoplankton abundance may result in increased water clarity. An increase in large-bodied *Daphnia* is especially important for reducing phytoplankton abundance (Shapiro and Wright 1984, Elser et al. 2000) because *Daphnia* are more efficient grazers than smaller members of lake zooplankton communities (Gliwicz 1990, Lampert and Sommer 1997).

Since the first international meeting on biomanipulation (Gulati et al. 1990), over ten reviews (e.g. Shapiro 1990, Hansson et al. 1998) have been written on scores of biomanipulations. The outcomes of these biomanipulations have been mixed. The majority of biomanipulations have involved the removal of planktivores (e.g. Kairesalo et al. 1999; roach (*Rutilus rutilus*) and smelt (Osmeridae) were removed which led to a 3.5 fold increase in secchi depth in a large shallow lake of southern Finland). In other cases,

piscivores were simply stocked into a lake with no planktivorous fish removed (e.g. Caird 1945; addition of largemouth bass reduced severe algal blooms). Other “biomanipulations” have resulted from natural disturbances such as winterkill (e.g. Shapiro et al. 1982), summerkill (e.g. Temte 1988), and disease (e.g. DeBernardi and Giussani 1978). The majority of fish killed in these cases were planktivores, which led to increased *Daphnia* abundance and reduced algal biomass. However, a few cases (<15%) of biomanipulations have failed to improve water clarity for even one year (Drenner and Hambright 1999). Fish toxins (e.g. Kiser et al. 1963; rotenone), planktivore additions (e.g. Scholz et al. 1985; rainbow trout (*Oncorhynchus mykiss*)), and zooplankton habitat modification (e.g. Shapiro et al. 1982, Taggart 1984; aeration), all led to the demise of *Daphnia* in some lakes. Rapid regrowth of planktivore populations can further reduce the effectiveness of a biomanipulation (e.g. Van Donk et al. 1990a, Van Donk et al. 1990b; Lake Breukeleveen in the Netherlands had two thirds of its planktivorous and benthivorous fish removed and had piscivores added, but the water did not clear due to the rapid re-growth of the planktivorous bream (*Abramis brama*) population). Another reason for failed biomanipulations is that planktivorous predatory invertebrates such as *Chaoborus* can greatly reduce zooplankton abundances (Riessen 1999). Although *Chaoborus* selectively prey on relatively small members of the zooplankton community, large *Daphnia* swim faster and have a higher encounter rate with this predator (Pastorok 1980). Large-bodied *Daphnia* phenotypes escape predation by *Chaoborus* in most lakes unless *Chaoborus* are large and zooplankton density is low (Riessen and Young 2005). Once again, the importance of a high abundance of large-bodied *Daphnia* can be seen.

Many of the successful planktivore-removal biomanipulations have involved either a complete or near complete planktivore removal (e.g. Hanson and Butler 1994, Hansson et al. 1998, Meijer et al. 1999, Perrow et al. 1999) through winter or summer kill, mechanical removal, or with toxicants. However, water quality improvement through biomanipulation is not guaranteed based on planktivore removal alone. Mehner et al. (2004) stated that prior to any biomanipulation to improve water quality in European temperate lakes, external total phosphorus (TP) loading to a lake must be reduced to $<2 \text{ g TP/m}^2/\text{yr}$ through catchment rehabilitation and mean annual concentration of in-lake TP should be reduced to $<250 \text{ }\mu\text{g/L}$. Following the TP reductions, planktivore biomass should be reduced to $<50 \text{ kg/ha}$ (Mehner et al. 2004), but a minimum planktivore biomass of 20 kg/ha is needed to limit zooplanktivorous invertebrates such as *Chaoborus* (Thorp 1986, Wissel et al. 2000). However, the above recommendations are for temperate lakes.

There does exist a question as to whether biomanipulations can be successful at lower latitudes. Specifically, top-down interactions are generally not as strong in lakes in warmer climates (Jeppesen et al. 2005), which are often dominated by small cladocerans (Dumont 1994, Lewis 1996, Branco et al. 2002, Garcia et al. 2002) and omnivorous fish (Lazzaro 1997, Aguiaro and Caramaschi 1998). Omnivorous fish have the capability of reaching higher densities than obligate planktivores and also do not only affect one prey type (i.e., zooplankton) in the trophic cascade. Furthermore, the small cladocerans present in lakes at lower latitudes do not graze as efficiently as do large individuals (Gliwicz 1990, Lampert and Sommer 1997). Crisman and Beaver (1990) found that despite an increase in cladoceran abundance, water clarity was no different between fish

(gizzard shad (*Dorosoma cepedianum*)) and fishless enclosures in Florida lakes due to a lack of large-bodied cladocerans. Again, these large-bodied cladocerans are better grazers than small-bodied cladocerans as they have the ability for more throughput and ingestion of a larger range of particles (Gliwicz 1990, Lampert and Sommer 1997).

THE CLEAR WATER PHASE IN LAKES

One way to analyze the success or failure of a biomanipulation is through evaluating changes in the duration and magnitude of the spring clear-water phase. Many eutrophic lakes have a distinct stage each spring of relatively clear water called the clear-water phase (CWP) during which zooplankton biomass soars and phytoplankton biomass plummets (Sommer et al. 1986). This CWP may last only two weeks (Lampert et al. 1986), but the increase in secchi depth can be ten-fold (Tilzer 1983). The end of the spring CWP phase in lakes is associated with an algal bloom and the early- to mid-summer decline of large cladocerans. Zooplanktivorous fishes, such as bluegill (*Lepomis macrochirus*), are known to selectively feed on the largest available zooplankton (O'Brien et al. 1976, Mittelbach 1981, Li et al. 1985). Such selective predation by planktivores has been hypothesized to lead to an earlier decline in the largest zooplankton in the community and can lead to a reduction in the duration of the spring CWP. Luecke et al. (1990) reported that the duration of the spring CWP in Lake Mendota had a strong positive correlation with large *Daphnia* abundance; the end of the CWP was attributed to declining algal resources for *Daphnia* and extensive *Daphnia* predation by planktivores. However, Voigt and Hulsmann (2001) found that *Daphnia* in Bautzen Reservoir (Germany) and in a predator-free laboratory setting declined at exactly the same time,

indicating that food limitation and predation were not likely the cause of the *Daphnia* decline in the reservoir. Hulsmann and Weiler (2000) reported that the *Daphnia* decline in Bautzen Reservoir was due to a succession of: (1) a rapid increase in *Daphnia* abundance leading to a peak cohort during the CWP, (2) declining food quality and decreased fecundity and recruitment of *Daphnia* compared to earlier in the spring, and (3) high adult mortality when the peak cohort reached “old age.” Other proposed reasons for the midsummer decline of *Daphnia* in temperate lakes include blue-green algal toxins (Trabeau et al. 2004), invertebrate predators (Wojtal et al. 2004), temperature (Wagner and Benndorf 2007) and predation by young-of-the-year fishes (Hansson et al. 1998, Romare et al. 1999). However, none of the previously mentioned mechanisms are mutually exclusive. Therefore, biomanipulations that reduce planktivorous fish consumptive demand for *Daphnia* may not necessarily lead to an extended clear water phase.

DESCRIPTION OF CAMPUS LAKE

In this study, I evaluated the effects of a biomanipulation at Campus Lake (Figure 1), located on the Southern Illinois University Carbondale (SIUC) campus in Jackson County, Illinois within the Big Muddy River Watershed. This impoundment, located at 37°N latitude, is characterized as eutrophic, and has a surface area of 16.2 ha, a maximum depth of 5.2 m, a mean depth of 2.43 m, and a volume of 395,000 m³ (Muchmore et al. 2004). The Campus Lake watershed, which covers 94 ha, is primarily urban to the north (one half of the catchment), heavily wooded to the south, and a mix of woods and grasses to the west. Two smaller drainages, the Horticulture Pond to the northwest and the

President's Pond to the southwest, lie within the Campus Lake watershed. The Horticulture Pond overflows into the lake during spring run-off and heavy rain events during the remainder of the year. The President's Pond is connected via a small channel that dries during the summer. No permanent tributaries feed the lake, so water only enters directly as rain or runoff. The mean retention time is 1.73 years, and when the spillway is topped, water flows out through an unnamed tributary to Piles Fork Creek and eventually reaches the Big Muddy River (Muchmore et al. 2004).

The Campus Lake phytoplankton community is typically dominated during summer by blue-green algae (cyanobacteria), causing a pea green color in the lake (Muchmore et al. 2004). Blue-green algae and green algae create extensive mats along the shore during the summer bloom. Excessive blooms and die-offs of algae have been primarily responsible for hypoxia at depths greater than two meters (which encompasses ~30% of the lake's volume) during summer stratification prior to 2005 (Muchmore et al. 2004). The CWP of Campus Lake has traditionally occurred from late March to late May with secchi depths greater than two meters (Muchmore et al. 2004).

CAMPUS LAKE ZOOPLANKTON COMMUNITY

The zooplankton community in Campus Lake is composed mainly of small-bodied taxa. The extremely small rotifers and herbivorous copepods in the lake do not effectively graze and have little effect on algal biomass (Bergquist et al. 1985, McQueen et al. 1986), and cladocerans consist mainly of *Daphnia ambigua*, *Ceriodaphnia reticulata*, and *Bosmina* (Muchmore et al. 2004). *Bosmina* and *Ceriodaphnia* are among the smallest of all cladocerans. Larger cladocerans, such as *Daphnia* (especially *D.*

magna or *D. pulex*), more effectively graze on phytoplankton than do *Bosmina* and *Ceriodaphnia* (Lampert and Sommer 1997). In Campus Lake, *Daphnia* reach peak densities during May then rapidly decline, while *Ceriodaphnia* and *Bosmina* peak later in the summer (Muchmore et al. 2004). Following draining and dredging (more details later), the Horticulture Pond zooplankton community, in contrast to Campus Lake, was dominated by large-bodied *Daphnia magna* with body sizes of up to 4.2 mm (F. Wilhelm, personal communication), perhaps due to the absence of planktivorous fish. Thus, there is some evidence of the potential for *Daphnia* that are larger than those currently present in Campus Lake to become established in the lake in the absence of predation pressure from zooplanktivorous fish.

CAMPUS LAKE FISH COMMUNITY

Annual fall electrofishing surveys have shown that the Campus Lake fish community is composed mostly (> 95% of fish captured in fall surveys) of bluegill, redear sunfish (*Lepomis microlophus*), largemouth bass, black crappie (*Pomoxis nigromaculatus*), and channel catfish (*Ictalurus punctatus*) (Wahl, unpublished). Green sunfish (*L. cyanellus*), longear sunfish (*L. megalotis*), warmouth (*L. gulosus*), white crappie (*P. annularis*), bowfin (*Amia calva*), common carp (*Cyprinus carpio*), and grass carp (*Ctenopharyngodon idella*) have also been collected annually, but in lesser numbers than the five dominant species (Wahl, unpublished).

Of the species of fish in Campus Lake, only bluegill are likely to have a major direct effect on the cladoceran zooplankton community because bluegill is the only species present that is highly planktivorous throughout its entire life history (Werner and

Hall 1976, Werner 1977, Werner and Hall 1977, Werner et al. 1981). Although bluegill are planktivorous, they can have highly variable diets across body sizes (Engel 1988, Werner and Hall 1988) and seasons (Keast 1978, Michaletz 2006). Gaskill (2003) found that juvenile *Lepomis* in the littoral zone of Campus Lake that were smaller than 30 mm primarily fed on cladocerans and copepods, while those in the 30-59 mm TL size range selectively fed on chironomids during the fall. No cladocerans were found in stomachs of fish in the (30-59 mm TL) size class. This study indicated that juvenile fish have variable diets between size classes and seasons. Bluegill have also been known to have diurnal diet variability (Keast and Welsh 1968, Sarker 1977). As visual predators, bluegill often switch to larger more visible prey or more abundant prey in low light scenarios. Other than bluegill, the only other species of fish that are known to prey significantly on zooplankton are black and white crappies (Ball and Kilambi 1972, Mathur 1972). However, crappies also consume young-of-the-year fish and macroinvertebrates. Fall survey data have indicated crappies are far less abundant in Campus Lake than bluegill (2005 mean catch per unit effort (CPUE) bluegill 271 fish/hr, crappies 7 fish/hr; Wahl, unpublished). Redear sunfish, the second most abundant species in Campus Lake (after bluegill), also prey on macroinvertebrates, with a preference for gastropods (Huckins 1997). Macroinvertebrates also dominate the diets of green sunfish (Werner and Hall 1976, Werner 1977, Werner and Hall 1977) and longear sunfish (Shoup and Hill 1997). Warmouth prey on macroinvertebrates, crayfish, and other fish (Collar et al. 2005). Largemouth bass under 75 mm TL feed on macroinvertebrates, while bass over 75 mm TL are primarily piscivorous in most systems (Dibble and Harrel 1997, Olson and Young

2003). However, all fish species present in Campus Lake likely prey on zooplankton as early age-0 fish.

Historically, bluegill and redear sunfish have grown to a maximum total length (TL) of 185 mm and 200 mm, respectively, at age 5 in Campus Lake. However, recent data suggest that the bluegill population was becoming increasingly dominated by smaller individuals. Largemouth bass, the top predator in Campus Lake, have historically shown a stockpiling in the range of 200-300 mm TL—numerous fish in this size range, but relatively few individuals reach > 300 mm (maximum length 350 mm TL at age 6). Statewide average lengths at age 5 in Illinois are 180 mm TL, 225 mm TL, and 390 mm TL for bluegill, redear sunfish, and largemouth bass, respectively (IDNR 2001). This indicates that fishes in Campus Lake are growing below the statewide average and potentially indicates an unbalanced fish community in the lake.

Size structures of bluegill, redear sunfish, and largemouth bass in Campus Lake, described by proportional stock density (PSD), have been characterized in recent years (2003-2005) by high proportions of relatively small fish (Brooks, unpublished, Wahl, unpublished). PSD is calculated for a species by dividing the number of fish that are greater than or equal to quality length by the number of fish greater than or equal to stock length times 100 (Anderson 1976). Stock length is the minimum length at which fish mature, can be effectively sampled by traditional gears, and provide recreational value (Gabelhouse 1984), while quality length is the minimum size of fish most anglers like to catch (Anderson 1976). Another index for population size structure is relative stock density-preferred (RSD-P), which is similarly calculated for a species as the number of fish that are greater than or equal to a specified length (in this case preferred length)

divided by the number of fish greater than or equal to stock length times 100 (Wege and Anderson 1978). RSD-P is similar to PSD, except preferred length of a species is longer than quality length. Quality, stock, and preferred lengths for several species are listed in Gabelhouse (1984). PSD for bluegill in Campus Lake was 61 in 2003, 24 in 2004, and 33 in 2005 with a goal of 20-60 (Anderson 1985). When the PSD falls within the goal range, it indicates a balanced population (Willis et al. 1993). PSD for redear sunfish was 40 in 2003, 38 in 2004, and 46 in 2005. Redear sunfish do not have a well-documented goal PSD, yet the goal should likely be around 30-60, similar to that of bluegill and crappies (Willis et al. 1993). Largemouth bass PSD was 32 in 2003, 33 in 2004, and 30 in 2005 while the goal is 40-70 (Gabelhouse 1984). When PSD values are in the goal range for both bluegill and largemouth bass (which has not been the case in Campus Lake in recent years), it is considered a mutual balance in the lake (Anderson 1980, Willis et al. 1993). Redear sunfish are generally not included in the “mutual balance” as they do not fit directly into the planktivore-piscivore relationship of bluegill and largemouth bass. Furthermore, RSD-P for both bluegill (0 from 2003 to 2005) and largemouth bass (7 in 2003 and 0 in 2004 and 2005) have also been below the goal ranges of 5-20 (Anderson 1985) and 10-40 (Gabelhouse 1984), respectively, indicating a small size structure of the bluegill and bass populations in Campus Lake.

Another way to explore the condition of a fish population is through fish mass, specifically relative weight (W_r). The mass of a fish responds much quicker than fish length to environmental variables. Relative weight is calculated using the equation:

$$W_r = (W/W_s) \times 100$$

where W is the weight of an individual and W_s is the length-specific standard weight of that individual (Wege and Anderson 1978). Standard weight is calculated for each individual using the equation:

$$\log_{10}(W_s) = a' + b \times \log_{10}(L)$$

where a' is the intercept value and b is the slope of the $\log_{10}(\text{weight})$ - $\log_{10}(\text{length})$ regression equation and L is the total length of that individual. Values of a' and b for many common fish species are given in Anderson and Neumann (1996). Relative weight can be averaged across a population to obtain the general condition of the fish therein. Relative weight values well below 100 represent poor condition, while values near or over 100 represent plump fish (Anderson and Neumann 1996). Mean relative weights in Campus Lake during fall surveys of 2003 and 2004 were 82 and 82, 84 and 88, and 83 and 84 for bluegill, largemouth bass, and redear sunfish, respectively (Brooks, unpublished).

CAMPUS LAKE RESTORATION

Efforts to improve Campus Lake water quality to date have concentrated on reducing nutrient (especially TP) inputs to the lake, which is the best approach to control nuisance algal blooms and increase water clarity (Hosper and Jagtman 1990). TP loading has occurred with in-lake concentrations reaching up to 150 $\mu\text{g/L}$ (Muchmore et al. 2004), which has contributed to algal blooms and hypoxia in the hypolimnion. To reduce sediment and nutrient inputs into the lake, the Horticulture Pond, which provided roughly 27% of the annual TP input to Campus Lake (Muchmore et al. 2004), was drained and excavated to a depth of 4.5 m in 2005. In addition, water that flows out of the

Horticulture Pond now flows through a series of three small retention basins, constructed in late 2005, designed to reduce input of nutrient-bearing sediments to Campus Lake. The primary component of the TP budget in Campus Lake (~70%) has come from internal loading (Muchmore et al. 2004). To alleviate this problem, an aerator and four diffusers were added to Campus Lake in 2005 (two more diffusers were added in summer 2007) to increase dissolved oxygen in deeper portions of the lake by eliminating stratification. The increased oxygen concentration reduces internal loading of phosphorus from lake-bottom sediments by allowing oxidation of soluble ferrous phosphate to insoluble ferric phosphate, which will then settle to the bottom of the lake and be unavailable to phytoplankton (Hutchinson 1957, Wetzel 2001). Following the installation of the aerator in 2005, the CWP of Campus Lake began in February and continued through May with secchi depths over 2.5 meters (Wilhelm 2005).

BIOMANIPULATION IN CAMPUS LAKE

Bio-manipulation of planktivorous fishes in Campus Lake offers the potential to contribute additional efforts to improve water clarity. However, although considered a temperate lake, Campus Lake is farther south than most successful bio-manipulations, so there is some question as to whether trophic interactions will be strong enough to force the necessary top-down cascade. Campus Lake already has a substantial population of largemouth bass, so adding more bass or other piscivores likely would not efficiently reduce planktivore biomass. A review of bio-manipulations by Drenner and Hambright (1999) reported partial planktivore removal bio-manipulations have had 90% success rates as compared to only 66.7% success for eliminating all the fish then restocking, 60% for

adding piscivores and removing planktivores, 40% for complete fish kills, and 28.6% for piscivore additions. Based on these findings, a partial fish removal was performed in which planktivores were removed manually. A near-complete removal of planktivores (especially when the planktivores are sport fish such as bluegill) would have greatly reduced the impoundment's recreational fishing opportunities, and removing too many planktivorous bluegill would have reduced the forage base for largemouth bass, potentially further impeding the growth of this species. Yet, removing too few planktivores would not affect water quality or planktivore growth. A combination of catchment rehabilitation, internal phosphorus reduction, and partial planktivore removal appeared to be the best methods to achieve a successful biomanipulation in Campus Lake.

CONSUMPTIVE DEMAND OF BLUEGILL AND LARGEMOUTH BASS FOR PREY

Bioenergetics models frequently have been used to quantify the amount of prey consumed by predators (Ney 1990). For Campus Lake, largemouth bass consumptive demand can be compared to the size of the remaining bluegill population to ascertain what percentage of the bluegill population the largemouth bass consumed annually. Bioenergetics models can also be used to estimate the impact of the biomanipulation on the zooplankton community by estimating the consumption of planktivores (e.g. Luecke et al. 1990, Badgery et al. 1994, Lathrop et al. 2002). Depending on the number of fish removed versus those present, the bioenergetics modeling approach also can be used to direct future management actions by modeling consumption estimates versus zooplankton biomass remaining in the lake. The Wisconsin Bioenergetics model also provides a P-value for each simulation, which represents the proportion of the maximum consumption

ability for that cohort (Kitchell et al. 1974). The P-values can help determine whether fish are feeding near their maximum capacity or if their consumption is limited, possibly by competition or ability to find food.

The Wisconsin Bioenergetics model, developed by Kitchell et al. (1974), is given by the formula:

$$C = G + (M + F + E),$$

where cumulative food consumption, C (g), is a function of specific growth rate, G (g/g/d), active and inactive metabolism and specific dynamic action (M), egestion (F), and excretion (E). Each variable is described by mass- and temperature-dependent functions. This model has been shown to successfully predict consumption and growth rates for largemouth bass in the lab by Whitley and Hayward (1997) and in field experiments by Rice et al. (1984); it has similarly been validated for bluegill in the lab by Whitley et al. (1998) and in the field by Kitchell et al. (1974).

BIOMANIPULATION GOALS AND RESEARCH OBJECTIVES

The goals of the Campus Lake biomanipulation (conducted from fall 2006 to early spring 2007) were to improve water clarity by inducing a trophic cascade through the removal of planktivorous fish and to improve the size structure of bluegill and largemouth bass populations. More specifically, the manipulation was intended to increase the magnitude and duration of the spring CWP, increase zooplankton abundance (particularly *Daphnia*), and improve growth rates of bluegill and largemouth bass. The effects of the biomanipulation on redear sunfish (i.e., diet, growth, and population size

structure) were also explored because this species is ecologically similar to bluegill and may exhibit some response to the bluegill and largemouth bass removals.

As mentioned earlier, top-down trophic cascades resulting from biomanipulations are often weak or non-existent in warm climates. Therefore, a biomanipulation with a removal of planktivore biomass akin to that in temperate lakes may fail. Here I used a biomanipulation in Campus Lake—a small (16 ha), shallow (mean depth = 2.4 m; max depth = 5.2 m) impoundment located at 37°N latitude—to test whether a removal recommendation for temperate lakes (i.e., limit planktivore biomass to <50 kg/ha, Mehner et al. 2004) would work at a more southern latitude. Evaluation of the effects of this biomanipulation was completed through several objectives:

- 1) Compare chlorophyll *a*, total phosphorus, secchi depths, and zooplankton abundances before and after the biomanipulation;
- 2) Quantify the diets of bluegill, largemouth bass, and redear sunfish before and after the biomanipulation;
- 3) Determine size structure (measured by PSD, RSD-P, and W_r) and population sizes of bluegill, largemouth bass, and redear sunfish before and after the biomanipulation;
- 4) Compare annual growth rates of bluegill, largemouth bass, and redear sunfish before and after the biomanipulation;
- 5) Determine bluegill and largemouth bass consumptive demand for prey before and after the biomanipulation using the Wisconsin bioenergetics models for these species.

METHODS

THE BIOMANIPULATION

The biomanipulation was conducted by removing 13,500 bluegill (roughly 30% of the population) under 150 mm TL (88.4 kg of biomass) from Campus Lake using AC electrofishing and a minnow seine from September 2006 to March 2007. Also, Neumann et al. (1994) found that removing 40% of the largemouth bass between 200 and 300 mm TL in a South Dakota impoundment improved largemouth bass size structure. Eder (1984) similarly demonstrated that removal of 19 largemouth bass < 300 mm TL per hectare per year increased largemouth bass growth and condition. Therefore, 300 largemouth bass (~15% of the population; 19/ha) < 300 mm TL were also removed from Campus Lake during fall 2006 to increase growth in the remaining bass population. Removing this small number of largemouth bass was intended to allow for improved growth of the remaining population without substantially reducing their ability to effectively control the bluegill population.

LIMNOLOGICAL PARAMETERS AND ZOOPLANKTON DYNAMICS

Zooplankton abundance (number/L) along with total phosphorus (surface and bottom of the lake) (ug/L), chlorophyll *a* (ug/L), and secchi depth (m) were measured during 2006 and 2007 by the SIUC Limnology lab. These samples were taken on a bi-weekly basis except during winter months (November to February) when they were taken monthly. Two sites were sampled for each: one at the deepest point in Campus Lake and one farther up the main portion of the lake (Figure 1).

FISH DIET ANALYSIS

A standardized fish monitoring survey, developed by R.M. Neumann, has occurred every fall since 2003. The same protocol was used for collecting bluegill, largemouth bass, and redear sunfish during fall 2006-2007 for diet analysis. Five transects were made at night (1830-2200h) during late October using pulsed direct current (DC) electrofishing with Wisconsin ring droppers, 20 peak amps, and around 250 volts. Pulsed DC was used because it is less harmful to fish than alternating current (AC) and more effective at capturing fish than straight DC (Reynolds 1996). The pulse rate was set at 50Hz and the duty cycle set to 50% to most effectively capture spiny rayed (Novotny and Priegel 1974) and young fish (Reynolds 1996). Each transect consisted of 20 minutes total time and from ten to twelve minutes of pedal time (amount of time that the foot pedal was pressed, the circuit was completed, and electrofishing took place) in fifteen second bursts. The entire littoral zone of the lake was sampled in the five transects. The first five individuals from each 1-cm length class of each species of fish were retained for analysis. These fish were placed in bags and put on ice in coolers. Upon return to the laboratory, they were immediately placed in a freezer. For all other fish captured, species and total length were recorded after which they were returned to the lake. Frozen fish kept during the fall survey were thawed in batches, identified to species, and had their stomachs removed and placed individually into vials containing 95% ethanol for later diet analysis.

To analyze the diet of bluegill in early spring, fish were collected during the last week in March (early clear water phase and beginning of the growing season) at 1800h and 1900h in 2006 and 2007, respectively. The 2007 collection was at 1900h because of

the earlier start of daylight savings time. To collect fish < 70 mm total length, two hauls with a minnow seine were completed, while fish > 70 mm were collected from two littoral transects with AC electrofishing. Sampling transects were indiscriminately chosen in the field. Ten bluegill from each 5-cm length group (0-4.9 cm, 5.0-9.9 cm, etc.) were kept, but only five fish were collected from each transect to incorporate possible variation in diet composition among individuals collected in different areas of the lake. To preserve any cladocerans present, the stomach was immediately removed after measuring total length and wet mass of each fish and placed into a vial of buffered formalin (Haney and Hall 1973).

To examine possible diet shifts of bluegill throughout the duration of the CWP and early summer decline of *Daphnia*, bluegill were also collected on one day each in late April, mid May, and early June, representing mid-, late-, and post-CWP, respectively, in Campus Lake. These samples were collected using AC electrofishing in similar fashion to the March sample. To examine possible diurnal differences in diet composition, five to ten bluegill were also collected from each 5-cm length class every four hours from 0600 h to 2200 h. Bluegill were also collected at 0200 h in 2007 to obtain diets from a complete 24-h period. Successive collection transects began at least 100 m past the end of the previous transect. Stomachs of these fish were also immediately removed and placed into buffered formalin (Haney and Hall 1973).

To analyze the diets of largemouth bass and redear sunfish, individuals were collected in June 2006 and 2007. Up to five individuals from each 1-cm length class of each species were captured using AC electrofishing in the littoral zone from 1900 h until dark on two consecutive days to ensure that representatives from the full size range of

each species were collected. Total length and wet mass were recorded for each fish before removing the stomach and preserving it in 95% ethanol. Buffered formalin was not used because these species of fish do not typically eat zooplankton as juveniles and adults (Keast 1985, Dibble and Harrel 1997, Huckins 1997, Olson and Young 2003).

To examine contents of preserved fish stomachs they were removed from preservative, carefully rinsed and contents emptied onto a gridded dish counting dish. Stomach contents were identified using Merritt and Cummins (1996) for insects and Smith (2001) for all other invertebrates. Larval fish and fish eggs were visually identified, but not characterized to any lower resolution. Fish in largemouth bass stomachs were identified as *Lepomis* using morphometric characteristics; bluegill were separated from other *Lepomis* based on mouth size (green sunfish and warmouth have larger mouths than bluegill) and gill raker size (bluegill have longer gill rakers than other species). Any prey item that was digested beyond recognition was counted as “unknown.” Each prey type was then counted using a hard part that occurs once on each individual (head capsule or mouthparts) or the whole body in the case of zooplankton, fish, and crayfish. Because stomachs were immediately preserved, digestion should have been halted soon enough to keep all recently eaten prey items identifiable. Frequency of occurrence (percent of stomachs containing a given prey type) and percent composition by number (percent of the total number of all prey items eaten that are represented by a given prey type) were calculated for comparisons among species, sizes, dates, time of day, and years.

A subsample of 100 each of *Bosmina*, *Daphnia*, chydorids, copepods, and ostracods from bluegill stomachs from the 1800 h sample from each sampling date had

total length measured to the nearest 0.001 mm. Total length of cladocerans, as described by and shown in Figure 1 of Culver et al. (1985), is from the anterior edge of the head to the base of the tail spine. The 1800 h sample was used because preliminary data suggested this was the peak time that bluegill fed on zooplankton, and to compare March and fall samples (1800 h only) to the other spring sampling dates. These measurements were then used to assess changes in the sizes of zooplankton in bluegill diets both within and between years.

Dry mass for each cladoceran taxa (*Daphnia*, *Bosmina*, and chydorid) consumed by individual bluegill was calculated using zooplankton length-dry mass regressions from Culver et al. (1985) and mean monthly total lengths of each of these taxa from bluegill stomach contents. The entire stomach contents for each bluegill was then filtered through a 47-mm Whatman GF/C glass microfiber filter, dried at 60°C to a constant mass (roughly 24 hours), and weighed. Percent composition by dry mass of the cladoceran taxa was then calculated for later use in bioenergetics models. All other prey items were lumped into an “other” category because I was specifically interested in calculating consumption of cladocerans by bluegill, given the importance of cladocerans as phytoplankton grazers. Non-cladoceran prey was only lumped when expressing diet composition on a dry mass basis.

FISH POPULATION SIZES AND SIZE STRUCTURE

To estimate the population sizes of bluegill, largemouth bass, and redear sunfish in Campus Lake, the Schnabel (1938) multiple mark-recapture method was used on seven successive days during late June in both 2006 and 2007 after the completion of all diet

sampling. Sampling for < 7 days would have resulted in too few fish being marked and estimates would not have been precise, but sampling for much more than 7 consecutive days may allow for mortality and recruitment to the gear. Mortality or recruitment during the mark-recapture period would violate an assumption of the Schnabel method that no additions to the population should occur and that any losses from the population, if present, must affect marked and unmarked individuals equally. AC electrofishing was conducted so that the entire littoral zone (extensive pelagic sampling using a gill net, shad trawl, and both AC and DC electrofishing yielded very few fish) was sampled with one trip around the lake. Species and total length of each largemouth bass, bluegill, and redear sunfish were recorded before clipping the right pelvic fin with scissors and returning the fish to the water. All other species of fish were also measured, marked, and recorded, but the low numbers of other species resulted in few recaptures. Because of high macrophyte abundance in Campus Lake during 2006, very few fish in general were recaptured. The 2007 population estimates had higher recaptures and were therefore used as a surrogate. The number of each species removed (13,500 bluegill and 300 largemouth bass) was added to the population estimates (and associated confidence intervals) from 2007 to approximate pre-biomanipulation population levels (natural recruitment was not factored into this estimate).

To characterize the size structure of bluegill, largemouth bass, and redear sunfish during summer 2006 and 2007, length frequency data obtained for each of these species during the mark-recapture sampling period was calculated. Only fish equal to or greater than stock length were used, as smaller individuals were not effectively captured by the gear (Gabelhouse 1984). Biomass (kg/ha) was calculated for bluegill, largemouth bass,

and redear sunfish populations. To do this, the length frequency distribution of each species captured during summer mark-recapture sampling was scaled up to the entire estimated population size (and the 95% confidence intervals associated with the estimate). The number of fish in each 1-cm length class was then multiplied by the average wet mass of an individual in the size-class. Average mass was calculated from length-mass relationships for bluegill, redear sunfish, and largemouth bass collected during June for the diet study. Finally, the total mass of fish in each 1-cm length class was summed to obtain the total biomass of each species and divided by the surface area of the lake (16.2 ha).

From the fall survey (see *Fish Diet Analysis* section above for details regarding fish collecting for these samples), CPUE (number of fish per hour of electrofishing), PSD, RSD-P, and W_r were also calculated for bluegill, largemouth bass, and redear sunfish. CPUE, PSD, RSD-P, and W_r have been calculated annually from this survey since 2003 (Brooks, unpublished).

FISH AGE AND GROWTH ANALYSIS

To determine the age of fish captured during the the fall survey (see *Fish Diet Analysis* section for details regarding this sample), sagittal otoliths were removed and placed into coin packs for later examination and counting of annual growth rings (see Hales and Belk 1992, Buckmeier and Howells 2003 for validation). Otoliths were placed in immersion oil under a microscope and photographed using Scion Image 4.0.2 (Scion Corp. Frederick, MD). Two independent examinations were made of each otolith to account for any reader bias. Any fish for which the readers disagreed and all fish over

three years of age had the otoliths sectioned across the transverse plane for more accurate aging (Buckmeier and Howells 2003). These sectioned otoliths were then reread by two readers until a consensus age was reached; if a consensus age was not reached, that individual was removed from the analysis. Annual growth rate (mean length (mm) at age (yr) at the time of capture) for bluegill, redear sunfish and largemouth bass was determined every year (2006-2007 from this research and 2003-2005 from previous fall survey data).

DATA ANALYSIS

Differences in zooplankton abundances and in-lake values of chlorophyll a, total phosphorus, and secchi depths were analyzed among sampling dates and between years with a mixed model repeated measures analysis of variance (RM-ANOVA). To separate effects in the case of significant interaction terms, a simpler least squares (LS) means procedure was used to assess differences in mean values on each sampling date between 2006 and 2007.

To assess temporal diet shifts, all three species of fish (bluegill, largemouth bass, and redear sunfish) were sorted by sampling date. To assess effects of size and time of day on bluegill diets, bluegill diet data were also separated by size class (above and below 100mm total length) and three different times of day (daytime (1000h and 1400h), nighttime (2200h and 0200h), and low-light (0600h and 1800h)). Bluegill diet composition (percent composition by number) was analyzed using Chi-square tests for comparisons of diet proportions among size classes, time of day, and season. Because multiple comparisons were run using the same data sets, the critical alpha was Bonferroni

corrected to $p=0.0167$ for time of day (three comparisons), and $p=0.005$ for season (ten comparisons). Young-of-the-year (YOY) largemouth bass were separated from adults for comparisons to assess temporal shifts in largemouth bass diet composition because YOY largemouth bass had not yet completed the shift to piscivory,

Feeding strategy of bluegill, YOY largemouth bass and redear sunfish was determined for each fish species using the graphical method of Amundsen et al. (1996). With this method, frequency of occurrence was plotted on the x-axis and percent composition by number (only for stomachs in which that prey item occurred) was plotted on the y-axis for each prey type. Dominant prey items fell toward the upper right with rare prey items on the lower left. Prey items that were consumed in large numbers by a few individuals plotted on the upper left, while prey items on the lower right part of the graph represent taxa eaten in low numbers by many individuals. Finally, differences in sizes of zooplankton in bluegill diets were compared between years using an LS Means procedure.

To assess changes in fish population estimates and population size structures, bluegill, largemouth bass, and redear sunfish population estimates had 95% confidence limits calculated. A Kolmogorov-Smirnov test was used to determine if there was a shift from 2006 to 2007 in the length distribution of fish at least stock length of each species caught during the summer mark-recapture sampling periods. Size structure of bluegill, largemouth bass, and redear sunfish were analyzed using PSD and RSD-P. To statistically compare these values among years, 95% confidence intervals of PSD and RSD-P were calculated using procedures described in Gustafson (1988). The 95%

confidence intervals were then visually compared, and if they did not overlap, it was considered a significant difference between years.

To compare growth rates between years, von Bertalanffy growth models were fit to mean length-at-age data for each species using Fishery Analysis and Simulation Tools (FAST 2.0) (Slipke and Maceina 2001) for each year (2003-2007). Means and 95% confidence intervals of the theoretical maximum length (L_{∞}) and the growth coefficient (K) were calculated for pre-biomanipulation (2003-2006) years for each species; 2007 values of L_{∞} and K for each species were then compared to these means and confidence intervals (i.e., where did 2007 values fall in relation to 95% confidence intervals for previous years). Using two-way ANOVA, pre-biomanipulation (2003-2006) mean lengths at age were compared to 2007 mean lengths at age for each species. Finally, differences in the growth curves for each species were compared between 2006 and 2007 as well as among 2003-2007 using residual sum of squares (RSS) (Chen et al. 1992). RSS is a function similar to a general linear model of analysis of covariance (ANCOVA) that can be used for nonlinear models. Also, W_r values for each species were compared between years using a two-tailed homoscedastic t-test.

CONSUMPTIVE DEMAND OF BLUEGILL AND LARGEMOUTH BASS

The Wisconsin Bioenergetics Model was run using Fish Bioenergetics 3.0 (Hanson et al. 1997) and was used to estimate the annual consumptive demands of bluegill and largemouth bass populations in Campus Lake for prey (cladocerans and bluegill, respectively) before and after the biomanipulation (2006 vs. 2007). Required bioenergetics model inputs included diet composition, annual fish growth, water

temperature, fish population sizes, annual mortality rates, and energy densities of prey and predator. These inputs were determined for each cohort (age class) of fish. Diet composition was obtained from the diet portion of this study. Diet proportions by dry mass were used for bluegill, while diet proportions by number were used for largemouth bass (these stomachs were dominated by fish all of roughly the same size). Annual growth (in grams) was obtained from mean mass at age of fish captured for the age and growth portion of this study (I assumed no change in weight of fish from late October to January 1 of the following year), and total annual mortality was calculated from catch curves derived from plots of log-CPUE versus age for fall survey data. Water temperature ($^{\circ}\text{C}$) data were obtained in 2007 from a temperature logger placed in the middle of the lake at the surface. A regression between mean daily water and mean daily air temperature (obtained from National Oceanic and Atmospheric Association (NOAA) data for Paducah, Kentucky) was calculated in 2007, which was then used to estimate 2006 mean daily water temperature based on 2006 air temperatures (from NOAA data for Paducah, Kentucky). The models assumed the entire water column to be the same temperature as that at the surface. Population sizes and associated length frequency distributions (i.e., how many fish were within the sizes described as age x) were determined during the mark-recapture period and back-calculated to January 1 using the previously determined mortality rates. Predator and prey energy densities (joules/g wet mass) were acquired from Cummins and Wuycheck (1971). Each cladoceran taxa (for bluegill) and fish (for largemouth bass) had its respective energy density placed into the model, while all “other” prey types had a weighted mean energy density calculated.

The bioenergetics models were run for each cohort (age class) of both bluegill and largemouth bass, and P-values were recorded. Consumptive demand estimates for each cohort were then summed to determine the population-wide annual consumptive demand for each species in 2006 and 2007. The 95% confidence limits calculated for the bluegill and largemouth bass population estimates were used in the Wisconsin bioenergetics model as upper and lower population sizes to obtain confidence limits for consumptive demand. The P-values were then compared between years using a two-tailed homoscedastic t-test. Several hypothetical scenarios were also run with the bioenergetics model to estimate bluegill consumptive demand at population sizes below the 2007 (post-biomanipulation) estimate. These simulations were performed to estimate the effects of progressively larger bluegill removals on their annual consumptive demand for cladocerans, assuming no compensatory responses in growth, mortality, or diet of bluegill. The scenarios were run with 50%, 67%, and 75% reductions from the original (2006) bluegill population size.

RESULTS

LIMNOLOGICAL PARAMETERS AND ZOOPLANKTON DYNAMICS

Water quality parameters showed seasonal variations during both 2006 and 2007, however, there were no significant differences (LS Means-all $p > 0.10$) in any parameter between the two years. Secchi depth was highest during April and May both years (generally greater than 1.25 m), representing a well-defined clear water phase. Following this CWP, the water transparency decreased and remained low (~0.5-0.75 m) throughout the summer months (Figure 8). Chlorophyll *a* followed a pattern nearly opposite to that of secchi depth; chlorophyll *a* concentrations were lowest in the spring (<20 ug/L) and peaked during the summer at concentrations greater than 60 ug/L (Figure 9). Both surface (Figure 10) and bottom (Figure 11) total phosphorus showed marked peaks during the warm summer months of 100 and 200 ug/L, respectively.

During both 2006 and 2007, cladoceran and ostracod abundances were characterized by peaks during the spring, summer, or fall (depending on taxa) and troughs during the winter, while copepods remained at relatively consistent densities throughout the year. *Daphnia* was the first taxa to peak in late March or April at around 50-70 individuals per liter. Their density fell to <5 individuals/L by mid-June, and then rose to 20-30 individuals/L in late fall (Figure 2). This pattern in *Daphnia* abundance was visible during both 2006 and 2007, although their densities peaked slightly later in 2007. There was no difference in mean abundance between the two years (LS Means- $F_{1,32}=0.08$, $p=0.77$). Both *Bosmina* and ostracods had high abundances from June through October. *Bosmina* peaked at approximately 300-500 individuals per liter (Figure 3) and were significantly more abundant in 2007 than in 2006 (LS Means- $F_{1,32}= 4.13$, $p=0.05$).

Ostracods peaked at around 400-500 individuals per liter (Figure 4) and did not differ in mean abundance between years (LS Means- $F_{1,32}=0.00$, $p=0.96$). Copepods had relatively consistent densities (20-60 individuals per liter) during both years (Figure 5). Chydorids were collected in pelagic zooplankton tows only in 2006, peaking during May and June (Figure 6). Mean abundances of both copepods and chydorids were significantly lower in 2007 than in 2006 (LS Means- $F_{1,32}= 5.85$, $p=0.02$ and $F_{1,32}=4.10$, $p=0.05$, respectively). Total cladoceran abundance peaked between June and October during both years, driven predominantly by high *Bosmina* densities during summer, and were significantly (LS Means- $F_{1,32}=4.25$, $p=0.05$) more abundant in 2007 than in 2006 (Figure 7).

FISH DIET ANALYSIS

The proportion of prey items in bluegill stomachs was significantly ($X^2_3= 20.62$, $p = 0.0001$) different between the two size classes. The larger size class (>100 mm TL) had a higher proportion of cladocerans and a lower proportion of other zooplankton in their stomachs relative to the smaller size class (Figure 12). However, no diurnal differences (all $p>0.0167$) were seen in the proportion of prey items in bluegill stomachs during spring 2006 and 2007 sampling periods (Figure 13). Several differences were found in the proportion of prey items in bluegill stomachs among months of the spring clear water phase. Bluegill stomachs collected in May had a significantly lower proportion of cladocerans and higher proportion of other zooplankton than those collected in March ($X^2_3=15.00$, $p=0.0018$) and October ($X^2_3=15.92$, $p=0.0012$) (Figure 14). Also, bluegill collected in April had a higher proportion of non-cladoceran zooplankton and a lower proportion of cladocerans than those collected in March ($X^2_3=25.60$, $p<0.0001$), May

($X^2_3=14.38$, $p=0.0024$), June ($X^2_3= 23.75$, $p<0.0001$), and October ($X^2_3= 28.81$, $p<0.0001$) (Figure 14).

Mean total length of both *Daphnia* ($F_{1,8}=9.74$, $p=0.0142$) and ostracods ($F_{1,8}=15.71$, $p=0.0042$) found in bluegill stomachs were significantly larger in 2007 (0.91 and 0.57 mm, respectively) than 2006 (0.79 and 0.51 mm, respectively) (Figure 15).

Mean total length of *Bosmina* ($F_{1,7}=1.47$, $p=0.2650$), chydorids ($F_{1,7}=0.23$, $p=0.6460$), and copepods ($F_{1,8}=0.52$, $p=0.4924$) consumed by bluegill did not differ between years (Figure 15).

During all months of both years, cladocerans comprised less than 20% of the total dry mass of the bluegill stomach contents. *Daphnia* were the dominant cladoceran during all months, ranging from 0.5 to 15.5% of the total dry mass of all stomach contents. In 2006, cladocerans comprised nearly 9% of the dry mass of bluegill stomachs in March, dropped to roughly 1% from April through June, and peaked again in October at 10.5% of the total dry mass (Figure 16). In 2007, cladocerans comprised less than 1% of the total dry mass in March, then increased throughout the year to a peak of 17% in October (Figure 16).

On all sampling dates, redear sunfish diets were dominated by chironomids, which ranged from 43% of the total number of prey items eaten in October 2007 to 74% of the total number of prey items eaten in October 2006 (Figure 17). Other prey items varied slightly in abundance in the redear sunfish diets over the course of this study, but only gastropod (29%) in October 2007 and “other” in June 2006 (36%) represented more than 20% of the total number of prey items eaten on a given sampling date (Figure 17). In June 2006, the “other” prey was composed mainly of fish eggs.

The percent of adult largemouth bass stomachs that were empty varied over the course of this study, ranging from 18% empty in October 2007 to 63% empty in October 2006. During all sampling times, adult largemouth bass diets were composed of at least 75% fish; bluegill dominated the diets in October 2005, 2006, and 2007 and in June 2007, while YOY largemouth bass were the most abundant item in adult largemouth bass diets in June 2006 (Figure 18).

YOY largemouth bass diets were highly variable among sampling dates. YOY bass diets were composed of mainly zooplankton (48%) and insects in June 2006 and zooplankton (76%) and “other” in June 2007 (Figure 19); the “other” prey in June 2007 was predominantly amphipods. In June of both years, larval fish were present in the stomachs of largemouth bass as small as 31 mm TL. Stomach contents of YOY largemouth bass collected during October 2006 and 2007 were dominated by fish (30-100%) and insects (0-70%). No zooplankton were found in the stomachs of YOY largemouth bass during October sampling dates (Figure 19).

Analysis of the overall feeding strategy indicated that all three species (bluegill, redear sunfish, and YOY largemouth bass) were opportunistic predators, with most prey items being rare in the stomachs. However, each species of fish specialized on different prey types. Bluegill showed a consistent feeding strategy both years with *Daphnia* (DAP) being an important prey item for the majority of the population, and fish eggs (EGG) being important for a few individuals (Figure 20). Redear sunfish also had consistent feeding patterns, with chironomids (CHI) being important to the entire population both years. Fish eggs (EGG) were important to a few redear sunfish in 2006, while gastropods (GAS) were somewhat important to the majority of the population in 2007 (Figure 20).

The YOY largemouth bass population used both fish (FSH) and copepods (COP) as the most important prey items during both years, while amphipods (AMP) were also important to the population in 2007 (Figure 20).

FISH POPULATION SIZES AND SIZE STRUCTURE

The population estimate completed during 2006 yielded an estimate of 23,000 (95% CI 16,000-42,000) bluegill, 2,000 (95% CI 1,500-3,200) largemouth bass, and 10,000 (95% CI 7,300-16,000) redear sunfish. However, a high abundance of macrophytes led to very few recaptures (19 bluegill, 30 largemouth bass, and 26 redear sunfish) and proportion of at-large marked fish recaptured (2.1% of bluegill, 9.1% of largemouth bass, and 4.1% of redear sunfish). In 2007, lower macrophyte coverage allowed for higher recaptures (88 bluegill, 45 largemouth bass, and 91 redear sunfish) and a higher recapture rate (4.0% of bluegill, 10.3% of largemouth bass, and 10.8% of redear sunfish). Therefore, the population estimate completed during summer 2007 was deemed to be a more accurate representation of the true number of fish in the lake (at least those that had recruited to the electrofishing gear). The estimated population sizes from 2007 sampling were 32,000 (95% CI 27,000-42,000) bluegill, 2,300 (95% CI 1,800-3,300) largemouth bass, and 4,500 (95% CI 3,600-5,800) redear sunfish. Based on the 2007 population estimates, the populations of bluegill and largemouth bass prior to the removal (2007 estimates plus the number of each species removed) were estimated to be 45,000 (95% CI 39,000-51,000) and 2,600 (95% CI 2,100-3,600), respectively.

The length frequency distribution of stock length and larger bluegill in 2006 and 2007 were not significantly different ($KSa=1.14$, $p=0.1492$) (Figure 21), while the length

frequency distributions of largemouth bass ($KSa=2.41$, $p<0.0001$) (Figure 22) and redear sunfish ($KSa=3.33$, $p<0.0001$) (Figure 23) were significantly different between years. Median stock length and larger largemouth bass and redear sunfish were smaller in 2007 (287 mm and 132mm, respectively) than in 2006 (304 mm and 154mm, respectively).

Biomass estimates prior to the biomanipulation were 87.4 kg (95%CI 75.8-99.1 kg) of bluegill, 35.7 kg (95% CI 28.8-49.4 kg) of largemouth bass, and 14.4 kg (95%CI 10.5-23.0 kg) of redear sunfish per hectare of lake. In 2007, biomass estimates were 62.1 kg/ha (95%CI 52.5-81.6 kg/ha), 31.5 kg/ha (95%CI 24.7-45.3 kg/ha), and 10.4 kg/ha (95%CI 8.4-13.5 kg/ha) for bluegill, largemouth bass, and redear sunfish, respectively.

From 2006 to 2007, fall survey CPUE increased from 127 fish/hr to 133 fish/hr for largemouth bass and from 40 fish/hr to 93 fish/hr for redear sunfish. However, bluegill CPUE decreased from 258 fish per hour to 233 fish per hour. PSD significantly increased from 2006 to 2007 for bluegill (from 18 ± 6 to 34 ± 8) (Figure 24), while largemouth bass (from 44 ± 8 to 50 ± 12) (Figure 24) and redear sunfish PSD did not change (from 26 ± 20 to 39 ± 13). Only largemouth bass had preferred length fish caught during either year, and the RSD-P for this species showed no significant change from 5 (± 4) to 14 (± 9).

FISH AGE AND GROWTH ANALYSIS

Von Bertalanffy growth parameters following the biomanipulation indicated that both bluegill and largemouth bass had higher (values fell above the upper 95% confidence limit) theoretical maximum lengths (L_{∞}) than previous years (Table 1). Bluegill also had a lower (value fell below the 95% confidence limit) growth coefficient

(k) in 2007 compared to 2003-2006, while largemouth bass showed no change in k among years (Table 1). No change was seen in either L_{∞} or k for redear sunfish following the biomanipulation (Table 1).

Bluegill mean length at age was significantly ($F_1=3.66$, $p=0.0117$) lower following the biomanipulation (Figure 25). However, no change was seen in largemouth bass (Figure 26) or redear sunfish (Figure 27) mean length at age (all $p>0.05$). Residual sum of squares (RSS) analysis suggested no change in the growth curves of any of the three species either among 2003 to 2007 or between 2006 and 2007 (all $p>0.05$). From 2006 to 2007, mean W_r significantly (ttest, $p=0.002$) decreased from 92 (SE=1.00) to 88 (SE=1.00) for bluegill and significantly (ttest, $p=0.020$) decreased from 93 (SE=0.73) to 90 (SE=0.98) for redear sunfish. Mean W_r for largemouth bass in 2006 (95, SE=0.79) and in 2007 (95, SE=0.84) were not different (ttest, $p=0.675$).

BIOENERGETIC MODEL INPUTS AND CONSUMPTIVE DEMAND

Water temperature measured in 2007 and calculated water temperature for 2006 followed similar patterns to one another (Figure 28). No data was collected for a portion of early 2007, so a constant increase was assumed while temperature was not being recorded. Bluegill annual mortality was calculated as 56% in 2006 and 43% in 2007, while largemouth bass annual mortality was calculated to be 36% in 2006 and 37% in 2007.

The Wisconsin bioenergetics model predicted that the bluegill population consumed 331 kg (95% CI of 291 to 405 kg) of cladoceran biomass during 2006. Bluegill consumptive demand increased in 2007 to 480 kg (95% CI of 390 to 626 kg) of

cladoceran biomass (Table 2). Mean bluegill P-values significantly (t-test, $p=0.009$) increased from 0.4344 (SE=0.0341) in 2006 to 0.4656 (SE=0.0234) in 2007. The bioenergetics model similarly predicted an increase in largemouth bass consumptive demand on bluegill from 429 kg (95% CI of 316 to 666 kg) in 2006 to 2287 kg (95% CI of 1767 to 3245 kg) in 2007 (Table 3). The mean largemouth bass P-values of 0.5041 (SE=0.0186) in 2006 and 0.5659 (SE=0.0088) in 2007 did not differ (t-test, $p=0.448$).

With a 50% reduction in population size, the bioenergetics model suggested that the bluegill population would have consumed 425 kg (95% CI of 374 to 520 kg) of cladoceran biomass in 2007. With one third of the original (2006) population, the bluegill population would have consumed 284 kg (95% CI of 249 to 347 kg) of cladocerans in 2007; while at one quarter of the original population, the bluegill population would have consumed 213 kg (95% CI of 187 to 260 kg) (Table 2). A 67% reduction in the bluegill population would have been necessary to reduce bluegill consumptive demand to below that of 2006, while a 75% reduction in bluegill abundance would have been necessary to reduce their consumptive demand below 95% CI's for 2006 consumptive demand for cladoceran prey.

DISCUSSION

Overall, the Campus Lake biomanipulation did not lead to the dramatic changes in water clarity that were expected. The bluegill removal did not increase the abundance of *Daphnia*, and the TP levels remained extremely high during both summers. Therefore, chlorophyll *a* and secchi depth did not show any appreciable differences following the biomanipulation.

LIMNOLOGICAL PARAMETERS AND ZOOPLANKTON DYNAMICS

Secchi depth, chlorophyll *a* concentrations, and TP followed seasonal trends similar to historic data, but all water quality measurements were worse (lower secchi depth, higher chlorophyll *a* concentration, and higher TP) during both years of this study compared to prior years (Muchmore et al 2004). However, annual weather patterns (i.e., temperature, precipitation, etc.) are known to affect zooplankton and chlorophyll abundances and TP concentrations (Lathrop et al. 2002, Wagner and Benndorf 2007). Secchi depth was substantially lower during the clear water phase of 2006-2007 than in 1997 (>2 m during April-June) and 1981-2003 means (>2 m during April-May) (Muchmore et al. 2004). Also, the water clarity during the summer of this study was much reduced compared to historical data (always >0.75 m) (Muchmore et al. 2004). Similarly, chlorophyll *a* peaked earlier and remained higher later during 2006-2007 than in 1997-1998 (Muchmore et al. 2004). Historically, mean monthly chlorophyll *a* remained <30 ug/L during all months except July when chlorophyll *a* reached concentrations over 75 ug/L (Muchmore et al. 2004). During 2006-2007, TP was also higher than historical (1981-1998) maximum mean monthly values of <100 ug/L and 130

ug/L at the surface and bottom, respectively (Muchmore et al. 2004). High phosphorus concentrations appeared to be the driving force behind the high chlorophyll concentrations during the summer. Other studies have shown that reductions in phytoplankton cannot be expected to occur following a biomanipulation if phosphorus concentrations are not first reduced to well below 100 ug/L (Jeppesen et al 2000, Mehner et al. 2004). Hot temperatures during both summers (> 30°C at the surface of the lake for much of July and August) led to high microbial metabolism and oxygen demand in the sediments. The oxygen concentrations were therefore reduced near the bottom (F. Wilhelm, personal communication), and the decreased oxygen concentration, along with microstratification of the water column, created a small anoxic zone in the deepest portion of the lake (near the aerators). Internal loading of TP became a major problem during this time. The aerators essentially turned into TP pumps, sending phosphorus to the surface, which led to inevitable algal blooms and high chlorophyll *a* concentrations.

The bluegill reduction did not successfully increase the magnitude or duration of peak *Daphnia* abundance during spring. However, *Daphnia* abundances were similar to those seen in 1997-1998 (Muchmore et al. 2004). Declining algal resources in late spring and early summer (Luecke et al. 1990, Hulsmann and Weiler 2000), blue-green algal toxins (Trabeau et al. 2004), invertebrate predators (Wojtal et al. 2004), and predation by young-of-the-year fishes (Hansson et al. 1998, Romare et al. 1999) may have also played a role in limiting *Daphnia* abundance during this study. *Bosmina* abundances were significantly higher during summer 2007 than in summer 2006, but the small-bodied *Bosmina* are not as effective at limiting phytoplankton as larger cladocerans (Shapiro and Wright 1984, Gliwicz 1990, Lampert and Sommer 1997).

FISH DIET ANALYSIS

Bluegill, redear sunfish, and largemouth bass all had some seasonal variation in diet composition as well as variability among individuals, but the diet of each species was dominated by a particular prey type that differed among species. However, the three species did not appear to feed outside of what is typical of each respective species within their native range (planktivorous bluegill, benthivorous redear sunfish, and piscivorous largemouth bass (Huckins 1997, Olson and Young 2003, Michaletz 2006)).

The difference in the diets of bluegill 0-100 mm and over 100 mm is likely due to a shift in habitat. The small size class foraged mainly in the littoral zone; the zooplankton prey of this size class consisted of mainly chydorids and copepods, two taxa commonly found in the littoral zone (Smith 2001). The large size class of bluegill, however, foraged on zooplankton characteristic of the pelagic zone, as evidenced by an abundance of *Daphnia* and *Bosmina*. This diet shift with fish size has also been reported by Engel (1988) and Werner and Hall (1988) in bluegill between 50 and 80 mm TL. The authors believed the shift in the diets of bluegill was mainly due to the larger individuals being able to escape predation of largemouth bass, and thus the bluegill were able to utilize the open-water habitat. The diet shift of bluegill in Campus Lake is likely also due to the fish being able to escape predation as only 6 (<5%) of the bluegill found in largemouth bass stomachs during this study were >100 mm TL.

The bluegill in Campus Lake did not show a diurnal shift in diet composition as has been shown in previous studies (Keast and Welsh 1968, Sarker 1977). Specifically, the largest percentage of the diets of bluegill in Campus Lake was cladocerans during all times of day, and total zooplankton (all taxa combined) was over half of the number of

prey items found in the stomach at all times. However, diurnal sampling was conducted on only three days during spring each year, and it is possible that there may have been diurnal shifts in diet composition on dates that were not sampled.

The shift in the proportion of cladocerans in bluegill diets from April to June mirrored the trends of *Daphnia* abundance in the lake during spring of both years; the high abundance of total cladocerans in bluegill diets during June was associated with an increase in the in-lake abundance of the smaller cladoceran, *Bosmina*. The higher proportion of non-cladoceran zooplankton (copepods and ostracods) in bluegill diets from April, relative to the other seasons, was likely again due to high in-lake abundances of these prey items. Keast (1978) and Michaletz (2006) similarly reported shifts in bluegill diet from late spring to summer as the fish followed trends in prey densities in lakes.

Following the bluegill removal, the increased size of *Daphnia* may be due to reduced bluegill population and thus, reduced predation pressure on the largest *Daphnia* in the population (O'Brien et al. 1976, Mittelbach 1981, Li et al. 1985). Furthermore, when the sizes of *Daphnia* in found in the bluegill stomachs were compared to the sizes of *Daphnia* in the lake (Wilhelm, unpublished), the bluegill were feeding on the largest individuals in the *Daphnia* population during the latter parts of the spring. This size selectivity suggests that larger *Daphnia*, one of the key factors to improving water clarity (Shapiro and Wright 1984), may have been present in Campus Lake during 2007 than in 2006. No change was seen in the mean total length of other cladocerans between 2006 and 2007; however the data suggest that bluegill do not prey heavily on these individuals when larger prey (i.e., *Daphnia*) are present. However, the mean length of chydorids during 2006 did show a substantial decrease; in March, the chydorids were mainly the

genera *Alosa*, while during all other sampling months the major genera was the smaller *Chydorus*. It is likely that bluegill predation on this littoral cladoceran led to the decline of the larger taxa (O'Brien et al. 1976).

Redear sunfish and both YOY and adult largemouth bass in this study showed slight seasonal and annual variation in their diets, which has also been shown in other studies (Dibble and Harrel 1997, Ward and Neumann 1998, VanderKooy et al. 2000, Olson and Young 2003). Similar to the patterns seen in the bluegill diets through the duration of the spring, the variability in redeer sunfish and largemouth bass diets was likely an aspect of prey availability. For example, the elevated proportion of young largemouth bass in adult largemouth bass diets during June 2006 was likely due to a high abundance of largemouth bass fry in Campus Lake compared to other sampling periods.

The feeding strategy of bluegill, redeer sunfish, and YOY largemouth bass in Campus Lake suggested that these species were opportunistic feeders, as evidenced by the number of prey types found in the stomachs. At high densities, bluegill have been reported to become more opportunistic feeders (Olson et al. 2003). However, each species did specialize on one to three prey items on a population-wide level, and these prey types differed among species. This niche partitioning allows different species to limit competition. Similar niche partitioning has been reported in bluegill and the molluscivorous pumpkinseed (*Lepomis gibbosus*) (Werner and Hall 1976, Werner 1977, Werner and Hall 1977, Werner and Hall 1979), bluegill and redeer sunfish (VanderKooy et al. 1999, VanderKooy et al. 2000), and bluegill and juvenile largemouth bass (Olson et al. 1995).

FISH POPULATION SIZES AND SIZE STRUCTURE

Both bluegill and largemouth bass showed reduced biomass following the biomanipulation, which was not surprising given that individuals were removed from these populations. However, the bluegill reduction was not sufficient to reduce biomass to below 50 kg/ha as is often recommended for successful biomanipulations (Mehner et al. 2004). More bluegill may have been removed had not high macrophyte abundance prevented an accurate population estimate in 2006 (macrophytes limited the ability to recapture fish, thus biasing the population estimate). The original population estimate (2006) indicated a bluegill biomass of only 29.7 kg/ha (95% CI 20.5-54.0 kg/ha). Based on this value, the bluegill biomass after removal of 13,500 individuals would have been only 12.5 kg/ha (95% CI 3.3-36.8 kg/ha). Also, because very few fish were captured in the open-water of Campus Lake, it is likely that the fish population densities in the pelagic were much lower than the estimate, and the densities in the littoral zone were much higher. The population estimate did, however, provide a reasonable approximation of the number of fish present in Campus Lake.

The increased PSD for both bluegill and largemouth bass in 2007 may have been partly caused by the removal, as all fish removed were less than quality length. Currently, the PSDs for bluegill and largemouth bass indicated a balanced predator-prey community, but a stable state that results in clear water is assumed to exist with high bluegill PSD and low largemouth bass PSD (Carpenter et al. 1985). When bluegill PSD is high and largemouth bass PSD is low, small largemouth bass are often abundant, limiting the number of bluegill. This alternative state may be reached in subsequent years; it often takes multiple years to see substantial changes in the size structure of fish populations due

to the length of their life spans (Hanson et al 2006). However, bluegill populations can be quickly forced back to a small size structure by anglers (Coble 1988, Beard and Essington 2000). Also, it can take many years for large bluegills to once again occur after regulation changes (Beard and Essington 2000). No data currently exists regarding the angling pressure in Campus Lake. The relative weights of the three species of fish were higher during 2006-2007 than values seen in 2003-2004, which suggests these fish may be feeding more efficiently (Anderson and Neumann 1996). The growth rates of bluegill, largemouth bass, and redear sunfish may increase in subsequent years because of this more efficient feeding.

The decreased mean length of largemouth bass may have been caused by the removal; more likely though, the change was caused by variable year class strength (Summerfelt 1975). Similar to the largemouth bass, the decrease in mean length of redear sunfish was likely caused by a higher abundance of age-1 individuals in 2007. These fish (hatched in 2006) appeared to have had high recruitment which was likely caused by variable year class strength as has been suggested for other species (i.e. Bonvechio and Allen 2005, Phelps et al. 2008). The fact that bluegill mean length did not change following the biomanipulation may have been caused by the fact that most individuals removed were less than stock length, or, once again, a delay in the responses of the fish community (Hanson et al 2006).

FISH AGE AND GROWTH ANALYSIS

The three growth analyses (von Bertalanffy, ANOVA, and RSS) generated different results. The change seen in the von Bertalanffy growth parameter of largemouth

bass, specifically L_{∞} , was a factor of capturing individuals in the eight and nine year age classes in 2007, which had not been captured in previous years. The ANOVA and von Bertalanffy models suggested the growth changed (at least for bluegill), but mean lengths at age differed by less than 10 mm in all cases. Therefore, all changes in growth, though statistically significant, were considered nominal. More substantial changes in growth rates may be seen in the future as fish responses are often delayed relative to biota with shorter life spans such as zooplankton (Hanson et al 2006). However, additional removals may be necessary to allow for changes in fish growth rates to occur. Neumann et al. (1994) found improved growth rates of largemouth bass following annual removals of 40% of the largemouth bass population, but the most substantial changes came after several years. However, growth may be limited by other factors along with prey availability such as temperature, turbidity, and macrophyte coverage.

WISCONSIN BIOENERGETICS MODEL

The increased consumption estimate of both bluegill (on cladocerans) and largemouth bass (on bluegill) was likely caused by an increase in the proportion of these prey items in the diets of the respective predators; bioenergetic modeling is extremely sensitive to these changes (Kitchell et al 1977). The differences between the calculated and recorded water temperatures in Campus Lake did not appear to have drastic effects on the consumptive demand. However, the water temperatures in this study were for surface waters only, and the fish may have had reduced consumption and metabolism had they utilized deeper, cooler portions of the lake. Therefore, it is likely that the consumptive estimates presented in this study are slightly higher than the actual consumptive demand

of bluegill and largemouth bass in Campus Lake. Furthermore, annual consumption rates were based on only five and two days of diet sampling for bluegill and largemouth bass, respectively, and it is possible that diet composition differed on dates that were not sampled. The increased consumption estimates suggest that despite the population reductions, individual fish consumed prey at a higher rate, while Lathrop et al. (2002) found that consumptive demand of planktivore and piscivore populations were driven primarily by abundances of these populations in Lake Mendota, Wisconsin. The P-values for bluegill and largemouth bass in this study, which were similar to those found in similar studies (see Yako et al. 2000), suggest that bluegill fed at a higher proportion of their maximum consumption rate following the density reduction. However, with bluegill feeding at under 50% and largemouth bass feeding at just over 50% of their maximum capabilities, these two species have the potential to consume prey at much higher rates in Campus Lake.

The hypothetical reductions suggested that bluegill biomass in Campus Lake needed to be reduced well below the often recommended 50.0 kg/ha (Mehner et al. 2004) to significantly reduce bluegill consumptive demand for cladocerans. Along with the bluegill consumption estimate, phytoplankton and zooplankton production estimates would provide more insight into the exact biomass of bluegill that need to be removed to improve water clarity in Campus Lake.

SUMMARY AND IMPLICATIONS

Due to high water temperatures of Campus Lake, internal loading led to high TP levels that did not allow for a top-down trophic cascade to improve water clarity.

However, Sondergaard et al. (2007) suggested that the most substantial effects of a biomanipulation are often seen 4-6 years after the fish removal. To improve the water quality of Campus Lake, an intensive project must be undertaken to reduce in-lake TP. Additional aerators and diffusers may prevent thermal stratification, but six aerators have not been sufficient to prevent a small anoxic zone to occur due to high water temperatures. Aluminum sulfate (alum) additions have proven successful in reducing TP in other lakes (Welch et al. 1988), but treatment with this toxic substance is expensive and temporary at best. The most certain method of reducing in-lake TP would be to remove much of the TP associated with the lake sediments through draining and dredging. However, draining would remove the recreational aspect of the lake, and dredging would be expensive and disposal of the contaminated sediments (elevated toxicants include metals (i.e., arsenic and lead) and organic compounds (i.e., Dieldrin and PCB's) (Muchmore et al. 2004)) would be difficult. After reductions in TP have been completed, *Daphnia* abundances need to be increased by further reducing bluegill abundances in the lake to below 30 kg/ha. Stocking additional predators such as largemouth bass or flathead catfish would be the easiest, albeit costly, method to reduce the bluegill density. If both nutrients (phosphorus) and bluegill are reduced, Campus Lake may be shifted into an alternate stable state in which small largemouth bass dominate a clear vegetated system (Scheffer et al. 1993).

This study only presents data from one year pre-biomanipulation and one year post-biomanipulation. With the addition of more pre-biomanipulation (i.e., Mehner et al. 2004, Wilhelm, unpublished) and more post-biomanipulation (i.e., long term monitoring) data, the effects of this bluegill removal—as well as in-lake and watershed restorations—

can be much better understood. It currently appears as though the removal of bluegill and largemouth bass may lead to improved size structures of these populations, especially if subsequent removals are undertaken. Therefore, the biomanipulation in Campus Lake appears to be best suited to improving the fishery rather than improving water quality. However, at this point no data exist on what effect anglers are having on fish populations in Campus Lake (i.e., population sizes and size structure). Recreational angling has been known to have drastic effects on fish populations (i.e., Coble 1988, Beard and Essington 2000, Siepker et al. 2007) as well as the physiology and behavior of fishes (i.e., Cooke et al. 2000, Barthel et al. 2003, Siepker et al. 2007). Creel surveys should be conducted in the future to better understand the effects of recreational fishing on the fish populations in Campus Lake.

Table 1. Von Bertalanffy growth parameters, L_{∞} (theoretical maximum length) and K (growth coefficient) for bluegill, largemouth bass, and redear sunfish collected in Campus Lake, Jackson County, Illinois from 2003 to 2007. Values for 2003-2006 are means (\pm 95% Confidence Intervals).

Species	2003-2006 L_{∞} (\pm 95% CI)	2007 L_{∞}	2003-2006 K (\pm 95% CI)	2007 K
Bluegill	192 (13)	218	0.50 (0.10)	0.27
Largemouth Bass	472 (112)	628	0.29 (0.13)	0.33
Redear Sunfish	249 (36)	254	0.32 (0.14)	0.33

Table 2. Consumptive demand of bluegill on cladocerans in Campus Lake, Jackson County, Illinois. Pre- (2006) and post- (2007) biomanipulation consumption estimates are given along with consumption estimates at several hypothetical reductions. The biomanipulation was roughly a 30% reduction in the bluegill population. Bluegill biomass in the lake and upper and lower 95% confidence intervals of consumption (based on CIs for population estimates) are also shown.

	Bluegill Biomass (kg/ha)	Consumption Estimate (kg)	Lower 95% CI Consumption Estimate (kg)	Upper 95% CI Consumption Estimate (kg)
2006	88.3	331	291	405
2007	62.1	480	390	626
50% Reduction	44.2	425	374	520
67% Reduction	29.5	284	249	347
75% Reduction	22.1	213	187	260

Table 3. Consumptive demand of largemouth bass on bluegill in Campus Lake, Jackson County, Illinois. Pre- (2006) and post- (2007) biomanipulation consumption estimates are given. The biomanipulation was roughly a 10% reduction in the largemouth bass population. Largemouth bass biomass in the lake and upper and lower 95% confidence intervals of consumption (based on CIs for population estimates) are also shown.

	Largemouth Bass Biomass (kg/ha)	Consumption Estimate (kg)	Lower 95% CI Consumption Estimate (kg)	Upper 95% CI Consumption Estimate (kg)
2006	35.7	426	316	666
2007	31.5	2,287	1,767	3,245

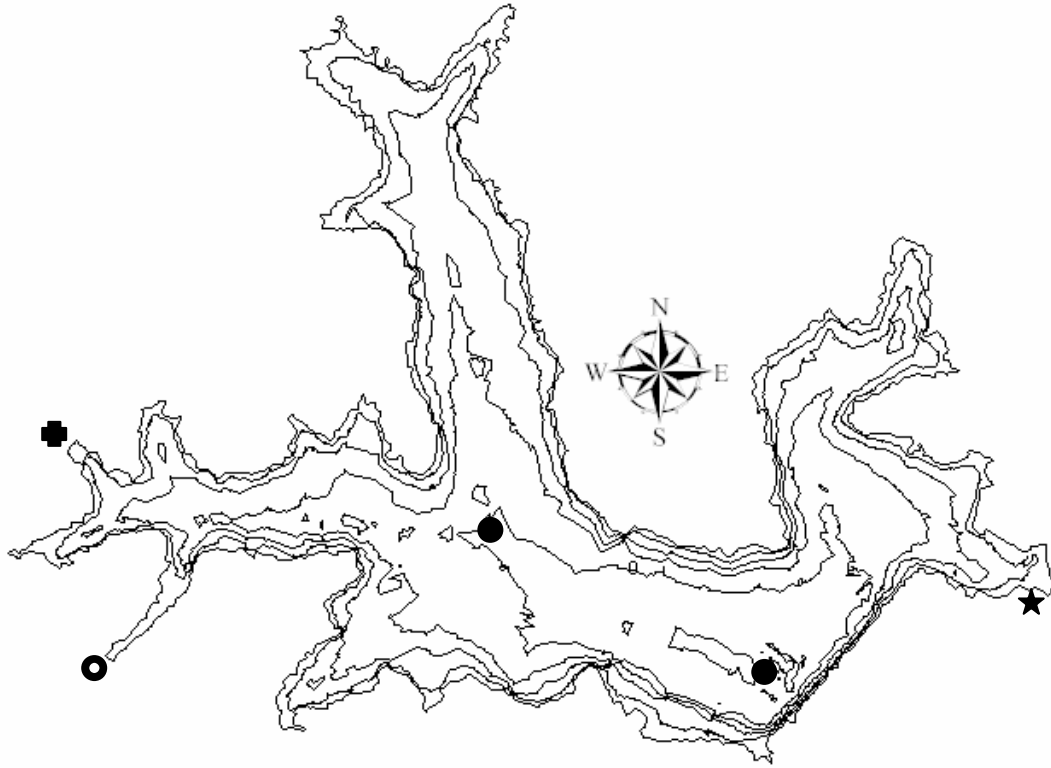


Figure 1. Bathymetric map of Campus Lake, Southern Illinois University Carbondale campus, Carbondale Illinois. Contour lines are in one meter intervals. Solid circles indicate locations of limnological sampling, plus sign indicates entrance of Horticulture Pond, open circle indicates President's Pond entrance, and star represents location of the spillway. Map obtained courtesy of R. Frank.

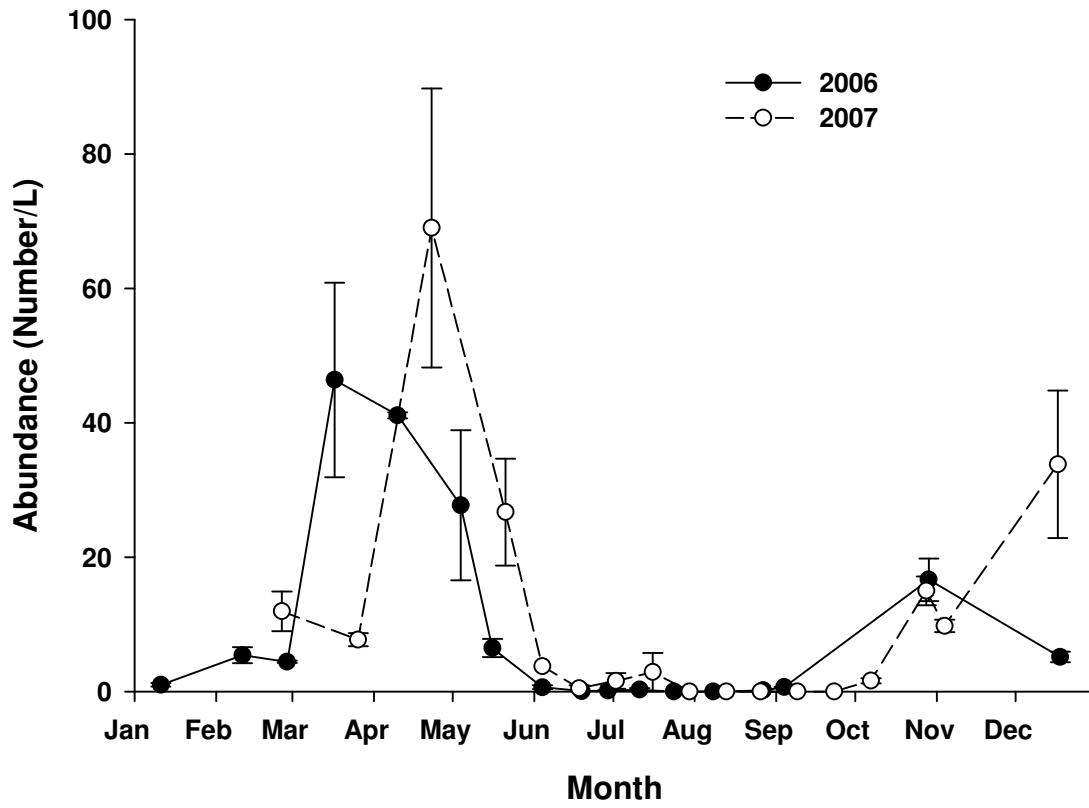


Figure 2. Mean abundance (number/L \pm SE) of *Daphnia* during 2006 and 2007 in Campus Lake, Jackson County, Illinois. Data collected by SIUC Limnology lab and obtained courtesy of F. Wilhelm.

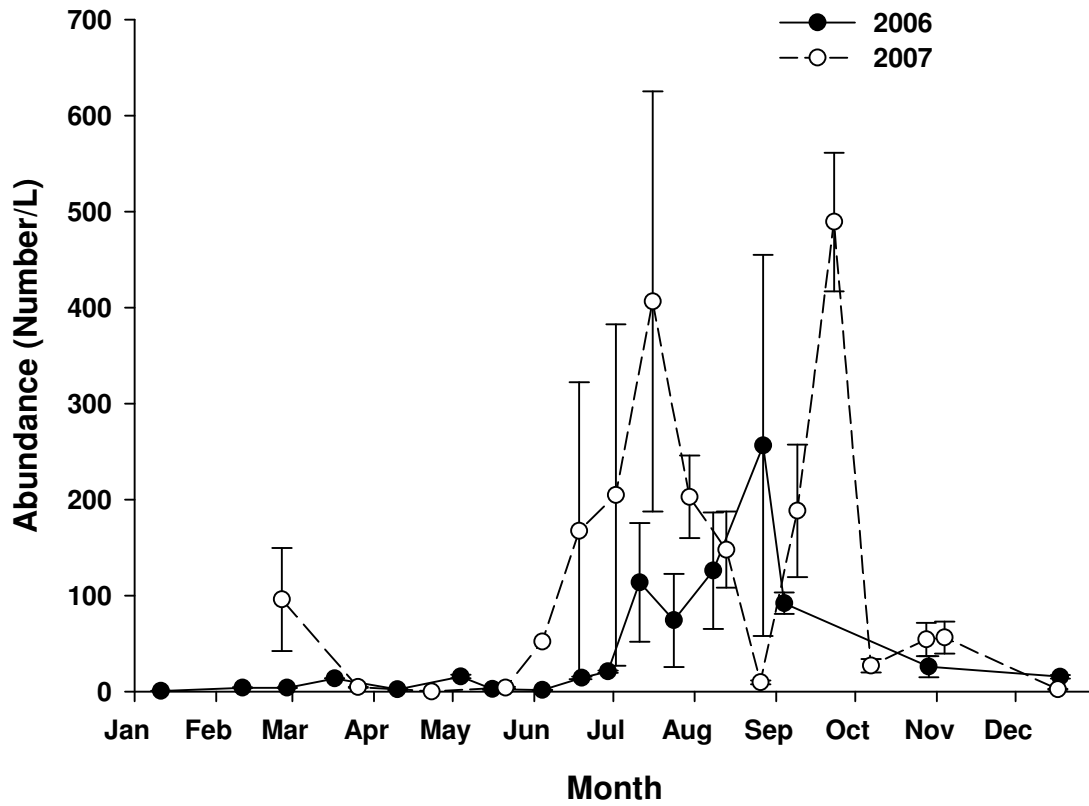


Figure 3. Mean abundance (number/L \pm SE) of *Bosmina* during 2006 and 2007 in Campus Lake, Jackson County, Illinois. Data collected by SIUC Limnology lab and obtained courtesy of F. Wilhelm.

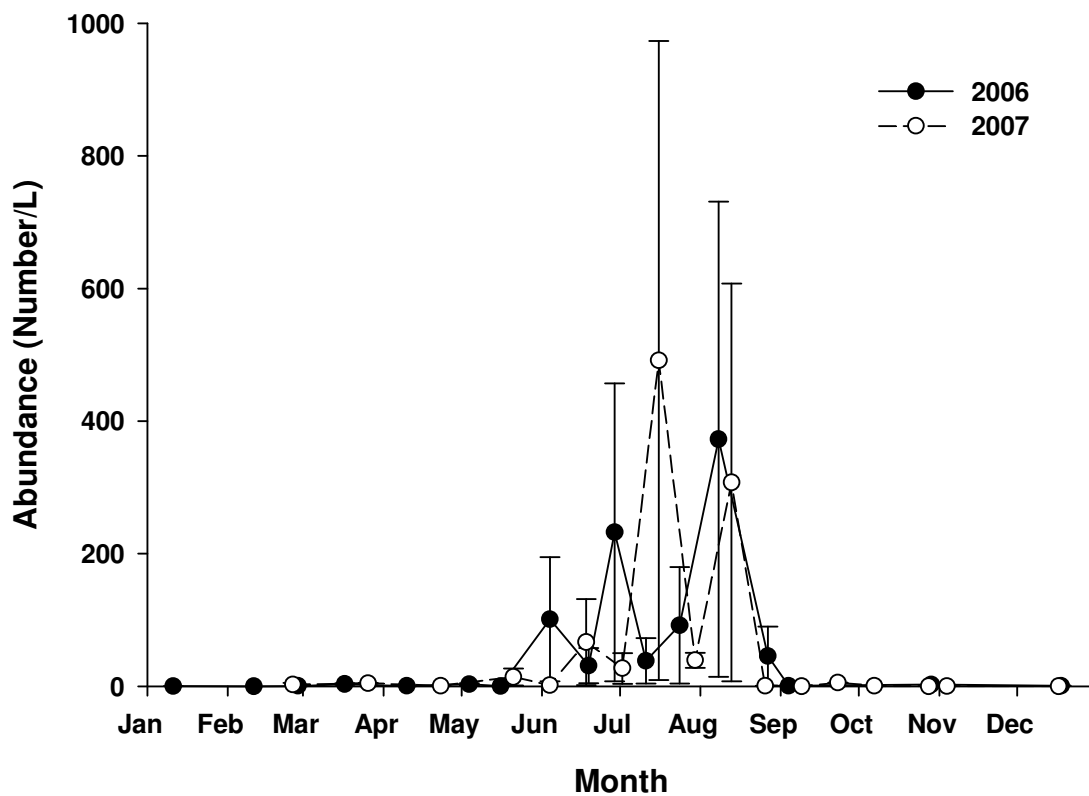


Figure 4. Mean abundance (number/L \pm SE) of ostracods during 2006 and 2007 in Campus Lake, Jackson County, Illinois. Data collected by SIUC Limnology lab and obtained courtesy of F. Wilhelm.

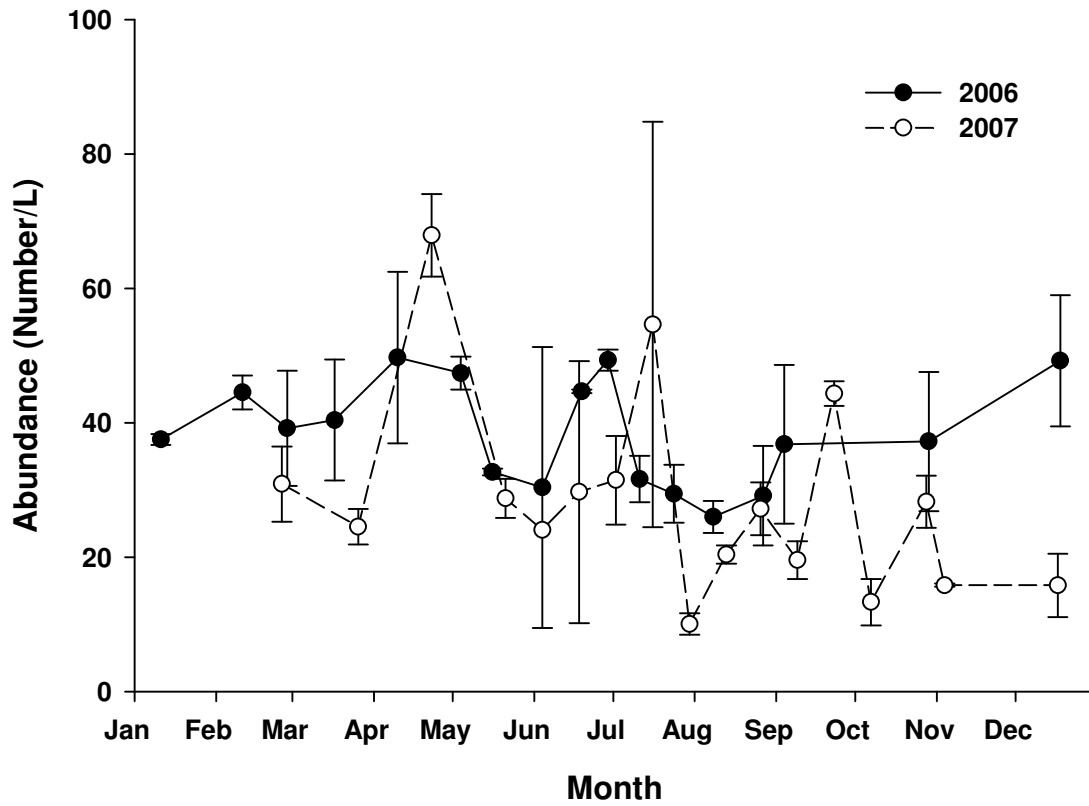


Figure 5. Mean abundance (number/L \pm SE) of copepods during 2006 and 2007 in Campus Lake, Jackson County, Illinois. Data collected by SIUC Limnology lab and obtained courtesy of F. Wilhelm.

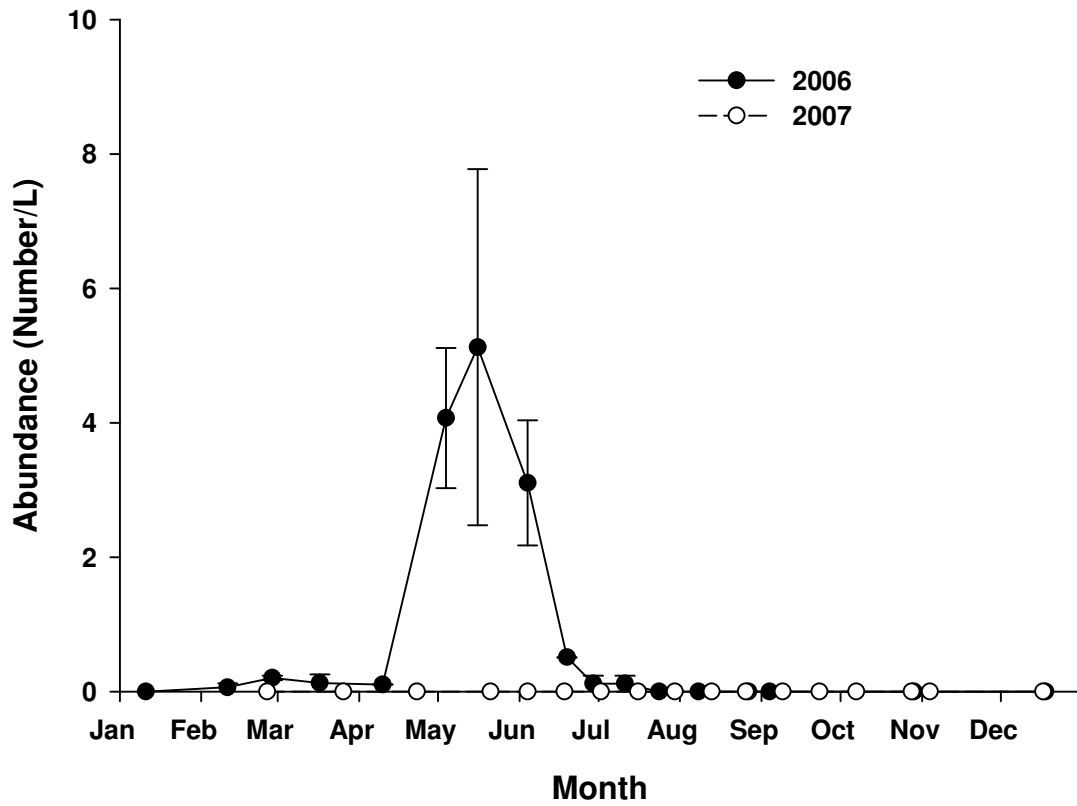


Figure 6. Mean abundance (number/L \pm SE) of chydorids during 2006 and 2007 in Campus Lake, Jackson County, Illinois. Data collected by SIUC Limnology lab and obtained courtesy of F. Wilhelm.

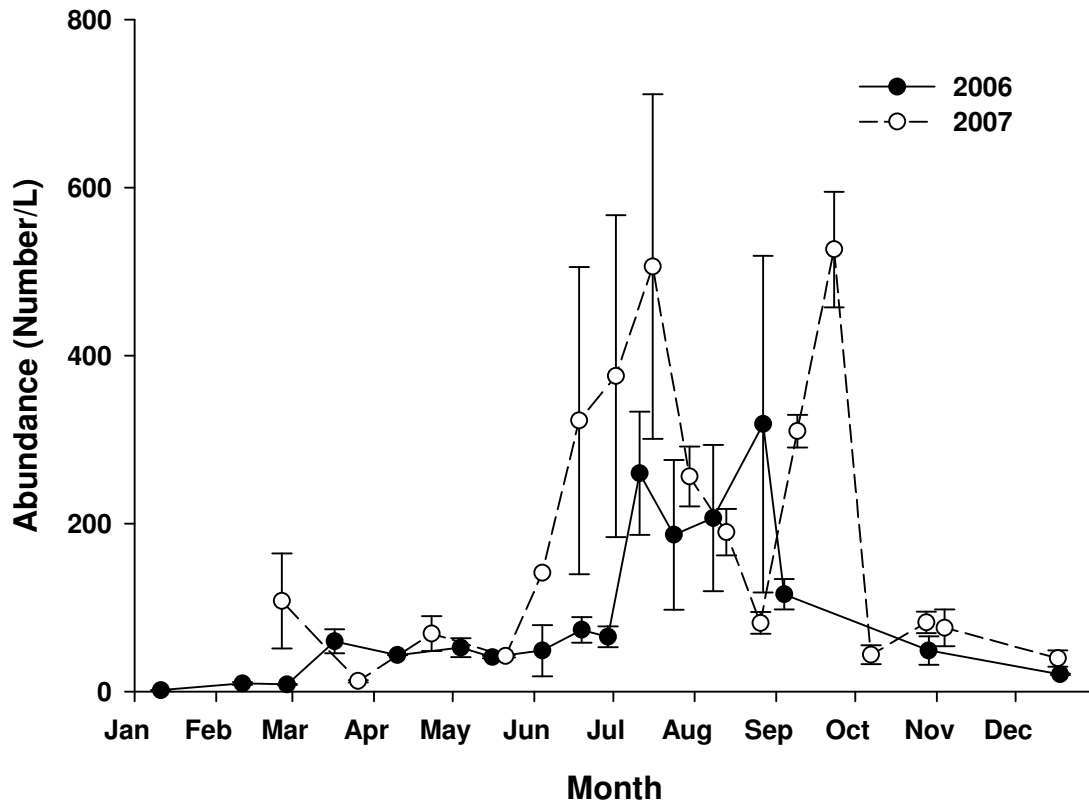


Figure 7. Mean abundance (number/L \pm SE) of total cladocerans during 2006 and 2007 in Campus Lake, Jackson County, Illinois. Data collected by SIUC Limnology lab and obtained courtesy of F. Wilhelm.

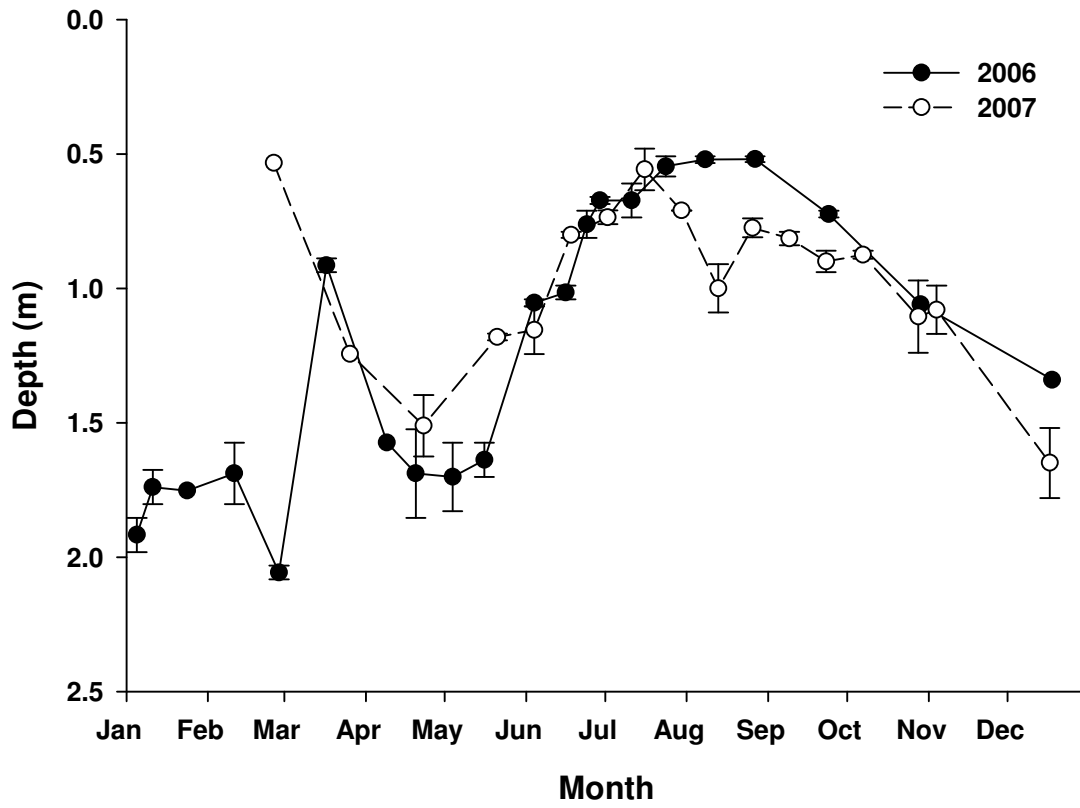


Figure 8. Mean secchi depth (m \pm SE) in Campus Lake, Jackson County, Illinois during 2006 and 2007. Data collected by SIUC Limnology lab and obtained courtesy of F. Wilhelm.

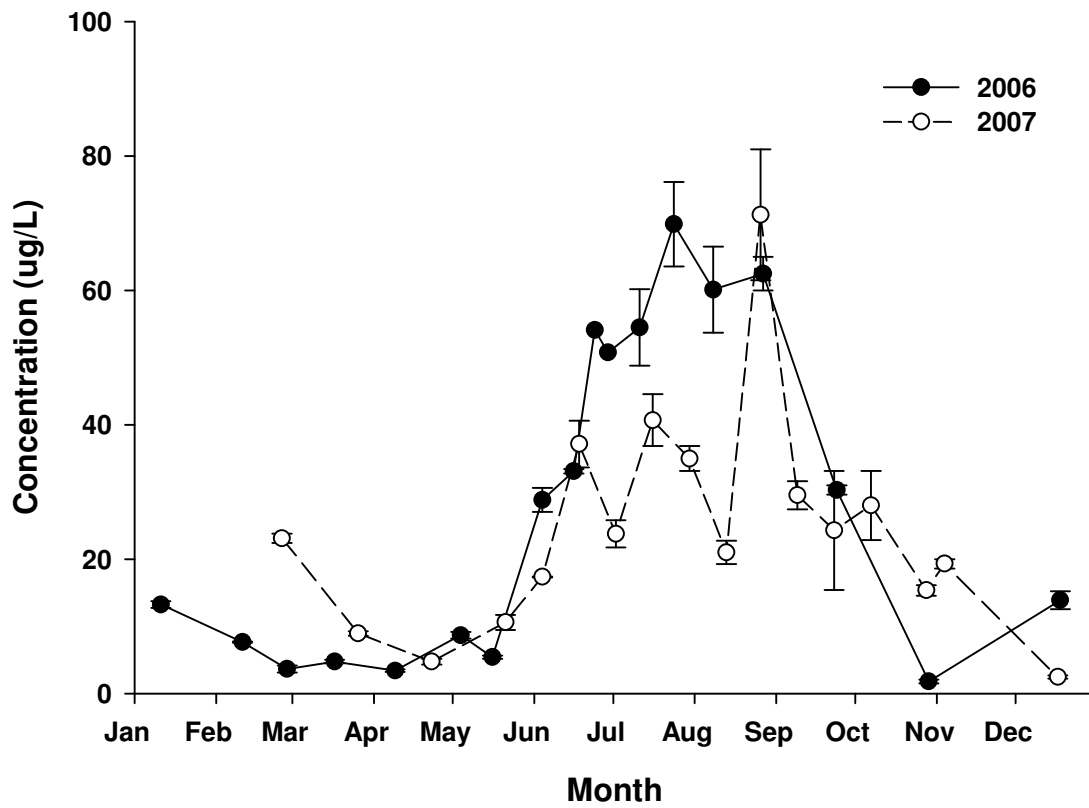


Figure 9. Mean chlorophyll *a* concentration (ug/L \pm SE) in Campus Lake, Jackson County, Illinois during 2006 and 2007. Data collected by SIUC Limnology lab and obtained courtesy of F. Wilhelm.

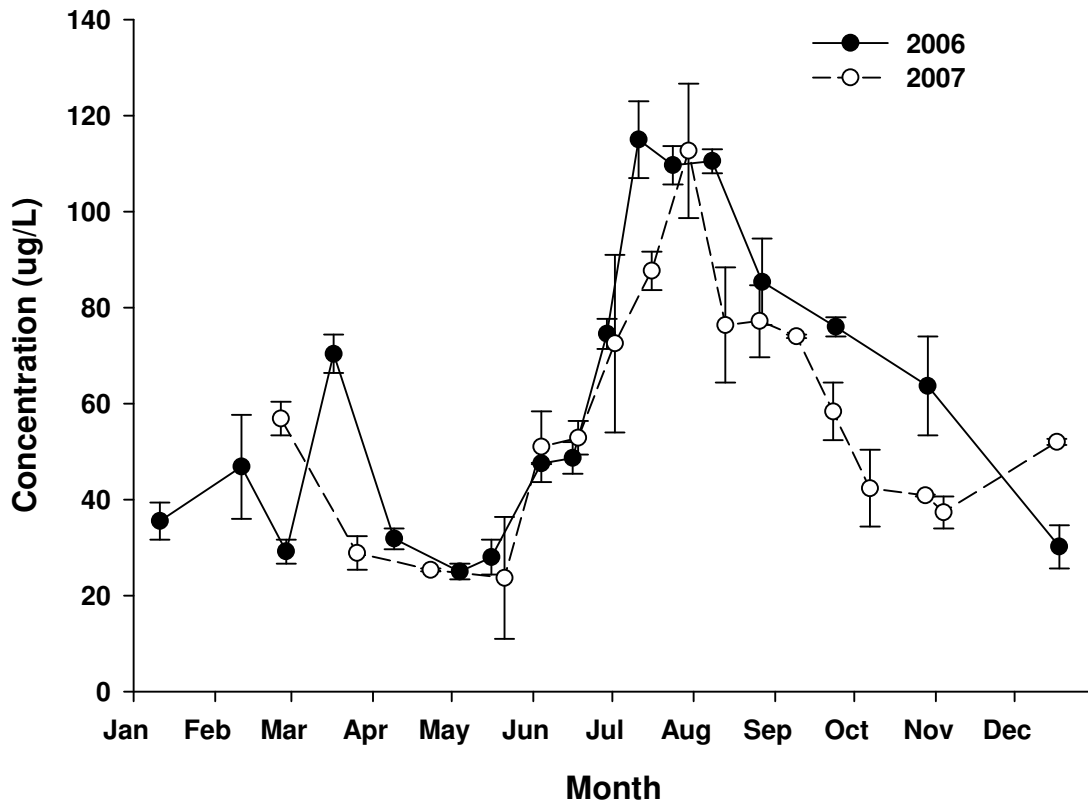


Figure 10. Mean surface total phosphorus concentration (ug/L \pm SE) in Campus Lake, Jackson County, Illinois during 2006 and 2007. Data collected by SIUC Limnology lab and obtained courtesy of F. Wilhelm.

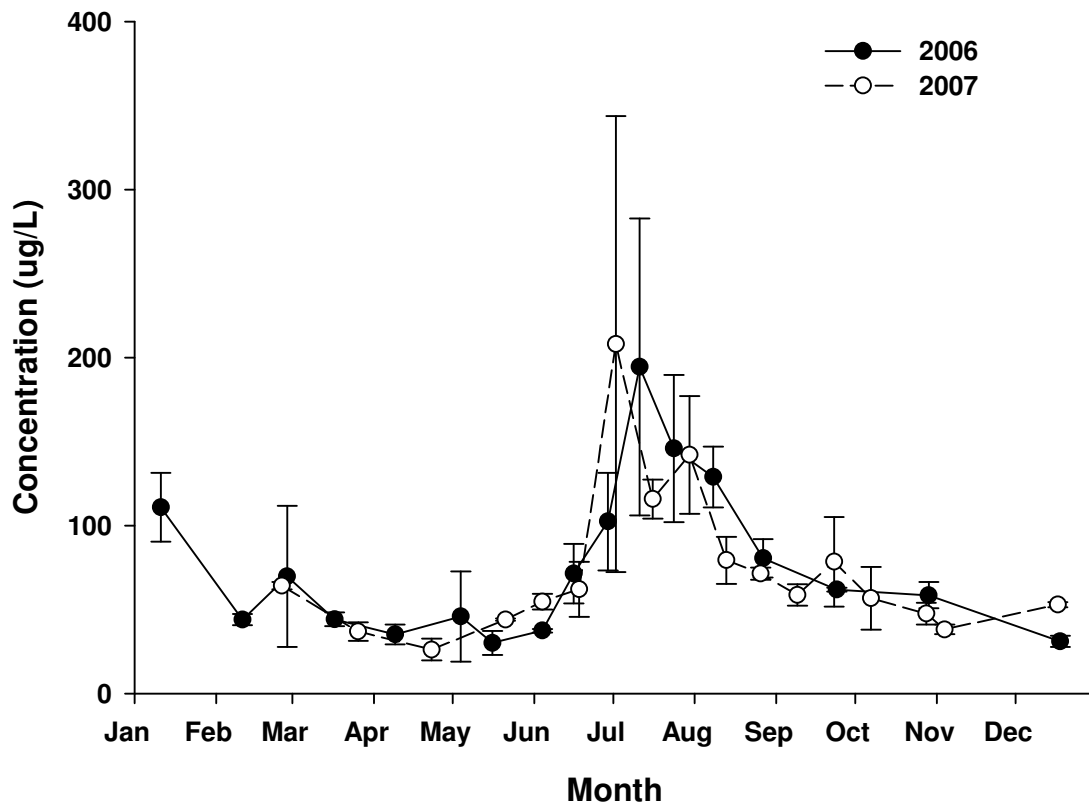


Figure 11. Mean bottom total phosphorus concentration ($\mu\text{g/L} \pm \text{SE}$) in Campus Lake, Jackson County, Illinois during 2006 and 2007. Data collected by SIUC Limnology lab and obtained courtesy of F. Wilhelm.

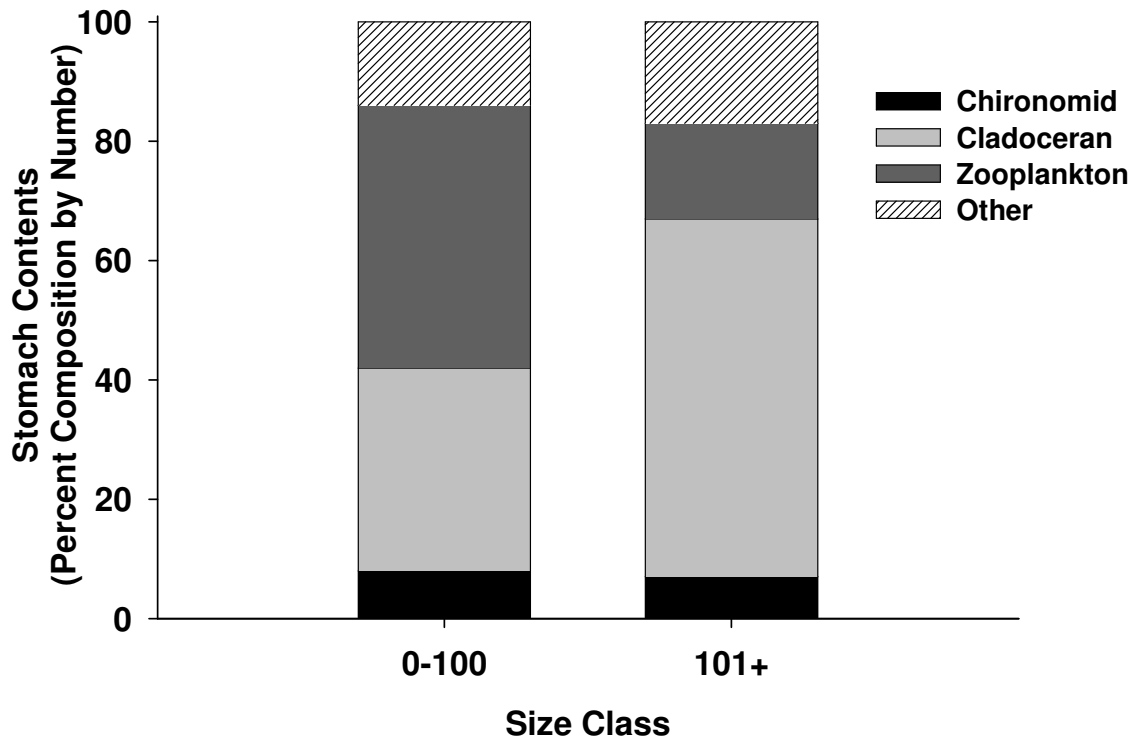


Figure 12. Stomach contents in percent composition by number of two size classes of bluegill collected during spring 2006 and 2007 from Campus Lake, Jackson County, Illinois. “Cladocerns” include *Daphnia*, *Bosmina*, and chydorids, while “zooplankton” includes copepods and ostracods.

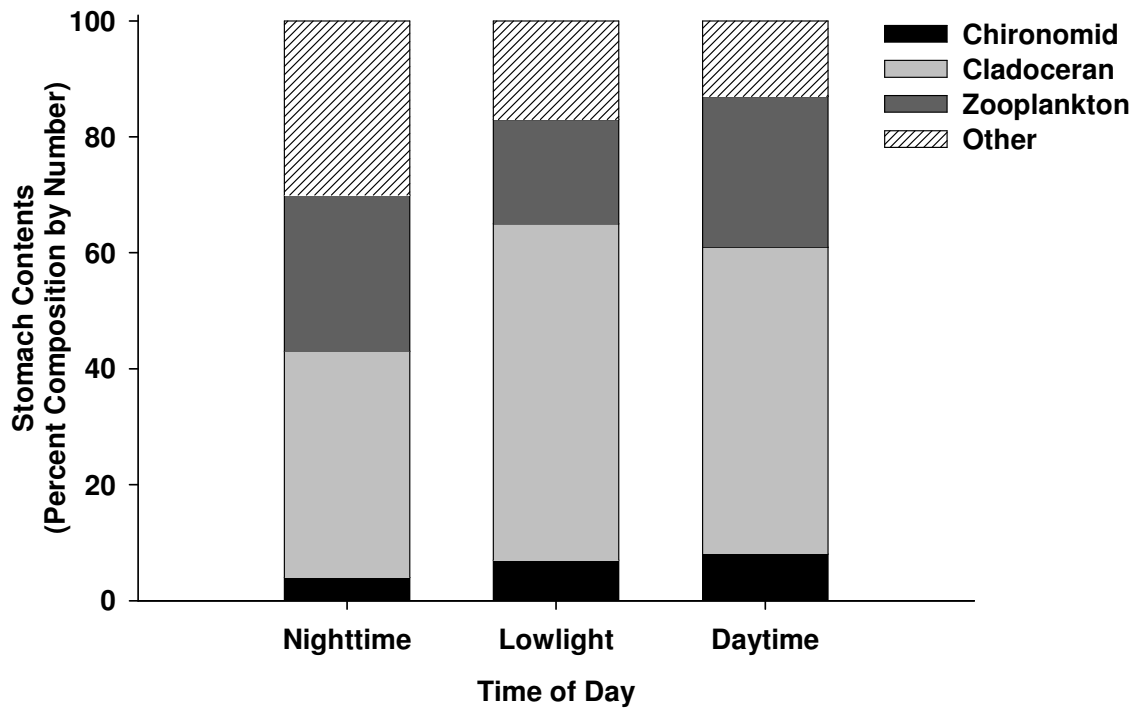


Figure 13. Stomach contents in percent composition by number for bluegill collected at the three times (“Nighttime” (0200 and 2200h), “Lowlight” (0600 and 1800h), and “Daytime” (1000 and 1400h)) of day during spring 2006 and 2007 from Campus Lake, Jackson County, Illinois. “Cladocerns” include *Daphnia*, *Bosmina*, and chydorids, while “zooplankton” includes copepods and ostracods.

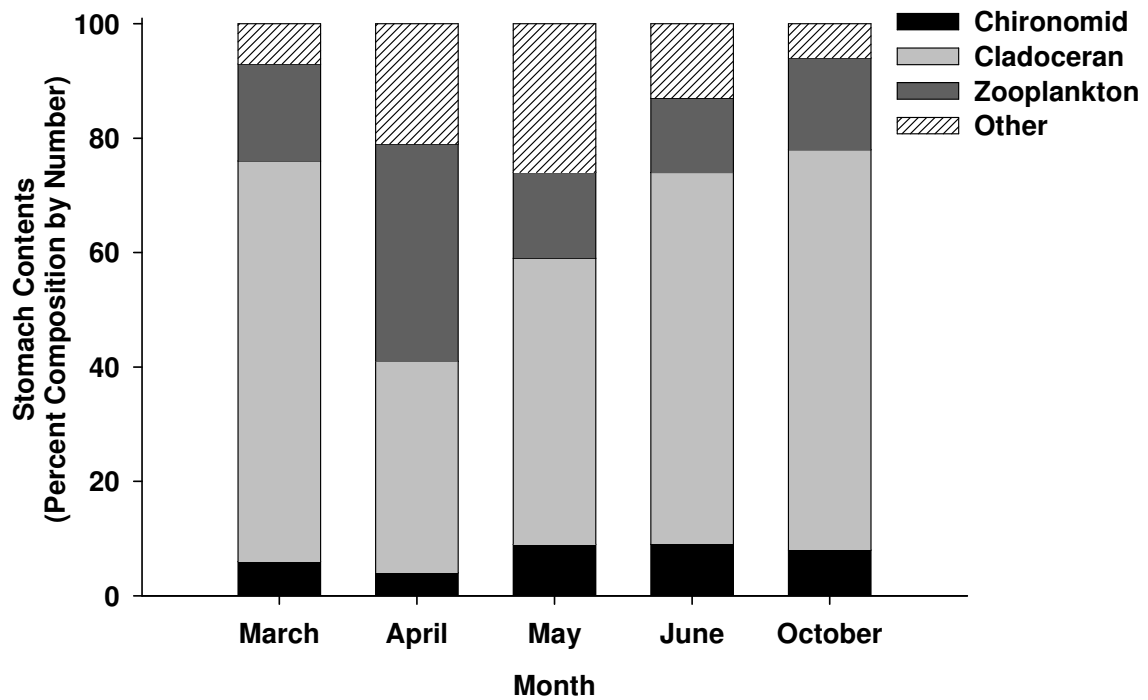


Figure 14. Stomach contents in percent composition by number for bluegill collected during the five sampling dates of 2006 and 2007 from Campus Lake, Jackson County, Illinois. “Cladocerns” include *Daphnia*, *Bosmina*, and chydorids, while “zooplankton” includes copepods and ostracods.

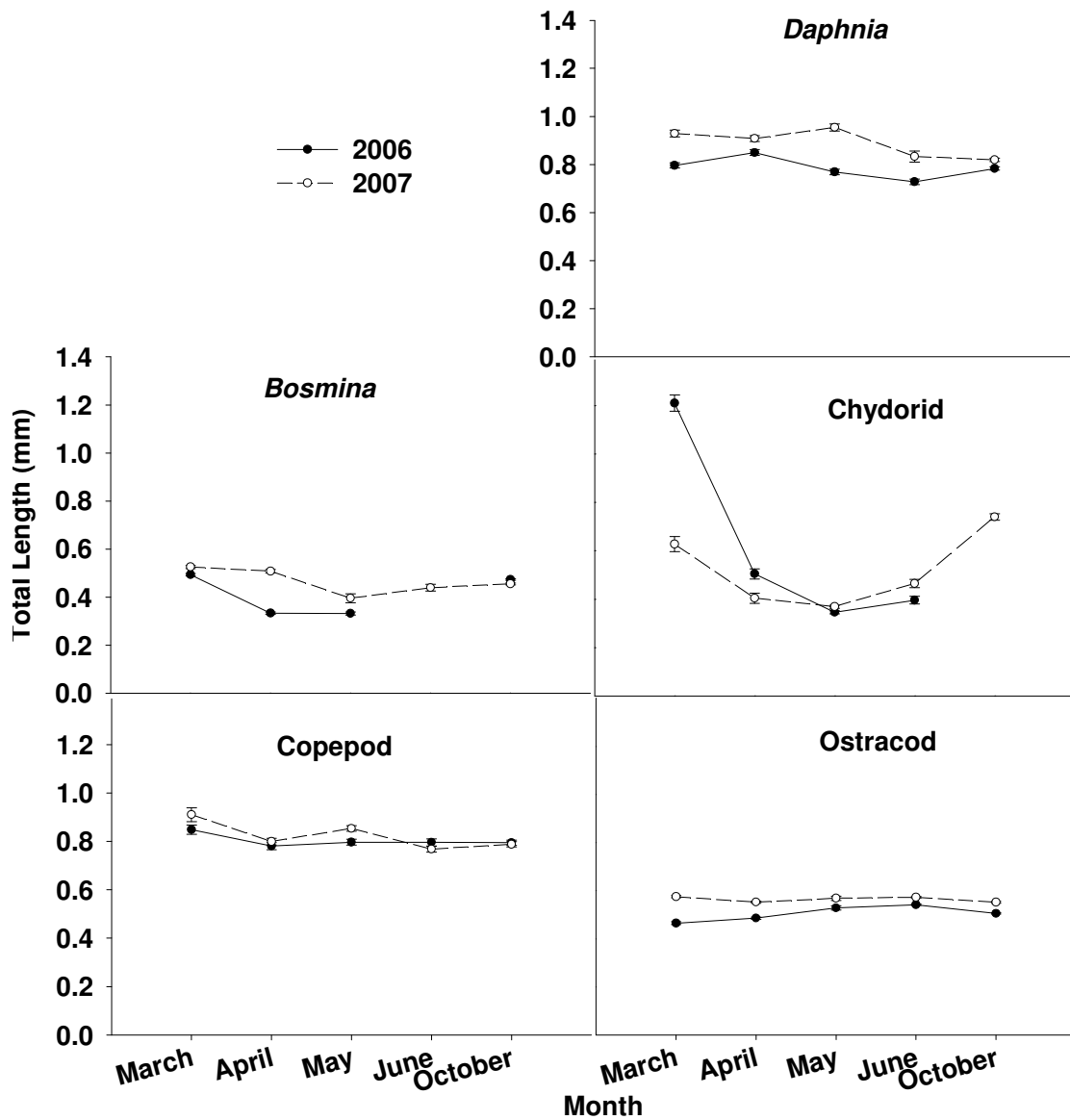


Figure 15. Mean total length (mm \pm SE) of *Daphnia*, *Bosmina*, chydorids, copepods, and ostracods found in stomachs of bluegill collected at 1800h during diet sampling in 2006 and 2007 from Campus Lake, Jackson County, Illinois.

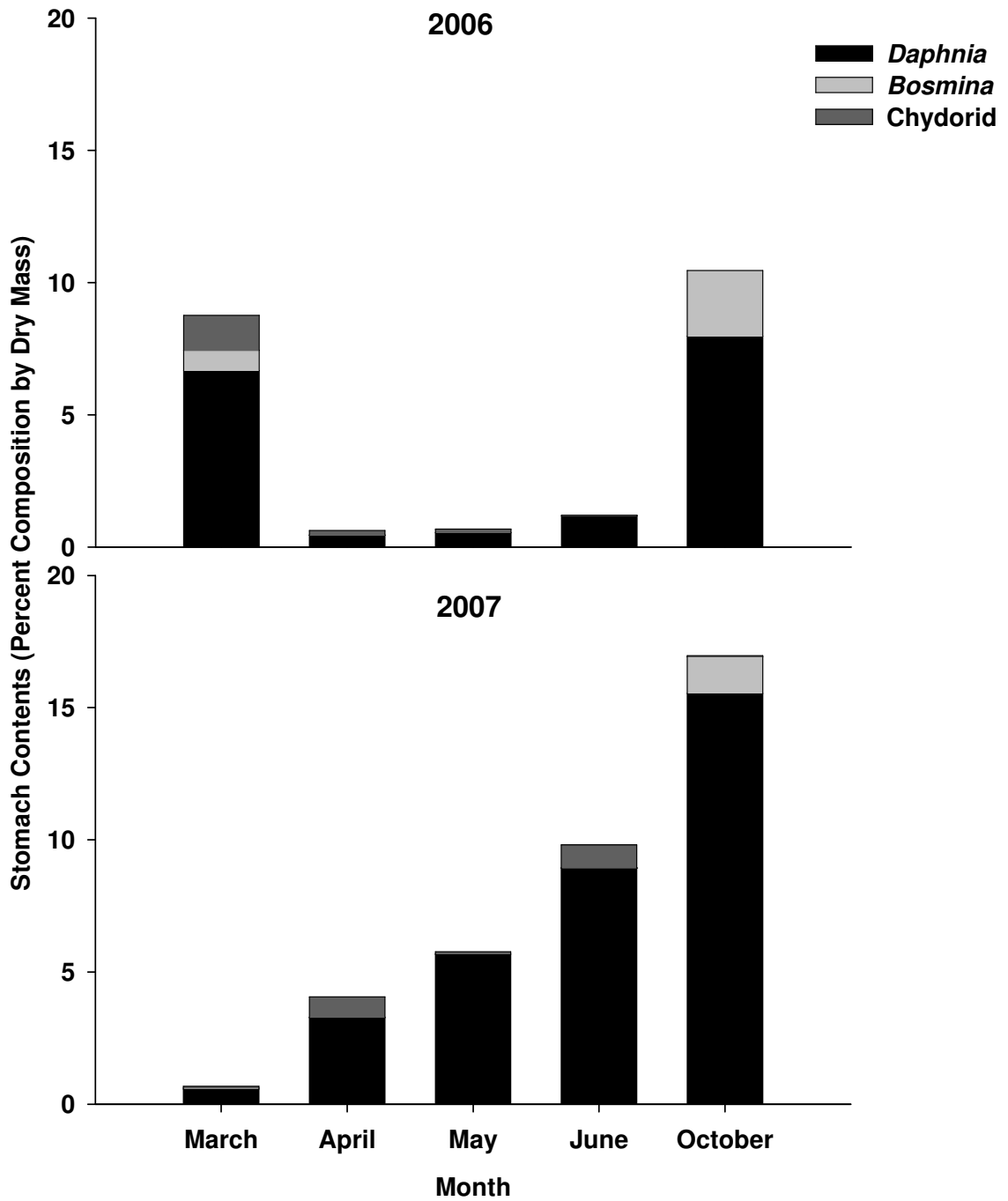


Figure 16. Stomach contents in percent cladoceran composition by dry mass for bluegill collected during the five sampling dates of 2006 and 2007 from Campus Lake, Jackson County, Illinois.

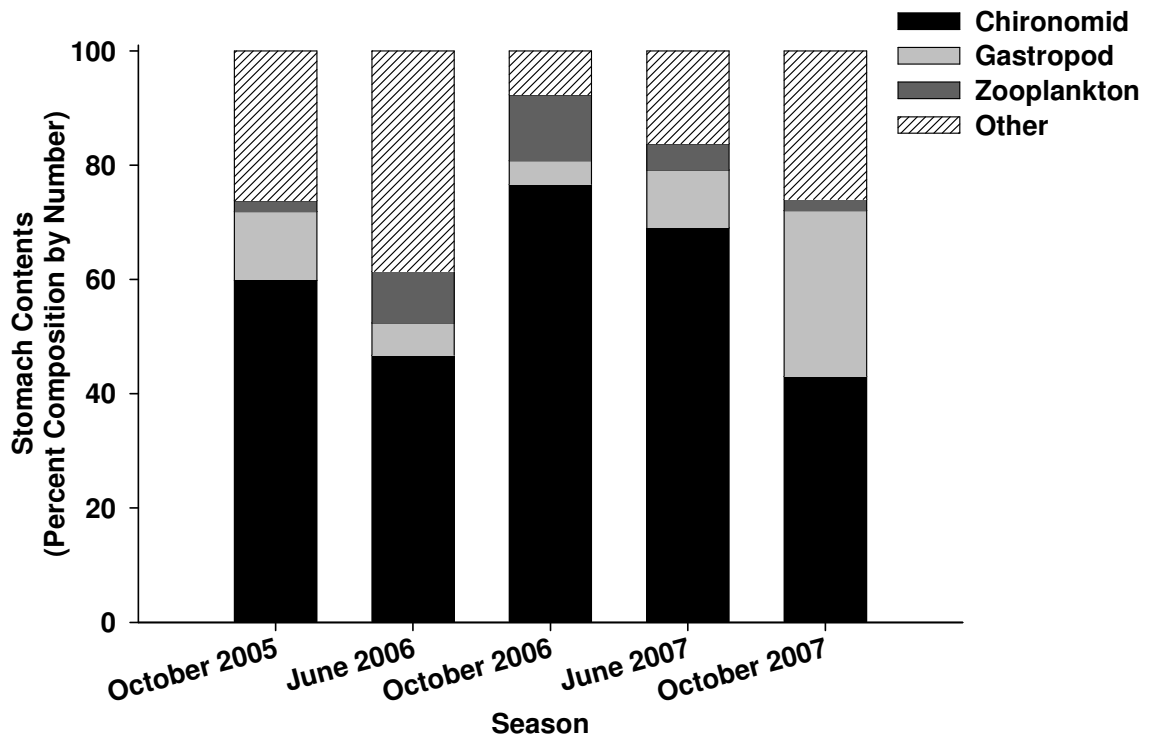


Figure 17. Stomach contents in percent composition by number for redear sunfish collected during October 2005 to October 2007 from Campus Lake, Jackson County, Illinois.

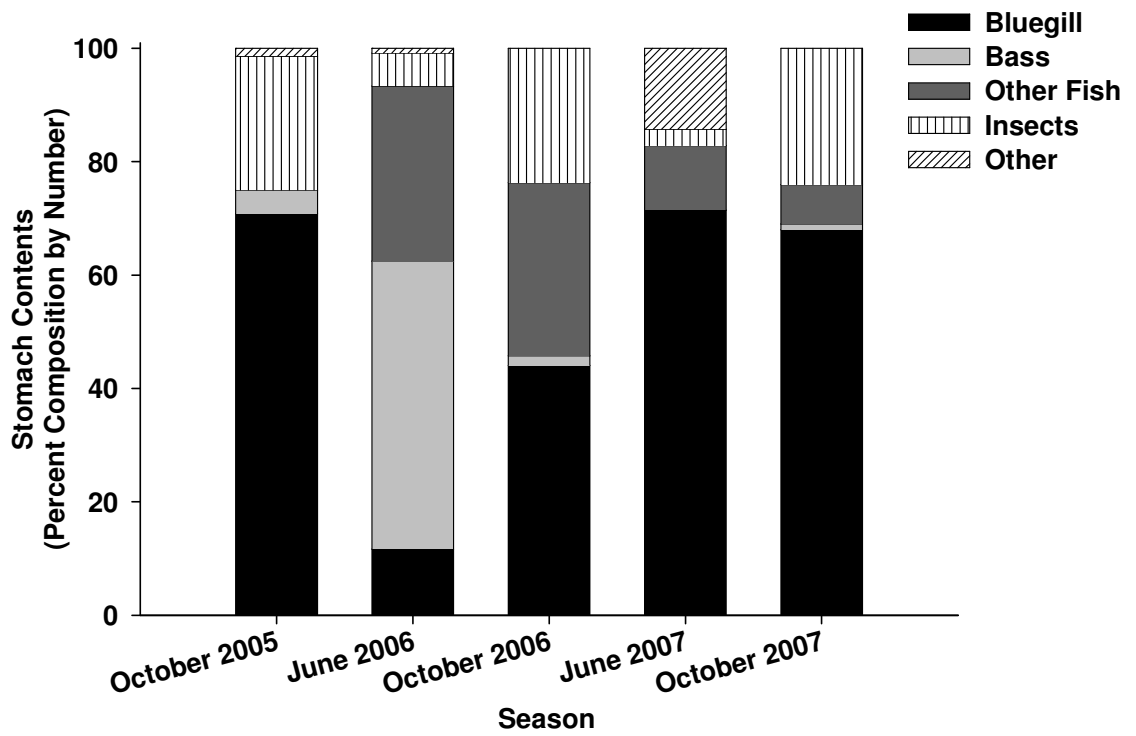


Figure 18. Stomach contents in percent composition by number of adult largemouth bass (> 60 mm TL in June or > 0 years of age in October) collected during October 2005 to October 2007 from Campus Lake, Jackson County, Illinois.

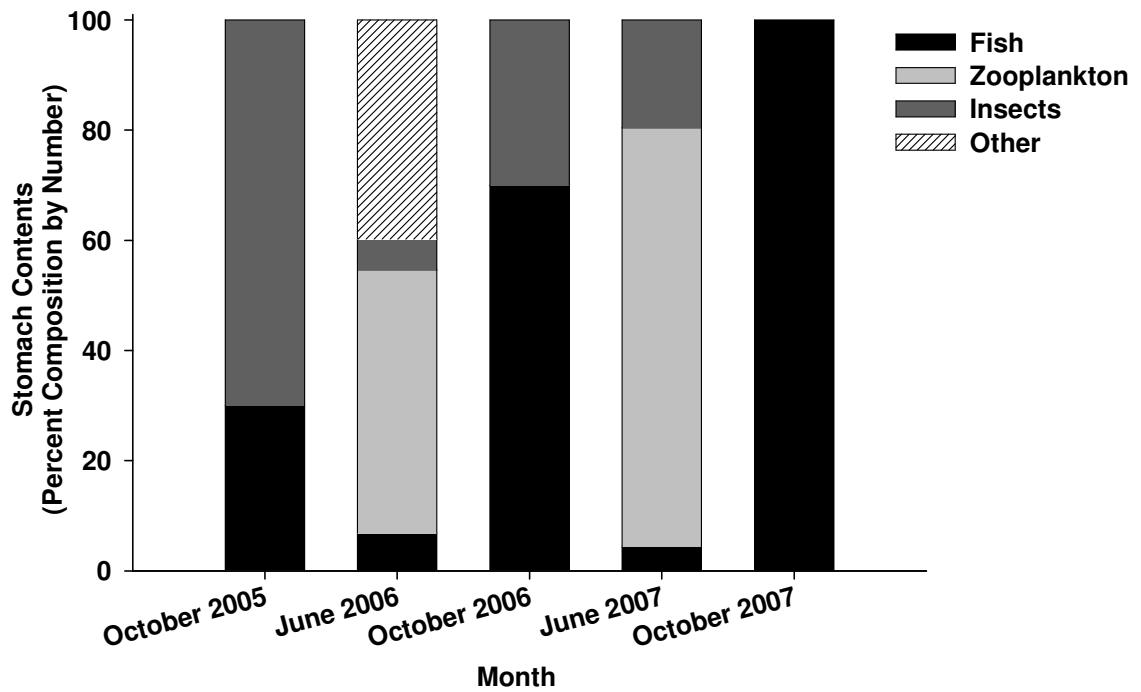


Figure 19. Stomach contents in percent composition by number of young-of-the-year (YOY) largemouth bass (< 60 mm TL in June or 0 years of age in October) collected during October 2005 to October 2007 from Campus Lake, Jackson County, Illinois.

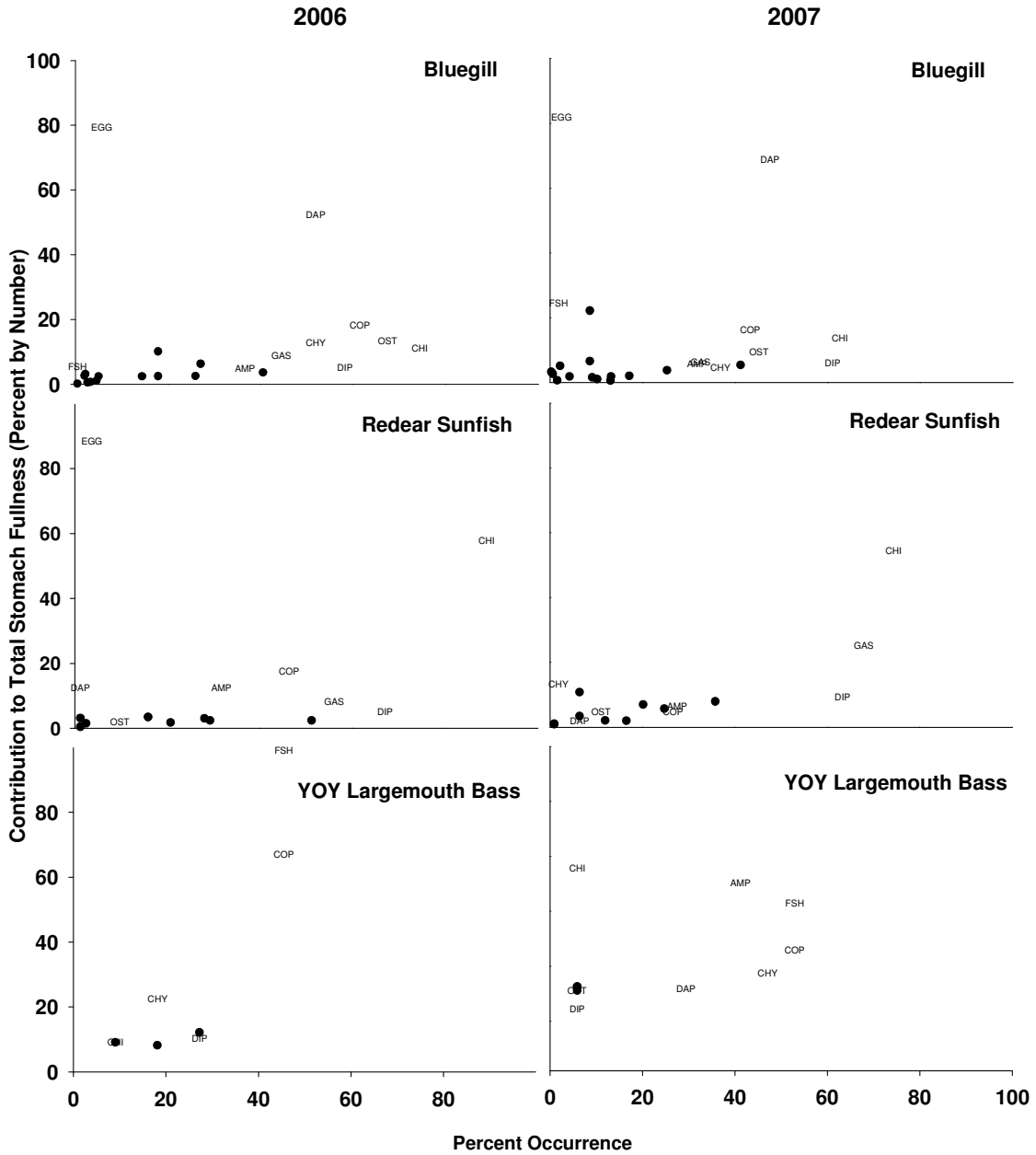


Figure 20. Feeding strategy, based off the graphical method from Amundsen et al. (1996) for different species of fish from Campus Lake, Jackson County, Illinois. Three letter abbreviations represent individual prey types as follows: AMP=amphipod, CHI=chironomid, CHY=chydorid, COP=copepod, DAP=*Daphnia*, DIP=dipteran pupae, EGG=fish eggs, FSH=fish, GAS=gastropod, and OST=ostracod. Black circles represent other less important prey types.

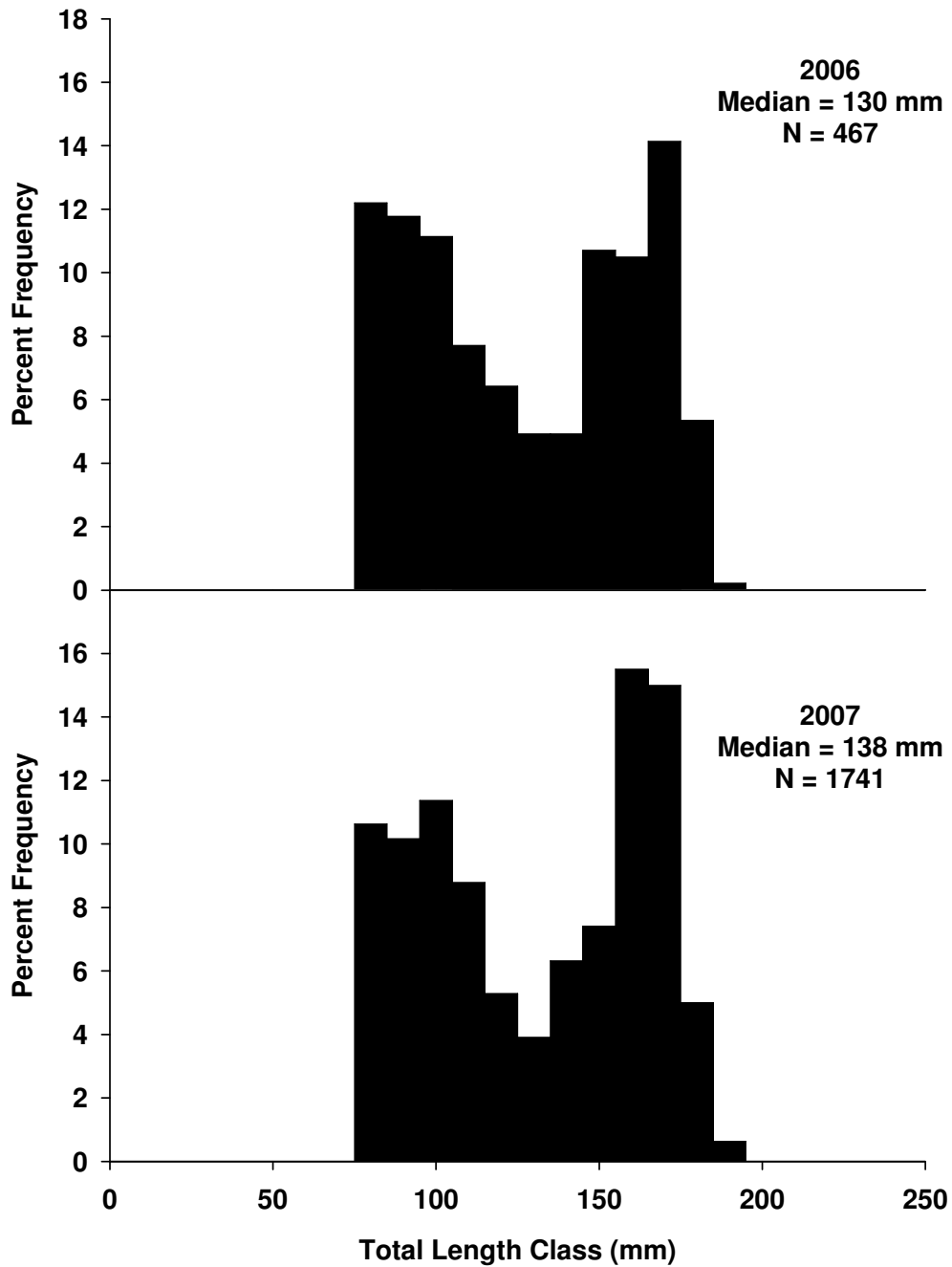


Figure 21. Percent frequency of bluegill at least stock length captured in Campus Lake, Jackson County, Illinois during summer mark-recaptures in 2006 and 2007. Median length and sample size are indicated for each year.

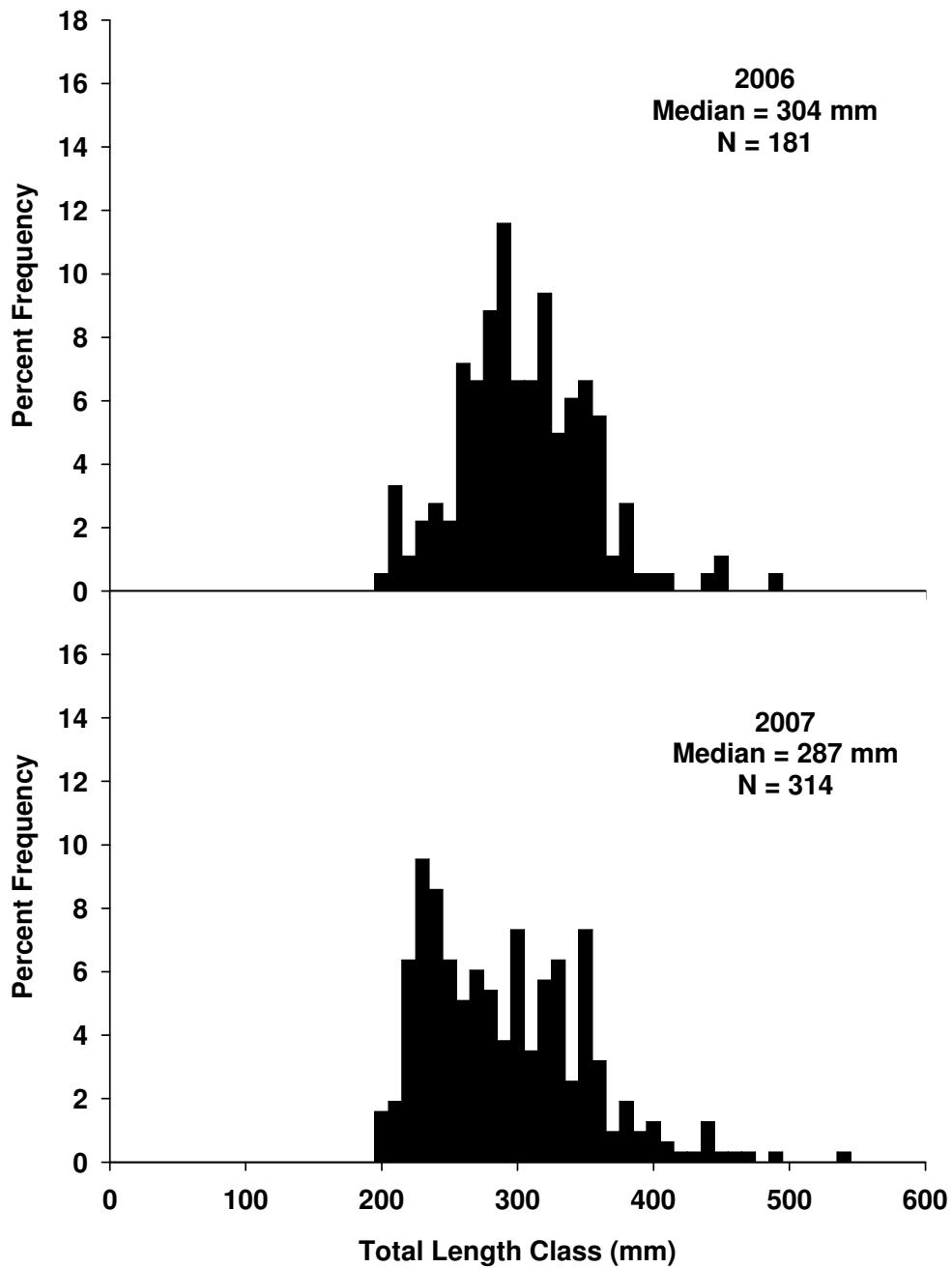


Figure 22. Percent frequency of stock largemouth bass at least stock length captured in Campus Lake, Jackson County, Illinois during summer mark-recaptures in 2006 and 2007. Median length and sample size are indicated for each year.

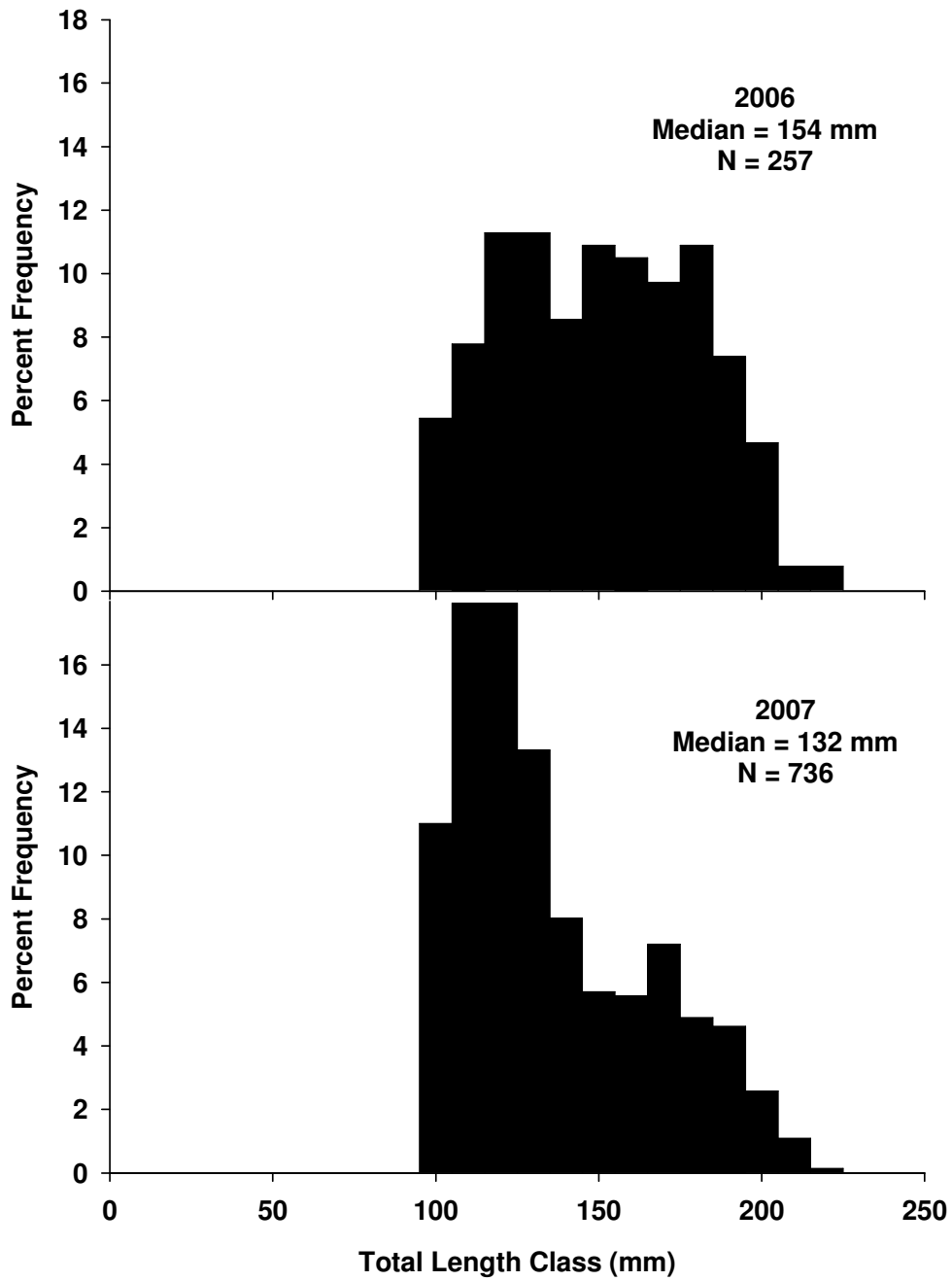


Figure 23. Percent frequency of redear sunfish at least stock length captured in Campus Lake, Jackson County, Illinois during summer mark-recaptures in 2006 and 2007. Median length and sample size are indicated for each year.

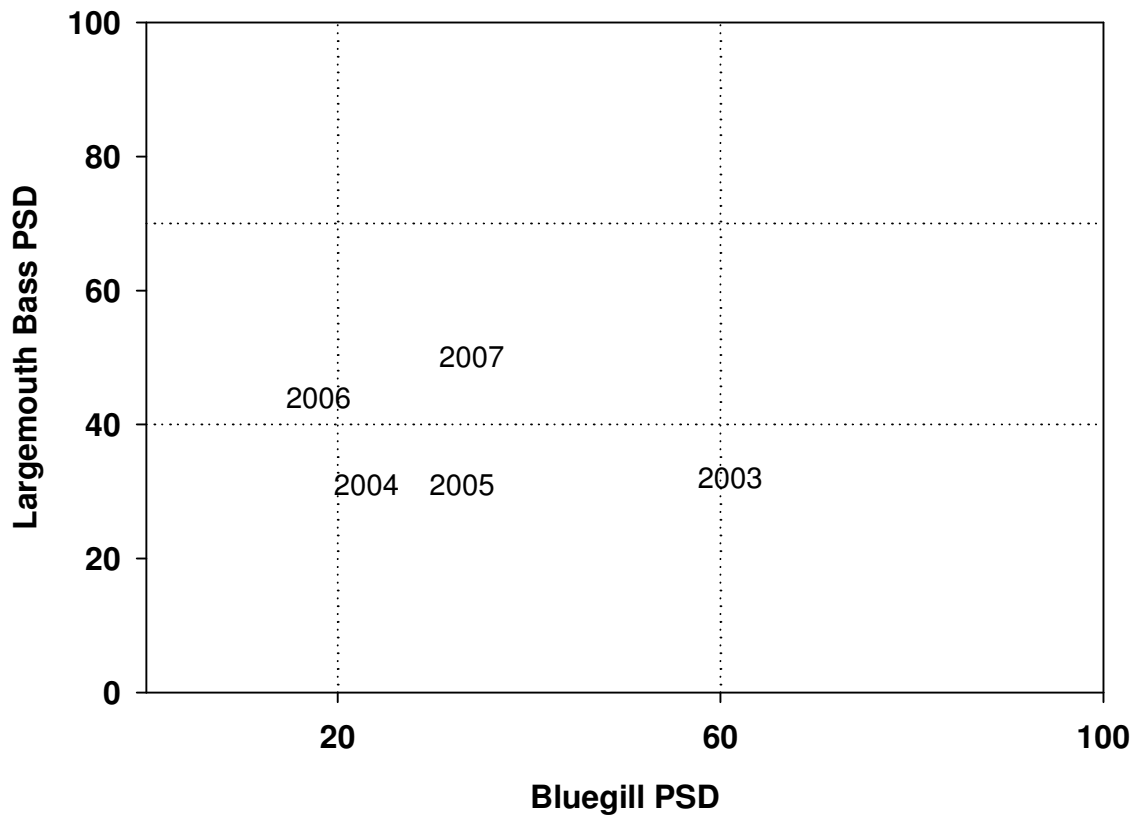


Figure 24. Proportional stock density (PSD) for bluegill and largemouth bass from Campus Lake, Jackson County, Illinois based on fall 2003 to fall 2007 surveys. Dotted lines indicate “goal ranges” for these species (Anderson 1985). 2003 and 2004 data collected courtesy of R. Neumann and obtain courtesy of R. Brooks.

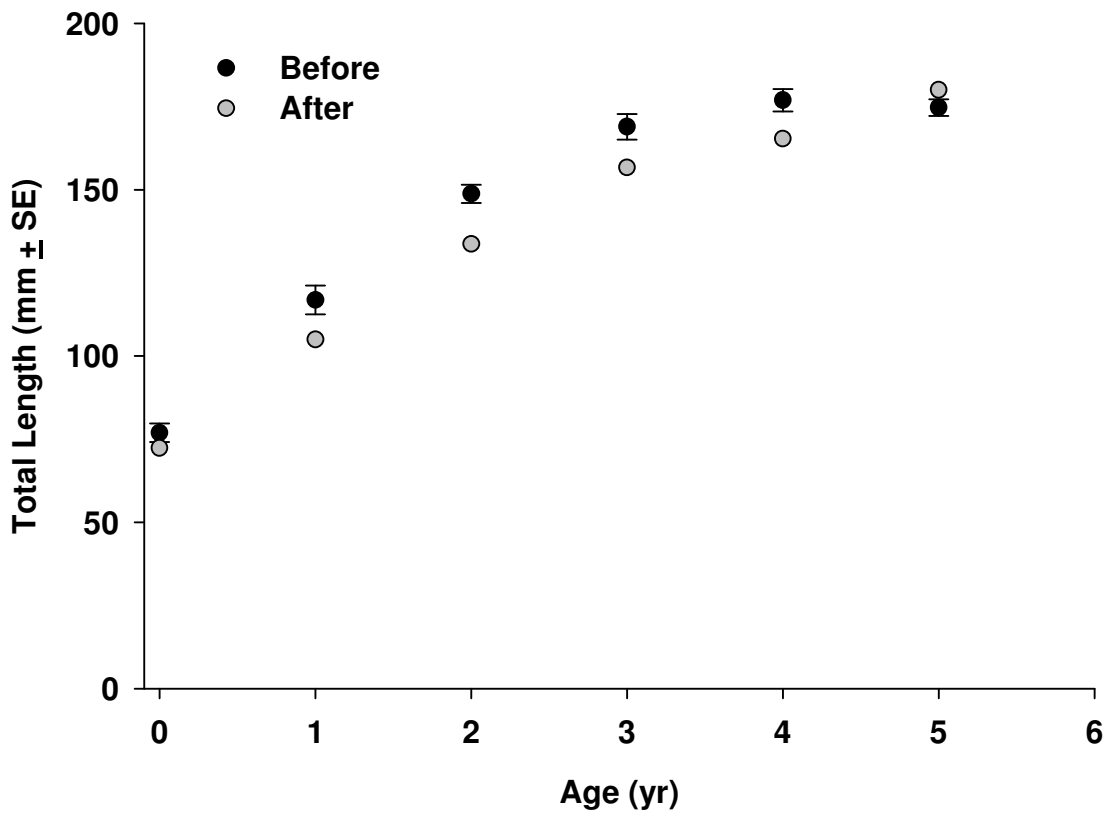


Figure 25. Mean length at age at capture of bluegill captured during October 2003 to October 2007 from Campus Lake, Jackson County, Illinois. “Before” data represent means and standard errors of 2003 to 2006; “After” data represent 2007. 2003 and 2004 data collected courtesy of R. Neumann and obtain courtesy of R. Brooks.

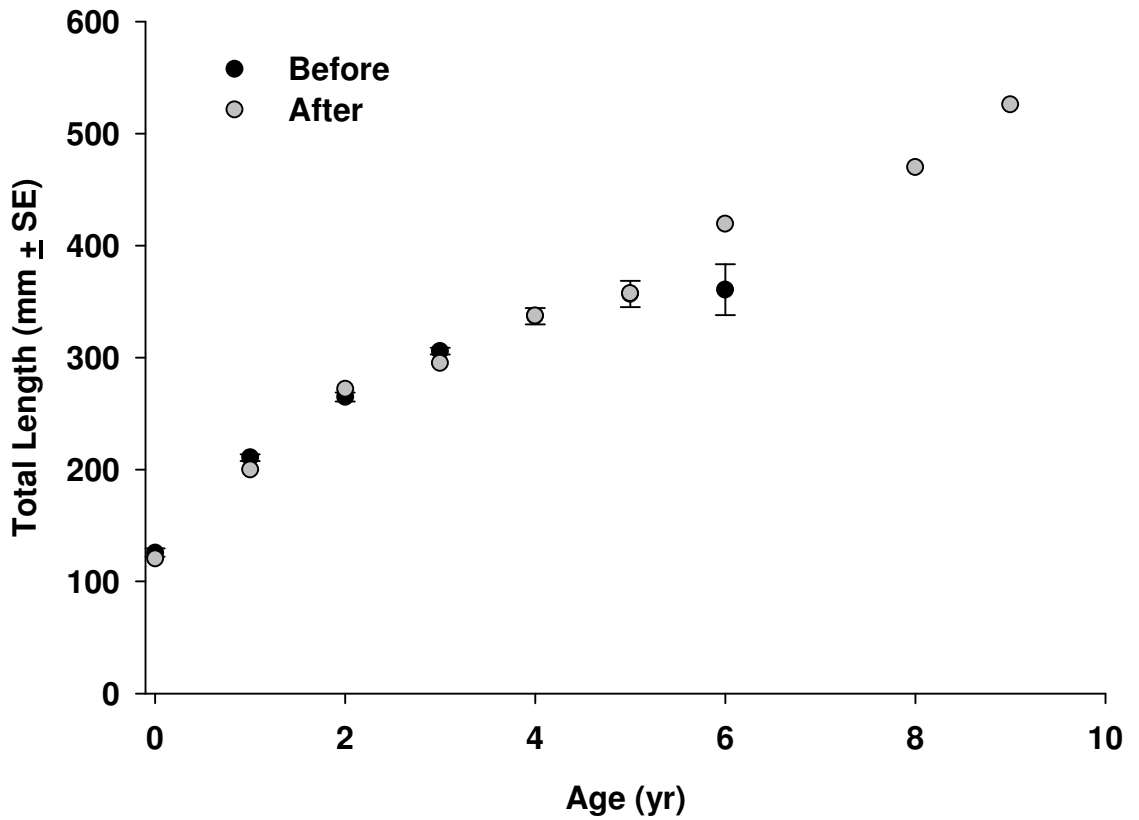


Figure 26. Mean length at age at capture of largemouth bass captured during October 2003 to October 2007 from Campus Lake, Jackson County, Illinois. “Before” data represent means and standard errors of 2003 to 2006; “After” data represent 2007. 2003 and 2004 data collected courtesy of R. Neumann and obtain courtesy of R. Brooks.

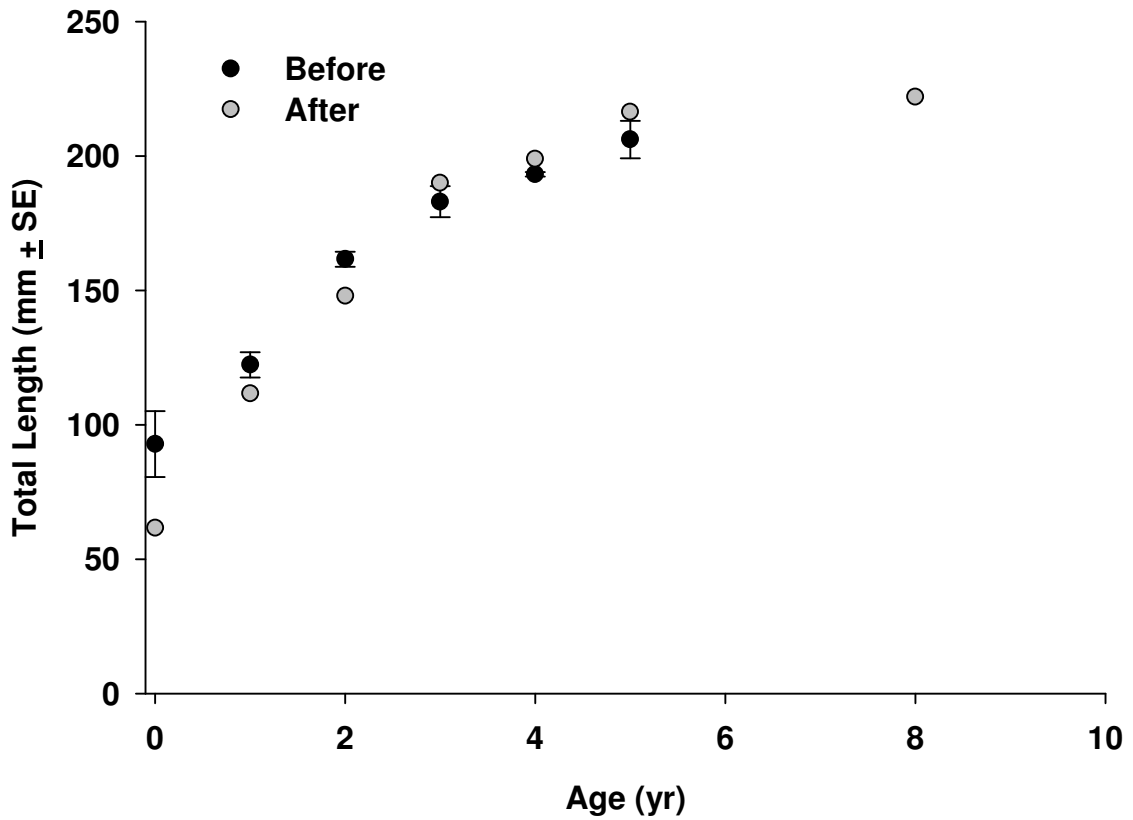


Figure 27. Mean length at age at capture of redear sunfish captured during October 2003 to October 2007 from Campus Lake, Jackson County, Illinois. “Before” data represent means and standard errors of 2003 to 2006; “After” data represent 2007. 2003 and 2004 data collected courtesy of R. Neumann and obtain courtesy of R. Brooks.

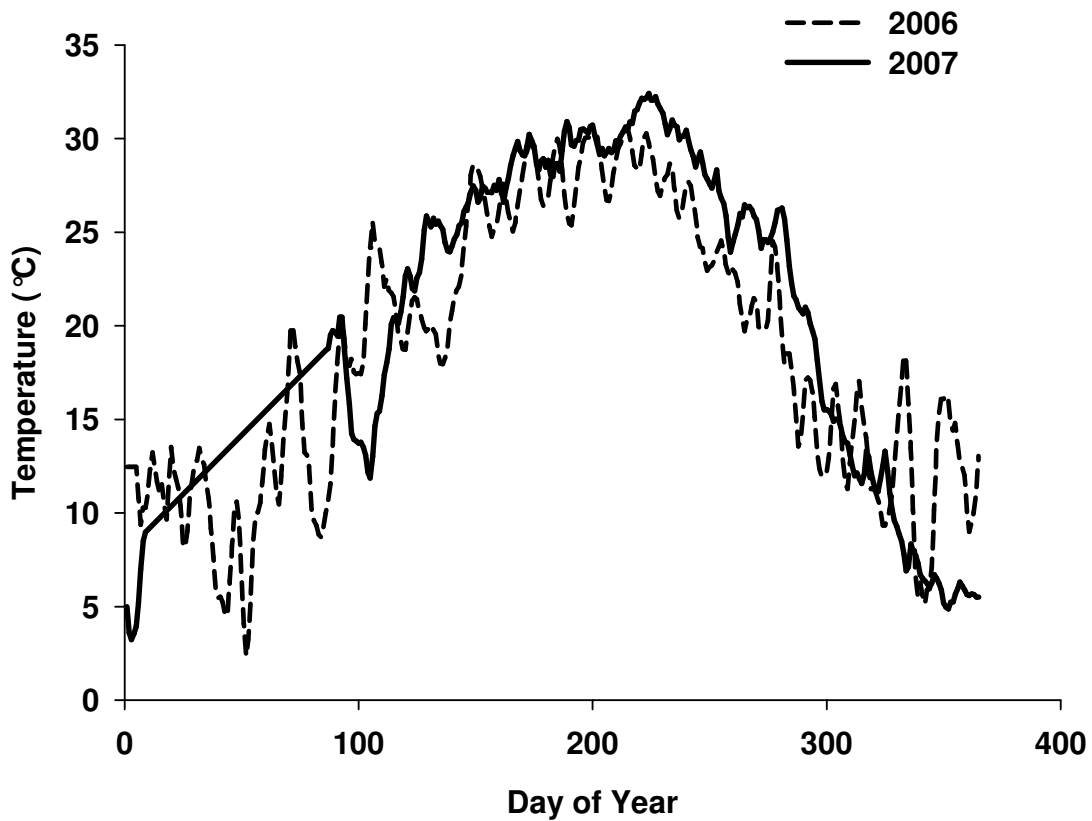


Figure 28. Mean daily water temperature for Campus Lake, Jackson County, IL during 2006 and 2007. Values from 2007 were recorded with a temperature logger, while values from 2006 were obtained using 2006 mean daily air temperatures and a mean daily air temperature-water temperature regression calculated for 2007. All air temperatures were obtained from the National Oceanic and Atmospheric Association in Paducah, Kentucky. No data was collected for a portion of early 2007, so a constant increase was assumed while temperature was not being recorded.

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VITA

Graduate School
Southern Illinois University

Nicholas C. Wahl

Date of Birth: November 9, 1983

290 Warren Rd. #27, Carbondale, Illinois 62901

Southern Illinois University Carbondale
Bachelor of Science, Zoology, May 2006

Thesis Title:

DETERMINING THE EFFECTS OF A PLANKTIVORE BIOMANIPULATION
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