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Pond Management Approaches and Effects on Trophic Dynamics

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Pond management approaches and effects on trophic dynamics

By

Michael Scott Sherman

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in the Department of Wildlife, Fisheries and Aquaculture

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Pond management approaches and effects on trophic dynamics

By

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Mississippi has an abundance of ponds which provides a number of opportunities for anglers. Several enhancement strategies are used to improve fish production in ponds, including fertilizing and supplemental feeding. These strategies may ignore the potential ecological impacts that may unexpectedly arise, such as prolific plant growth. This study consists of two phases; first, a mesocosm experiment investigating fertilizer application rates (mg P/L) in relation to potential sunfish growth, and second, a replicated pond experiment consisting of four treatments to simulate commonly used enhancement strategies. Mesocosm experiment showed a peak of sunfish growth at the 0.6 mg P/L level and served as a high fertilizer threshold level in pond experiment. Ponds were surveyed to assess treatment effects on each trophic level. The costs associated with each pond management strategy were documented. Results from this research help refine management recommendations to maximize results while minimizing costs to landowners and ecosystems.

DEDICATION

I dedicate this to my family and friends for their much needed support and love throughout this graduate process. To my wife, Samantha, who always supports me and has sacrificed so much along the way. To my parents, Scott and Michelle, mother-in-law, Donna, and sister-in-law, Tricia, who continue to show love and help me as much as possible.

ACKNOWLEDGEMENTS

I would like to thank Dr. Eric Dibble for bringing me into the graduate program and taking a chance on me. Thanks for being a mentor, educator and a true blessing throughout this entire graduate process. I also thank my committee members, Drs. John Madsen, and Ian Munn for their valuable time and assistance with my research and thesis. A special thanks to Drs. Ryan Wersal, Rachel Schultz, and Jonathan Fleming for much needed advice and assistance. Many thanks to all of the lab technicians, Neil Branson, Cody Cotton, Nathan Herring, and Phil Malone; without their hard work this project would have not been successful. In addition, I would like to thank Dr. Bruce Leopold and the Department of Wildlife, Fisheries and Aquaculture's faculty and staff for financial, support and guidance.

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CHAPTER I

INTRODUCTION

Ponds and small impoundments are vital fisheries resources throughout the United States. There are approximately 1.2 million hectares of ponds in the southeastern United States and many of these ponds are used to culture sportfish for recreational fishing (Boyd et al. 2002). Much of the angling effort is conducted in privately-owned and public ponds. Many anglers may prefer to fish ponds instead of larger bodies of water due to their proximity to anglers' homes, and because many anglers do not have the boat access needed to exploit larger water bodies (Mudre et al. 2002). Also, pond owners are able to provide themselves an alternative source of income by permitting public access on a fee basis. Furthermore, pond owners may prefer and enjoy creating and managing their own fishery. Therefore, ponds and small impoundments are promising future resources in the southeastern United States (Olive 2004).

Commonly, pond owners in the southeastern United States are prescribed to add fertilizer to their ponds to maximize fish production. This prescription does meet the goal of maximum fish production at 200 to 400 pounds per acre per year (Brunson et al. 1999), but it may overlook the associated costs of algae or aquatic plant control. Although the goal of fertilization is to stimulate a phytoplankton bloom, too much of a bloom may cause problems with water quality and nuisance aquatic plants. Dense phytoplankton blooms with secchi disk visibility less than 0.30 meters can lead to low dissolved oxygen due to phytoplankton die-offs, lower dissolved oxygen readings in the morning and elevated after-noon pH levels. Elevated pH levels increase concentrations of unionized (toxic) ammonia in the water. All of these negative conditions can stress fish. Furthermore, dense phytoplankton blooms can even produce toxins that are harmful to pets, livestock and other animals. Pond owners should consider the possibility of these potential impacts before applying fertilizer (Brunson et al. 1999).

Another common technique used by pond managers is to apply supplemental feed to fish in a pond. By providing a direct food resource typically to bluegill (*Lepomis macrochirus*), pond managers are able to improve the condition of bluegill because the energy cost for bluegill to feed on pellets is low in relation to the high caloric intake, which can be 4-5 times greater than those fed natural foods (Schalles and Wissing 1976). Supplemental feeding with pellets is used by pond owners to increase bluegill production, because fish growth often is limited by food resource availability (Lewis and Heidinger 1971; Murnyak et al. 1984; Porath et al. 2003). However, excessive feed may be utilized by phytoplankton and increase populations causing excessive algal blooms, and accelerated decomposition resulting in low dissolved oxygen levels.

Although many pond owners use these common techniques such as supplemental feeding and fertilizing, some prefer not to put any nutrients in their pond to prevent unsightly algal blooms for aesthetically pleasing purposes. Most times with no excessive nutrient inputs, water clarities tend to be high and more aquatic macrophytes tend to grow. Although macrophytes can provide many benefits to an aquatic ecosystem such as refuge, shelter and various feeding opportunities for fish and invertebrates (Dibble et al. 1996), population levels can reach nuisance levels and are often subjected to costs of management efforts such as physical, chemical, and biological treatments (Wiley et al. 1984). Aquatic macrophyte infestations can reduce sportfishing yields by hindering foraging efficiency and pose as an obstacle for recreational users (Colle and Shireman 1980; Savino and Stein 1982; Wiley et al. 1984) Also, excessive nutrients from run-off, livestock, and fertilizing may cause nuisance filamentous algae blooms in which algaecide use will incur more costs.

Pond management may have different effects on trophic levels and aquatic community structure. Increasing nutrients such as phosphorus typically increase the biomass of phytoplankton and therefore increase the biomass of zooplankton and macroinvertebrates. Understanding the costs associated with each pond management strategy is important because potential costs may influence the approach a pond manager chooses to meet a desired end point. However, to my knowledge, no study has been conducted to investigate costs of the different management approaches using fertilizer and supplemental feeding, and the potential impact each strategy has on trophic levels (phytoplankton, zooplankton, macroinvertebrates and fish) within recreational fishing ponds.

Goal of Research

Goals of my research are to determine the influence of each of these common pond management practices on the trophic pathways within ponds, and to document economic costs associated with each pond management strategy. I relate these costs to potential benefits for fish production and overall ecological impact on the aquatic community by documenting all costs of management and investigating each trophic level (phytoplankton, zooplankton, macroinvertebrates and fish). It is my intent to use results from this research to help refine current pond management recommendations to maximize targeted results while minimizing the economic costs to landowners and negative ecological impacts to pond systems.

I conducted two experiments to investigate phosphorus levels on sunfish growth, pond management approaches on trophic levels and economic costs of different management approaches. Results of the mesocosm experiment are summarized in chapter II, and pond experiment results are summarized in Chapter III. Specific objectives included in chapter II were (1) investigate phosphorus levels on growth of sunfish and (2) investigate phosphorus levels on water transparency, chlorophyll *a* and phytoplankton community. Two phosphorus levels from chapter II mesocosm chapter were tested at a larger scale and served as a treatment in the chapter III pond experiment. My specific objectives for chapter III for pond experiment were (1) investigate effects of different pond management practices on phytoplankton, zooplankton, and macroinvertebrates and (2) investigate different pond management practices on total lengths and relative weights for bluegill and largemouth bass. The objective of chapter IV was to evaluate pond management practices on the condition of the ponds in terms of water quality parameters, aquatic plants and phytoplankton biomass and obtain costs of each management approach.

CHAPTER II

MESOCOSM EXPERIMENT

Introduction

Commonly, the biomass of producers and consumers increases along a gradient of increasing nutrient (phosphorus) loading (Mittelbach et al. 1988). Phosphorus levels can impact fish production by increasing plankton production and hence increasing quantity of food resources available for fish. Fishery managers have been using fertilizers to increase phytoplankton production for many years (Swingle and Smith 1947; Hepher 1962; Boyd and Tucker 1998). Furthermore, the primary purpose of fertilization is to supplement nutrient deficiency for the phytoplankton (Bhakta and Jana 2002). Typically fertilizers contain phosphorus which is necessary for phytoplankton growth and reproduction (Conte 2000; Dodds 2002) and among other major nutrients is recognized as the key limiting factor for regulating primary productivity in many freshwater ecosystems (Boyd 1990). Through a web of nutrient assimilation and recycling, nutrients in fertilizers are incorporated into algal and zooplankton biomass and eventually incorporated into fish biomass (Mischke and Zimba 2004). Fertilization can increase total pounds of fish generated in a pond, often by as much as three to four times that of the standing crop (Neal and Clardy 2010).

To help explain differences in fish production among treatments, water quality variables such as chlorophyll a (chl a) and transparency are often measured in fertilization experiments to reveal relationships among these variables and fish production (Wudtisin and Boyd 2005). Also, phosphorus concentrations can have impacts on total phytoplankton densities and it is important to understand these impacts because total phytoplankton densities can strongly impact food quantity for higher trophic levels. Many fertilization rates (kg P_2O_5 /ha) for ponds have been shown to increase sunfish production (kg/ha). Dobbins and Boyd (1976) and Lichtkopler and Boyd (1977) showed that 9 kg/ha per application of P_2O_5 as triple superphosphate was suitable fertilization for ponds that are heavily fished in wooded watersheds of the southern U.S. and a 4.5 kg/ha per application of P_2O_5 did not significantly reduce sunfish production. Lichtkopler and Boyd (1977) suggested that 4.5 kg/ha application rate is suitable for woodland ponds receiving low or moderate fishing pressure. Research conducted over a 50 year period showed that 4 kg P_2O_5 /ha per application was sufficient phosphorus fertilization for ponds at Auburn, AL (Boyd and Tucker 1998). However, Wudtisin and Boyd (2005) showed ponds fertilized with 3 kg P_2O_5 /ha and increasing by 1 kg P_2O_5 /ha to 7 kg P_2O/ha per application showed little difference in bluegill production (kg/ha) and that 3 kg P_2O_5 /ha per application with adequate available nitrogen was sufficient for maximum bluegill production. Many studies have focused on fertilizing at surface acre rates but those studies do not consider pond depth. To achieve a target P concentration, pond average depth and area need to be considered when fertilizing.

Typically ponds and smaller lakes in the south and southeast are fertilized to increase nutrient levels so that primary productivity will increase and support more biomass of consumers. Although fertilizing has been shown to increase the net fish production, less is known on which phosphorus level (mg P/L) yields maximum sunfish production in terms of mean individual fish mass (g), total fish mass gain (g) and survivor fish mass gain (g). The goal of this study was to conduct a mesocosm experiment to evaluate different phosphorus concentrations on total phytoplankton density and sunfish production in terms of individual fish mass, total fish mass gain and survivor fish mass gain to determine which phosphorus concentration would yield maximum sunfish production. I measured weights (g) of fingerling bluegill (*Lepomis macrochirus*) and redear sunfish (*Lepomis microlophus*) before and after treatments to determine maximum sunfish production for each phosphorus concentration (mg P/L). I also investigated the relationship among different phosphorus concentrations (mg P/L) on water clarity, chlorophyll a and total phytoplankton density.

Methods

Experimental Design

I initiated experiment on April 19th, 2010 which extended through July 20th, 2010. There were 30 mesocosm tanks used at the Mississippi Agriculture Forestry Experimental Station located on the Mississippi State University campus. Tanks were 2.44 meters in diameter and 1.37 meters in height. The experiment constituted a treatment of 10 different phosphorus levels (mg P/L): 0.03; 0.06; 0.09; 0.12; 0.18; 0.24; 0.30; 0.60; 0.90; 1.20 mg P/L. The fertilizer source was potassium phosphate monobasic with 22.8% P.

Tanks were filled with 5,689 liters of well water at a depth of 1.22 meters and also, enriched with five gallons of pond water. The fertilizer amount was calculated by the following equation:

$$\text{mg P needed} = \text{mg P/L} \times 5{,}689 \text{ liters} / 0.228 \text{ P} \tag{2.1}$$

The mg P/L levels were randomly allocated to 30 tanks, replicating each level three times. Water level in all tanks was maintained throughout the experiment. Water transparency and chlorophyll *a* were measured during the middle of the day (10:00 a.m. to 1:00 p.m.) weekly through July 2010. Transparency was measured with a 120 cm transparency tube with a secchi disk at the bottom to estimate water clarity for each treatment (Dahlgren et al. 2004). *In vivo* chlorophyll *a* (chl *a*) was measured with an AquaFluor™ handheld fluorometer (Turner Designs, Sunnyvale, CA) to estimate algae density for each treatment (Wersal and Madsen 2011). To ensure adequate dissolved oxygen was available for fish, oxygen was pumped from two air stones from a forced-air blower for each tank. Water temperature and pH values were obtained with a Eureka manta multi-probe (Eureka Environmental Engineering, Austin, TX) weekly between 10:00 a.m. and 2:00 p.m. Water temperatures ranged from 24.09 ºC at the beginning of the study to 31.38 ºC at the end. The pH values ranged from 8.28 to 10.43. Two 25 ml water samples were taken from each tank in May and June and preserved in 4% formalin. Total phytoplankton density (cells/ml) were counted in five separate 1ml sedgewick grafter cells for each water sample and looked at five separate field views for each grafter cell under microscope at 200X magnification (Woelkerling et al. 1976). Phytoplankton was identified by Dillard 2008 and Belleinger and Sigee 2010.

Fingerling redear and bluegill were obtained from the North Mississippi Fish Hatchery in Enid, MS. A sub-sample of 25 sunfish were obtained from the collection and euthanized with 500 mg/L of tricaine methanesulfonate (MS-222) (Argent Chemical Laboratories Inc., Redmond, WA), then preserved in 10% formalin and returned to a lab in the Department of Wildlife, Fisheries and Aquaculture at Mississippi State University. In the laboratory, wet weight was measured to the nearest 0.01 gram using an electronic gram scale to obtain a mean fish weight (g) prior to stocking (Qin et al. 1994). Thirty fingerling redear and five fingerling bluegill were stocked in each tank on May 20th 2010. Tanks were drained July 20th 2010 and fish were collected and taken to the lab to be enumerated and weighed as described above.

Mean individual fish weight (g) per phosphorus level = (total fish weight per tank / total

fish count) all three replicates summed / 3 (2.2)

Total fish mass gain = total weight at end (g) – total initial weight (g). (2.3)

Survivor fish mass gain = Total weight at end (g) – (# Bluegill (initial weight)) +

(# Redear (initial weight)) (2.4)

Data Analysis

Mean individual fish mass, total fish mass gain, survivor fish mass gain, transparency, chl *a*, and total phytoplankton density were analyzed using nonlinear regression analysis. Number of fish that survived in each tank was analyzed using one way analysis of variance (ANOVA) using SAS version 9.2 (SAS Institute, Cary, NC). A Shapiro-Wilk test was performed to determine if the population was normally distributed. All tests were considered significant at $P < 0.05$.

Results

Mean individual fish mass showed a concave quadratic relationship ($R^2 = 0.58$, $P < 0.001$) with increasing phosphorus concentrations (Figure 2.1). Mean individual fish mass relatively increased as phosphorus concentration increased up to 0.6 mg P/L then subsequently began to decrease. Total fish mass gain showed a concave quadratic relationship ($R^2 = 0.44$, $P < 0.001$) with increasing phosphorus concentrations (Figure 2.2). Total fish mass gain relatively increased as phosphorus concentration increased up to 0.6 mg P/L then subsequently began to decrease. Survivor fish mass gain showed a concave quadratic relationship ($R^2 = 0.50$, $P < 0.001$) with increasing phosphorus concentrations (Figure 2.3). Survivor fish mass gain relatively increased as phosphorus concentration increased up to 0.6 mg P/L then subsequently began to decrease. Number of fish that survived did not differ significantly ($F = 0.82$, $P = 0.6$) among phosphorus concentrations (Table 2.1)

Mean transparency (Figure 2.4) ranged between 27 and 47 cm, and tended to decrease with increasing phosphorus concentrations ($R^2 = 0.67$, $P = 0.003$). Mean chlorophyll *a* (Figure 2.5) ranged between 3.67 and 61.62 µg/L, and tended to increase with increasing phosphorus concentrations ($R^2 = 0.92$, $P < 0.001$). Total phytoplankton for May showed a concave quadratic relationship ($R^2 = 0.48$, $P = 0.004$) with increasing phosphorus concentrations (Figure 2.6). Total phytoplankton densities for May relatively increased as phosphorus concentration increased up to 0.9 mg P/L then subsequently began to decrease. However, total phytoplankton densities for June were not correlated ($P = 0.07$) with increasing phosphorus concentrations (Figure 2.7).

Discussion

My goal was to evaluate different phosphorus concentrations that would give maximum sunfish production in terms of individual fish mass, total fish mass, and survivor fish mass. From the experiment, greatest mean for individual fish mass, total fish mass and survivor fish mass came from the 0.6 mg P/L concentration and tended to decrease thereafter. This may indicate there is a phosphorus concentration threshold for maximum individual fish growth as well as total fish mass. Similarly the positive correlation of chl a with phosphorus concentration suggests that a maximum threshold may exist for the phytoplankton biomass in which fish growth is maximized then ceases or decreases thereafter. Similar results have been seen in another fertilization experiment. Wudtisin and Boyd (2005) showed bluegill production increased up to a phosphorus rate of 3 kg P_2O_5/ha and leveled off at greater rates. Production was between 501 and 558 kg/ha at phosphorus rates of 3–7 P_2O_5/ha, and bluegill production and chl a peaked at the 5 kg P_2 O_5 /ha, and data conformed to a saturation relationship.

Many studies for sunfish production has focused on fertilizing at surface acre rates, but much success has been seen with fertilizing at nutrient concentration levels considering entire volume of aquaculture pond for saugeye (F_1 hybrid of female walleye [*Stizostedion vitreum*] X male sauger [*Stizostedion canadense*]) and walleye (*Sander vitreus*) production (Culver 1991; Jacob and Culver 2010). For this study I also fertilized at a concentration level; however, instead of weekly nitrogen and phosphorus fertilization, I focused on phosphorus fertilizing only at the beginning of study. Previous studies revealed that response of fish production to increasing fertilization may be related primarily to phosphorus rather than nitrogen addition (Wudtisin and Boyd 2005; Boyd and Tucker 1998) and phosphorus fertilization was more important than nitrogen fertilization (Boyd and Tucker 1998).

Many studies have shown that fertilized ponds increase in zooplankton density compared to unfertilized ponds (McIntire and Bond 1962; Hall et al. 1970). Different zooplankton or macroinvertebrates densities could have played roles in the different weight gains in the tanks. Sampling mesocosm tanks for macroinvertebrates and zooplankton was unsuccessful due to excessive filamentous algae constraining sampling equipment, therefore, structure and density of prey items in the treatment tanks with the sunfish were unknown. Future studies should focus on fertilizing effects on the aquatic community structure for these sunfish prey items as well as the overall impact on trophic level interactions in a given aquatic ecosystem.

Table 2.1 Mean (± SE) % survival, and fish count at the end of experiment for each mg P/ L level in mesocosm experiment conducted at Mississippi Agricultural Forestry Experimental Station, 2010.

mg P/L	% Survival	Fish Count
0.03	34.33 ± 6.0	12.00 ± 2.1
0.06	52.33 ± 12.5	18.33 ± 4.4
0.09	35.00 ± 9.8	12.33 ± 3.5
0.12	40.67 ± 13.4	11.00 ± 3.8
0.18	38.00 ± 4.4	13.33 ± 1.5
0.24	41.67 ± 5.8	14.67 ± 2.0
0.3	29.67 ± 4.1	10.33 ± 1.5
0.6	31.33 ± 4.9	11.00 ± 1.7
0.9	28.67 ± 6.6	10.00 ± 2.3
1.2	35.33 ± 8.4	12.33 ± 2.9

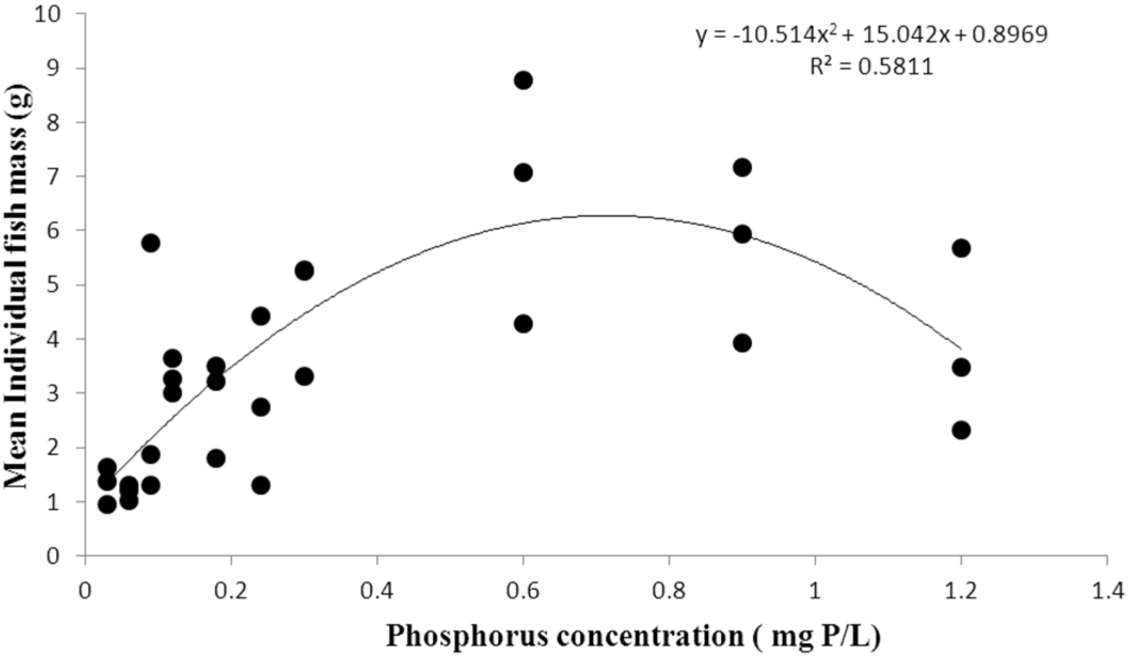

Figure 2.1 Mean individual fish mass (g) and phosphorus concentrations (mg P/L) for mesocosm experiment conducted at Mississippi Agricultural Forestry Experimental Station, 2010.

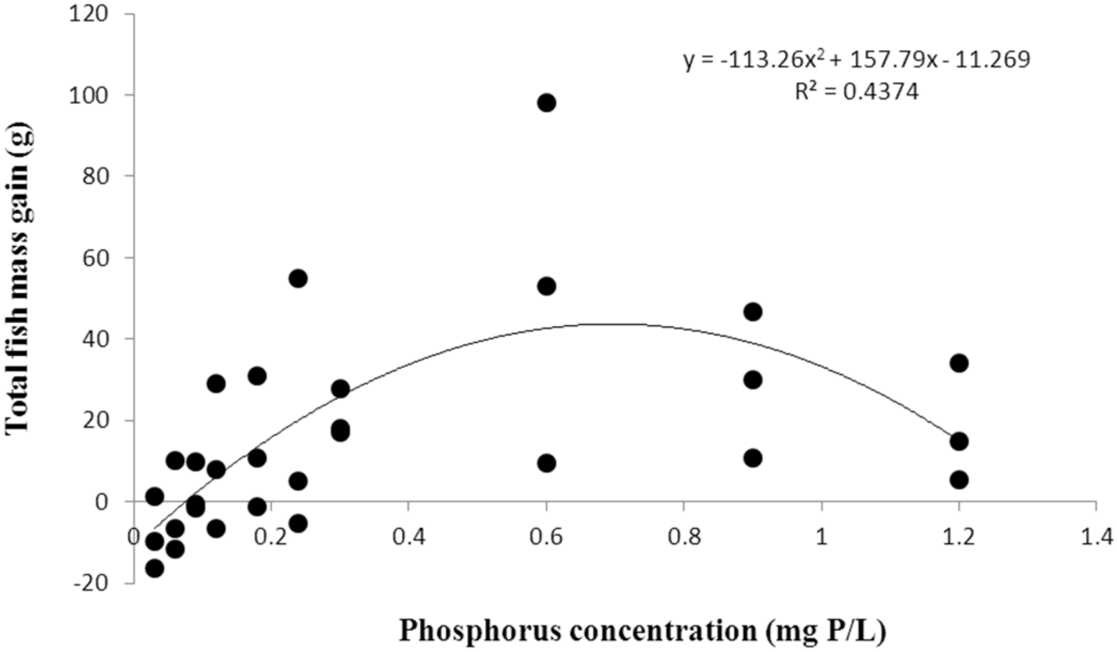

Figure 2.2 Total fish mass gain (g) and phosphorus concentrations (mg P/L) for mesocosm experiment conducted at Mississippi Agricultural Forestry Experimental Station, 2010.

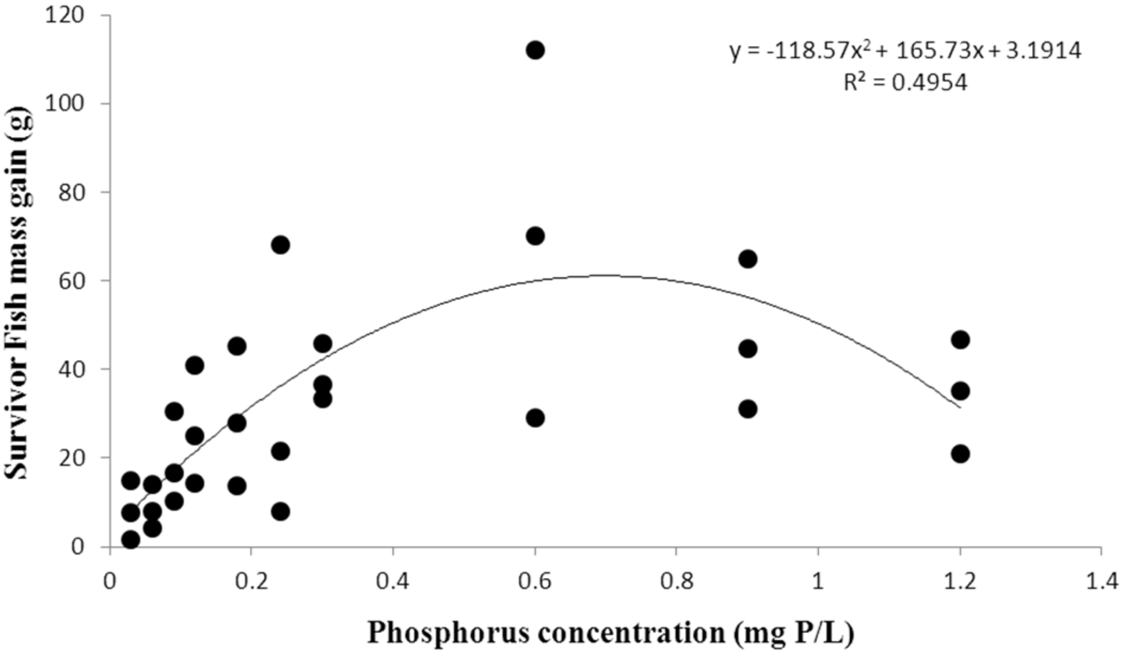

Figure 2.3 Survivor fish mass gain (g) and phosphorus concentrations (mg P/L) for mesocosm experiment conducted at Mississippi Agricultural Forestry Experimental Station, 2010.

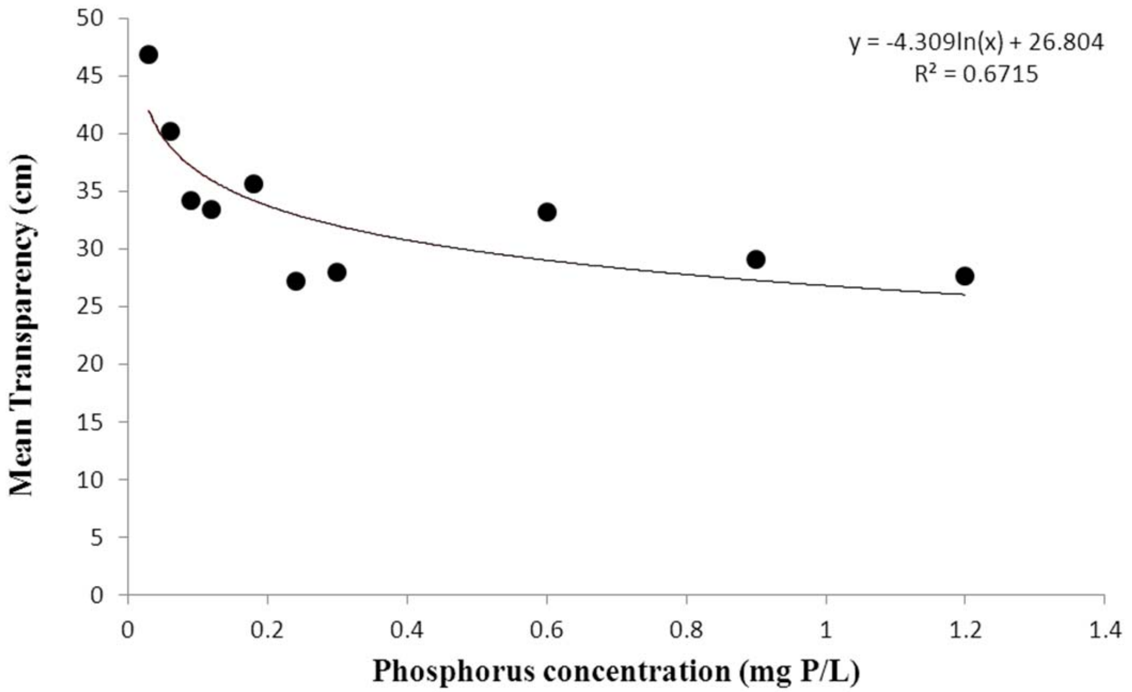

Figure 2.4 Mean transparency (cm) and phosphorus concentrations (mg P/L) for mesocosm experiment conducted at Mississippi Agricultural Forestry Experimental Station, 2010.

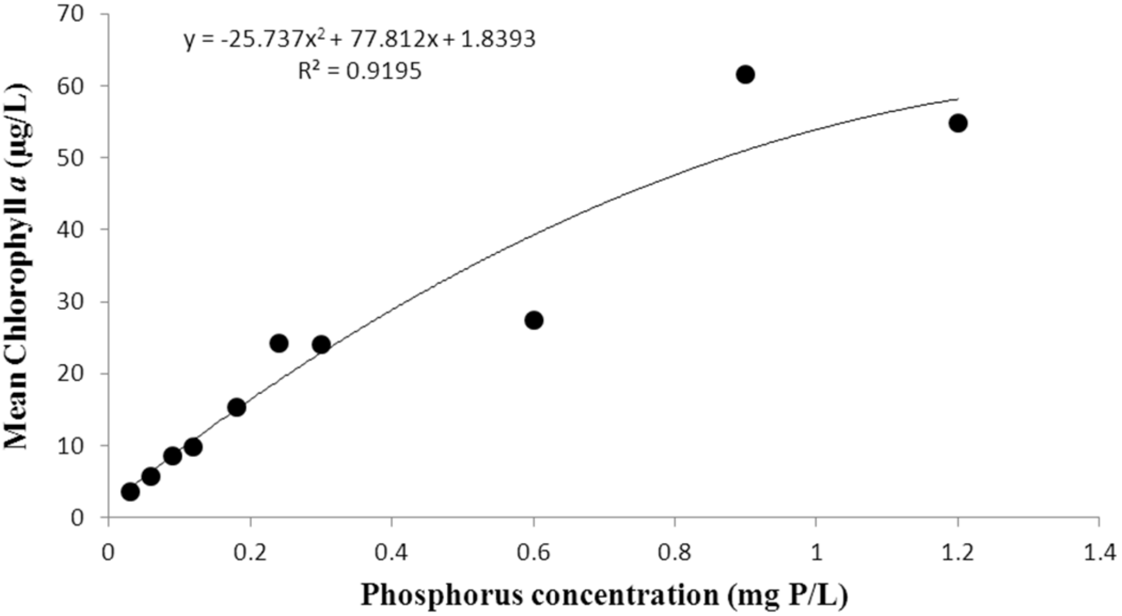

Figure 2.5 Mean chlorophyll *a* (µg/L) and phosphorus concentration (mg P/L) for mesocosm experiment conducted at Mississippi Agricultural Forestry Experimental Station, 2010.

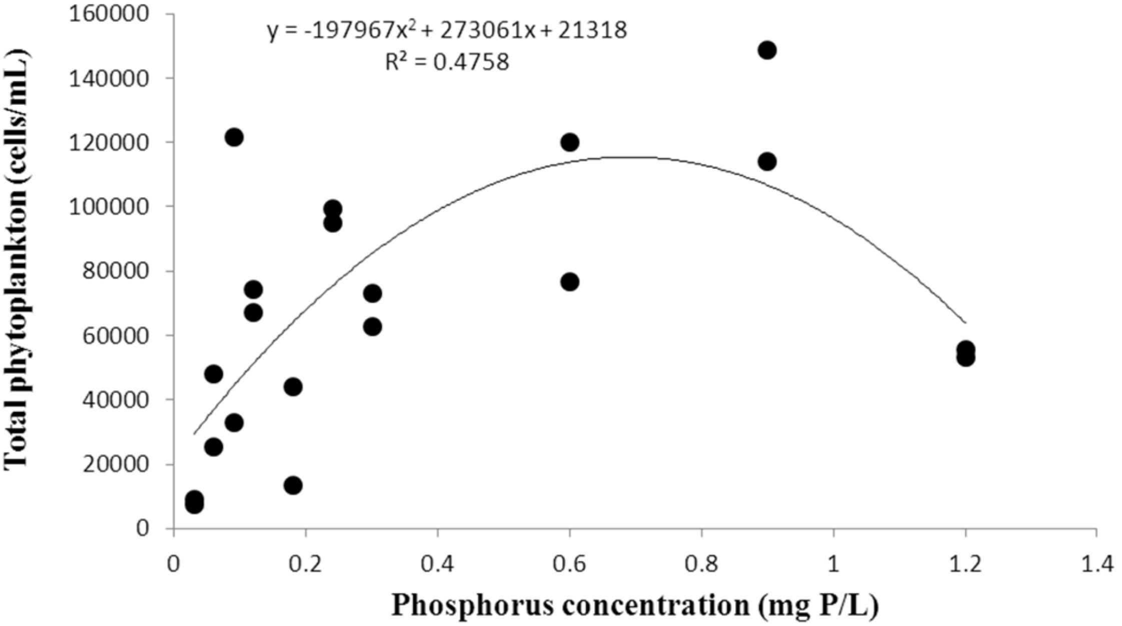

Figure 2.6 Total phytoplankton for May and phosphorus concentrations (mg P/L) for mesocosm experiment conducted at Mississippi Agricultural Forestry Experimental Station, 2010.

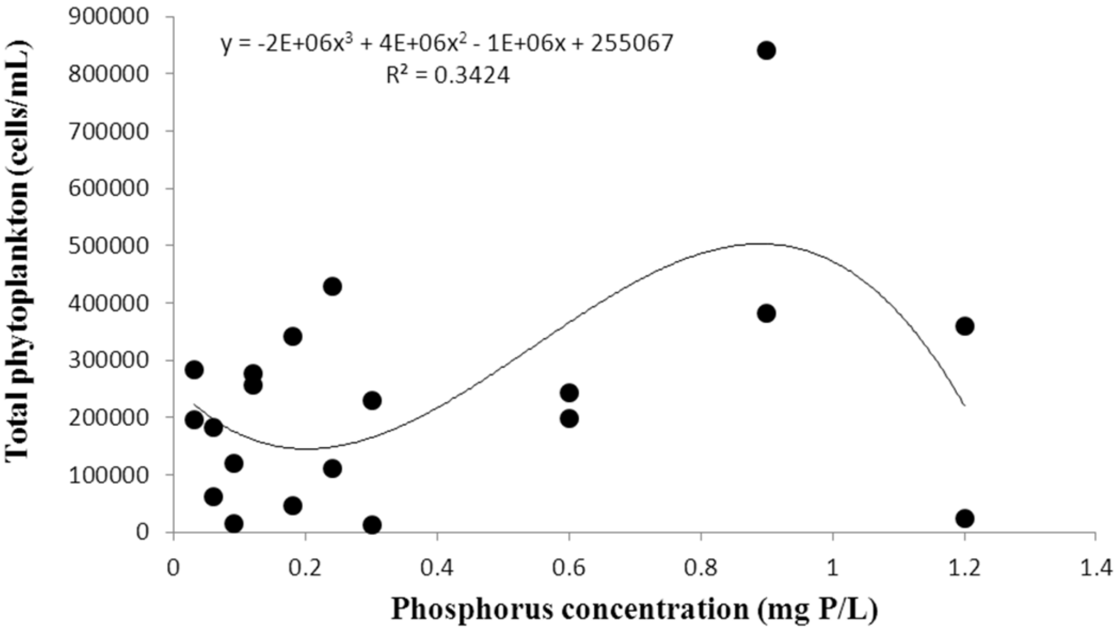

Figure 2.7 Total phytoplankton for June and phosphorus concentrations (mg P/L) for mesocosm experiment conducted at Mississippi Agricultural Forestry Experimental Station, 2010.

CHAPTER III

POND EXPERIMENT

Introduction

Mississippi has an abundance of ponds and small impoundments which may be preferred fishing spots for anglers. Out of the 365,000 licensed Mississippi anglers, 17% of them choose to fish private ponds with an average of six fishing trips per year (Schramm 1996). There are more than 160,000 water bodies less than 100 acres in Mississippi (Neal and Clardy 2010). Also, when ponds are properly managed they can enhance the aesthetics and may increase property values (Wolinsky 2005). Furthermore, pond owners have the ability to manage their ponds in different ways. Typically ponds are managed by increasing nutrient inputs either by applying supplemental feed which is directly consumed by fish or by increasing primary production to increase the forage base for the sportfish. The different ways that ponds are managed have different effects on trophic-dynamics. Understanding these effects on trophic-dynamics or the food web is important not only for efficiently managing a pond but also on furthering our understanding of pond ecology

One technique prescribed to increase primary production is to add fertilizer to the water. Fertilizers contain phosphorus, an important nutrient which limits primary production in many aquatic systems and it is necessary for phytoplankton growth and reproduction (Conte 2000, Dodds 2002). Increasing the population of phytoplankton increases the base of the food chain, and therefore, increases total productivity of the pond (Conte 2000). Fertilization can increase total pounds of fish generated in a pond, often by as much as three to four times that of the standing crop (Brunson et al. 1999; Neal and Clardy 2010). High nutrient loading of phosphorus can cause a dense phytoplankton biomass causing turbid water. Also, many biological changes may occur including loss of diversity of aquatic invertebrate communities (Søndergaard et al. 2003).

Pond owners may manage fish production with supplemental feeding instead of using fertilizer. Supplemental feeding is usually not needed in a healthy bluegill and largemouth bass pond to produce quality crops of fish because there are already essential food items available to feed on but bluegill growth can be increased with a supplemental feeding program (Neal and Clardy 2010). Fish growth is often limited by food availability, therefore, supplemental feeding is a pond management tool to improve condition of fish in ponds and small impoundments because the energy cost for bluegill to feed on pellets is low relative to the high caloric intake, which can be 4-5 times greater than those fed natural foods (Schalles and Wissing 1976). Overall length, weight, and relative weight of pellet-fed bluegills has been found greater than those of bluegills who did not receive pellet feed (Berger 1982). Automatic fish feeders are great tools for pond owners who are unavailable for hand feeding. Supplemental feeders serve as fish attractors which can provide excellent fishing spots to increase angler success and harvest (Berger 1982). However, uneaten feed and increased fish waste can act as a fertilizer and produce an algal bloom (Conte 2000).

Some ponds are not managed with fertilizer or supplemental feeding but instead are managed for aesthetics. Typically these ponds have high water clarities and therefore, more aquatic macrophytes. Aquatic macrophytes can stabilize sediments which help control erosion and turbidity (Madsen et al., 2001). Also, aquatic macrophytes can improve water clarity by reducing phytoplankton biomasses (Scheffer 1999) and provide food for waterfowl and other wildlife, habitat for fish and food source for invertebrates (Neal and Clardy 2010). Macroinvertebrates are not only important in food chains and food webs but can also be used to indicate water quality and relative health of a community (Cairnes and Pratt 1993). Unvegetated areas have a lower abundance and diversity of macroinvertebrates than vegetated areas because stems and leaves of vegetated areas provide substrate for attachment and protection from predators (Gilinsky 1984; Beckett et al. 1992).

When ponds are stocked with fish, they can present pond owners with recreational fishing opportunities. Mississippi ponds are stocked with largemouth bass (*Micropterus salmoides*) and bluegill (*Lepomis macrochirus*). These species are popular because they flourish well in pond ecosystems and also provide pleasurable fishing experiences (Wolinsky 2005). Because bluegill and largemouth bass are popular sport and recreational fishes, it is important to understand the impacts of nutrient input on prey abundance in aquatic systems.

The bottom trophic level consists of primary producers which manufacture their food from sunlight (Horne and Goldman 1994). Primary producers such as macrophytes or phytoplankton are consumed and transfer energy to primary consumers such as zooplankton and invertebrates, then those primary consumers become food for small fish which become food for the larger predator fish (Dodds 2002). Phytoplankton and zooplankton are vital components for marine and freshwater aquatic food webs. The amount of phytoplankton in the water can inform fisheries managers about health of their waterways and where a management action may be needed. Furthermore, too much phytoplankton can be detrimental to a pond, causing low dissolved oxygen levels for fish. Knowing the community of phytoplankton is important because some phytoplankton are less desirable such as cyanobacteria (blue-green algae) which can produce harmful toxins to humans, pets, and other animals. Also, blue-green phytoplankton can produce foul odors in a body of water. It is important to remember that many phytoplankton blooms may occur naturally during the early and late summer period without fertilization (Suthers and Rissik 2009). Macroinvertebrates are not only important in food chains and food webs but can be used to indicate water quality and relative health of a community (Cairnes and Pratt 1993). Little is known about different pond management approaches and their effect on density of plankton and macroinvertebrates that inhabit different trophic levels in these systems.

My goal was to conduct a field study to investigate how common pond management approaches influence four trophic levels (phytoplankton, zooplankton, macroinvertebrates and fish) within ponds located in north central Mississippi. I evaluate treatment effects on the first three trophic levels by quantifying differences in density and diversity of individuals within phytoplankton, zooplankton, and macroinvertebrate communities and the fourth by measuring differences in growth of individual bluegill and largemouth bass. Fish growth was determined by measuring differences in total length and relative weights of these two species sampled from ponds.

Methods

Experimental Design

The field study was initiated on March 29th, 2011 and conducted through September 29th, 2011. Preliminary samples were taken starting March 29th and pond treatments were applied April 5th. Twelve privately-owned ponds were selected within a 30 mile radius of the Mississippi State University campus. Pond sizes ranged between 0.26- 4.17 hectares and pond mean depths ranged between 1.13-2.01 meters. The ponds were selected to receive one of four treatments: 1) no fertilization or feeding, 2) supplemental feeding, 3) fertilizer at a low P threshold (0.3 mg P/L level determined by mesocosm experiment), 4) fertilizer at a high P threshold to meet maximum fish growth (0.6 mg P/L level determined by mesocosm experiment). Each treatment was replicated three times, for a total of 12 ponds.

ArcGIS was used to calculate surface acre values for each pond. A ten foot pvc pipe with one foot markings was used to measure depth every 20 feet for the width of each pond at different widths across each pond for five widths and same process was used for five lengths across each pond to get depth readings for the entire width of the pond as well as the entire length and calculated mean depth of each pond. Surface acres and mean depths were multiplied for each pond to get the volume of the pond in acre-feet.

Supplemental pellet feed was applied with automatic fish feeders once at 6:30 a.m. and once at 6:30 p.m. for a total of 1.5 lbs per day. Amount of feed was not accounted for pond size. For the fertilizer treatments, liquid fertilizer 10-34-0 was the fertilizer source. Preliminary total phosphorus samples were taken prior to treatments.

Total phosphorus was analyzed by ascorbic acid method 10210 using TNT plus ™ 843 and was calorimetrically determined on a DR 5000 spectrophotometer (Hach 2008). Total phosphorus was measured because it has a direct relationship with the phytoplankton biomass measured by chlorophyll-a (Dillon and Rigler 1974) and also I wanted to know what the phosphorus levels were before treatments were applied. Once total phosphorus was calculated, the low P fertilized ponds were calculated to increase the total phosphorus to a level of 0.3 mg P/L and high P fertilized ponds were calculated to increase the total phosphorus to a level of 0.6 mg P/L. Liquid fertilizer was diluted with two parts water to one part fertilizer before application. Fertilizer was applied by boat with a polyethylene tank fitted with two drip booms applied in a circular fashion around entire pond.

Ponds were measured for phytoplankton species, phytoplankton density, plant species, plant abundance, zooplankton density, macroinvertebrate density, total lengths and relative weights of Bluegill (*Lepomis macrochirus*) and Largemouth bass (*Micropterus salmoides*). A Yuma GPS was used to create a uniform grid of sampling points 25 meters apart to cover the entire area of each pond (Madsen 1999). Sampling occurred once monthly from March through September.

Phytoplankton was sampled by collecting water samples from three random points at each pond with 25 ml water vials at a depth of 0.5 meters at each location. Samples were taken once monthly from March to September and then taking five 1 ml Sedgwick rafter cells for each sample and looking at five random views on each cell to determine abundance of Chlorophycophyta (green algae), Cyanochloronta (blue-green algae), and Bacillariophyceae (diatoms). Phytoplankton taxa were classified using two standard references (Wehr and Sheath 2003; Dillard 2008).

Zooplankton was sampled by using a plankton tow net with a mesh size 64µm and 12.7 cm in diameter (Downing and Rigler 1984). Zooplankton was sampled by lowering the tow net vertically down to bottom and worked at a slow pace to the surface at three random points in each pond. Samples were collected within a 250 ml bottle at the end of the tow net. Samples were poured into whirl-paks and preserved in 4% formalin solution. Samples were filtered through container lids with a mesh size of 64µm then flushed into a beaker. The beaker was filled with distilled water to have a concentration of 50 ml, then swirled so zooplankton would not settle to the bottom and a Henson pipette was used to take a subsample of 1 ml to put directly into a sedgewick rafter counting cell. Five sedgewick rafter counting cells were used for each pond sample for 15 counting cells per pond. The entire counting cell was examined to count number of zooplankton per cell (Wetzel and Likens 2000) as well as identify number of rotifers, cladocerans, and copepods by Ecology and Classification of North American Freshwater Invertebrates (Thorp and Covich 2010).

Sampling points for macroinvertebrates were stratified by a 3 meter buffer zone from the shoreline for the entire perimeter of each pond. Thirty GPS points were throughout the buffer zone. At three random GPS points, a 500 micron meter mesch canvas dip net was used to sample (standardized to five successive thrusts) within a 0.33 m^2 transect at each point. Samples were then flushed into whirl paks and preserved with 4% formalin solution. Macroinvertebrate samples were taken to a Department of Wildlife, Fisheries and Aquaculture laboratory at Mississippi State University to be counted and identified under a dissecting microscope. Samples were counted for total number per sample as well as total number per family. Number of families per sample were counted for mean family richness. Macroinvertebrates were identified to family using two references (Voshell 2002; Merritt et al. 2008).

Pretreatment and post-treatment data was collected for largemouth bass and bluegill in each pond using a boat electro-fishing unit to evaluate existing length and size frequencies for bass and bluegill. Each pond was electro-fished for the entire shoreline perimeter or 20 minutes, whichever came first. Electrofishing power outage was held consistent with standards (Miranda 2005). Largemouth bass and bluegill were weighed to the nearest hundredth of a gram (g) on platform balance scale and measured for total length (TL) in mm. Floy tags were applied to fish to examine growth for largemouth bass and bluegill from the beginning to the end of experiment. Relative weights (Wr) were conducted on bluegill and largemouth bass in all ponds (Wege and Anderson 1978).

Data Analysis

Total phytoplankton, green phytoplankton, blue-green phytoplankton, and diatom phytoplankton densities were tested for normality with a Shapiro-Wilk test and were not normally distributed. Consequently, Friedman test nonparametric analysis of variance (ANOVA) with repeated measures was used to determine differences for these variables. Zooplankton density, macroinvertebrate density, rotifer density, copepod density, cladoceran density, and family richness of macroinvertebrates were transformed as necessary and followed a normal distribution as determined by Shapiro-Wilk tests and further analyzed by one-way analysis of variance (ANOVA) with repeated measures. Statistically significant values were assessed using a Tukey’s multiple comparison test using SAS version 9.2 (SAS Institute, Cary, NC). Overall total lengths and overall relative weights were tested for normality and transformed as necessary. T-tests were used to test for significant differences in overall total lengths and overall relative weights for largemouth bass and bluegill between pretreatment and post-treatment. All tests were considered significant at $P < 0.05$.

Results

Total phytoplankton density (cells/mL) for high P treatment was significantly (Friedman test, $P < 0.001$) greater than other treatments (Figure 3.1). The interaction between pond treatment and month was significant (Friedman test, $P < 0.001$) for total phytoplankton density (Figure 3.2). Blue-green phytoplankton density (cells/mL) differed significantly (Friedman test, $P < 0.001$) among treatments (Figure 3.3). The high P treatment had significantly greater blue-green phytoplankton density than other treatments. The interaction between pond treatment and month was significant (Friedman test, $P < 0.001$) for blue-green phytoplankton density (Figure 3.2). Green phytoplankton density (cells/mL) did not differ significantly (Friedman test, $P = 0.15$) among treatments (Figure 3.3). However, interaction between pond treatment and month was significant (Friedman test, $P = 0.002$) for green phytoplankton density (Figure 3.2). Diatom phytoplankton density (cells/mL) differed significantly (Friedman test, $P = 0.008$) among treatments (Figure 3.3). The high P treatment had significantly greater diatom density than low P treatment and low P treatment was found to have significantly greater diatom density than reference treatment. The interaction between pond treatment and month was significant (Friedman test, $P < 0.001$) for diatom density (Figure 3.2).

Total zooplankton density (No./L) differed significantly (F = 5.52, P = 0.001) among treatments (Figure 3.4). The low P treatment had significantly greater zooplankton density than feeding and reference treatments. High P treatment had significantly greater zooplankton density than feeding treatment. Rotifer density (No./L) did not differ significantly (F = 2.26, P = 0.08) among treatments (Figure 3.6). However, interaction between pond treatment and month was significant (F = 3.11, P < 0.001) for rotifer density (Figure 3.5). Copepod density (No./L) differed significantly (F = 3.25, P = 0.02) among treatments (Figure 3.6). The low P treatment had significantly greater copepod density than feeding treatment. The interaction between pond treatment and month was not significant (F = 0.67, P = 0.8) for copepod density (Figure 3.5). Cladoceran density (No./L) differed significantly (F = 12.88, P < 0.001) among treatments (Figure 3.6). The low P treatment had significantly greater cladoceran density than other treatments. The interaction between pond treatment and month was significant (F = 1.63, P = 0.04) for cladoceran density (Figure 3.5).

Macroinvertebrate density (No./0.33m^2) differed significantly (F = 12.19, P < 0.001) among treatments (Figure 3.7). The high P treatment had significantly greater macroinvertebrate density than other treatments and feeding treatment had significantly greater macroinvertebrate density than reference treatment. The interaction between pond treatment and month was not significant (F = 0.95 , P = 0.52) for macroinvertebrate density (Figure 3.8). Macroinvertebrate family richness differed significantly (F = 11.94, P< 0.001) among treatments (Figure 3.9). The high P treatment was significantly greater in family richness than low P and reference treatments. Feeding treatment was significantly greater in family richness than reference treatment.

There were only a few tagged fish captured, so fish data presented consists of all bluegill and largemouth bass collected for pretreatment and post-treatment. Bluegill total lengths for reference treatment did not differ significantly (t= -1.132, P= 0.264) between pretreatment and post-treatment (Figure 3.10). Mean length for pretreatment was 113.4 mm and mean length for post-treatment was 133.8 mm. Bluegill total lengths for feeding treatment did not differ significantly (t= -1.329, P= 0.189) between pretreatment and post-treatment (Figure 3.10). Mean length for pretreatment was 102.6 mm and mean length for post-treatment was 115.9 mm. Bluegill total lengths for low P treatment differed significantly (t= 4.12, P< 0.001) between pretreatment and post-treatment (Figure 3.10). Mean length for pretreatment was 151.91 mm and was significantly greater than mean length for post-treatment at 120.4 mm. Bluegill total lengths for high P treatment differed significantly (t = -2.932, P = 0.004) between pretreatment and post-treatment (Figure 3.10). Mean length for pretreatment was 126.8 mm and was significantly less than mean length for post-treatment at 157.2 mm.

Largemouth bass total lengths for reference treatment did not differ significantly (t = 0.464, P = 0.644) between pretreatment and post-treatment (Figure 3.11). Mean length for pretreatment was 254.2 mm and mean length for post-treatment was 243.5 mm. Largemouth bass total lengths for feeding treatment differed significantly (t = 2.127, P = 0.041) between pretreatment and post-treatment (Figure 3.11). Mean length for pretreatment was 245.3 mm and mean length for post-treatment was 196.4 mm. Largemouth bass total lengths for low P treatment did not differ significantly (t =1.545, P = 0.129) between pretreatment and post-treatment (Figure 3.11). Mean length for pretreatment was 241.0 mm and mean length for post-treatment was 214.2 mm.

Largemouth bass total lengths for high P treatment did not differ significantly (t = -0.289, P = 0.774) between pretreatment and post-treatment (Figure 3.11). Mean length for pretreatment was 248.8 mm and mean length for post-treatment was 256.6 mm.

Bluegill relative weights for reference treatment differed significantly (t =2.63, P = 0.013) between pretreatment and post-treatment (Figure 3.12). Mean relative weight for pretreatment was 100.1 and was significantly greater than mean relative weight for post-treatment at 91.1. Bluegill relative weights for feeding treatment did not differ significantly (t = -0.0736, P = 0.94) between pretreatment and post-treatment (Figure 3.12). Mean relative weight for pretreatment was 90.8 and mean relative weight for post-treatment was 91. Bluegill relative weights for low P treatment did not differ significantly (t = 0.065, P = 0.95) between pretreatment and post-treatment (Figure 3.12). Mean relative weight for pretreatment was 87.9 and mean relative weight for post-treatment was 87.6. Bluegill relative weights for high P treatment did not differ significantly (t = 0.256, P = 0.799) between pretreatment and post-treatment (Figure 3.12). Mean relative weight for pretreatment was 90.2 and mean relative weight for post-treatment was 89.3.

Largemouth bass relative weights for reference treatment did not differ significantly (t = -0.444, P = 0.66) between pretreatment and post-treatment (Figure 3.13). Mean relative weight for pretreatment was 83.7 and mean relative weight for post-treatment was 84.9. Largemouth bass relative weights for feeding treatment differed significantly (t = 2.34, P = 0.026) between pretreatment and post-treatment (Figure 3.13). Mean relative weight for pretreatment was 81.8 and was significantly greater than mean relative weight of post-treatment at 76.1. Largemouth bass relative weights for low P treatment did not differ significantly (t = 0.123, P = 0.9) between pretreatment and post-treatment (Figure 3.13). Mean relative weight for pretreatment was 82.8 and mean relative weight for post-treatment was 82.3. Largemouth bass relative weights for high P treatment differed significantly (t = -3.321, P = 0.002) between pretreatment and post-treatment (Figure 3.13). Mean relative weight for pretreatment was 76.5 and was significantly less than mean relative weight of post-treatment at 87.7.

Discussion

The purpose of this study was to investigate effects of common pond management approaches on different trophic levels. Total phytoplankton cell counts were significantly greater in the fertilized treatments. More nutrients were put into these ponds, so, therefore, more phytoplankton was able to grow and reproduce. Blue-green phytoplankton showed a peak in April and green phytoplankton showed a peak in May in the high fertilizer treatment due to responses of fertilization. This may indicate that the dominance of blue-green phytoplankton may change to green phytoplankton dominance within a month. A peak of green phytoplankton was observed in June for reference ponds. This was due to two of the reference ponds developing algal blooms in June. Also, because blue-green algae was significantly greater in the high fertilizer treatment than the low fertilizer treatment, the low fertilizer treatment may be a more suitable amount of fertilizer because blue-green phytoplankton are typically less desirable and unsuited for zooplankton grazing (Bernardi and Giussani 1990). Also, mean zooplankton density was greatest in the low fertilized treatment with more rotifers, copepods and cladocerans than other treatments. However, reference treatments did not significantly differ in mean rotifers and copepods density compared to both fertilizer treatments.

Macroinvertebrates compose a large part of a juvenile and adult bluegill's diet (Schramm and Jirka 1989; Ross 2001). Therefore management approaches to increase macroinvertebrate abundance may benefit bluegill production. This study showed that the high fertilizer treatment had greater macroinvertebrate density and was evident in having greater bluegill total lengths from pre to post. High fertilization resulted in greater nutrient inputs and the greater density was attributed to more midge larvae counts, which is a primary food source for sunfish (Pardue 1973). Chironomid (midges) are considered a "bridge" between phytoplankton and sport fish (Smith and Swingle 1939). Macroinvertebrate family richness was greatest in the high fertilizer treatment than all other treatments except for feeding treatment. Macroinvertebrate species richness may actually increase with nutrient enrichment and then decline as habitat and water quality conditions deteriorate (McCormick et al. 2004). Largemouth bass relative weights for high P showed significantly (P = 0.002) greater relative weights for post treatment. This could have been contributed from increases in the biomass at each trophic level which contribute to better growth for largemouth bass and bluegill (Olive 2004).

Although great results were seen for high P treatment, there was a 32.6 % increase in number of bluegill sampled for the low P ponds in the 50-100 mm total length category from pretreatment to post-treatement and 3.9 % increase in number of largemouth bass sampled in the 100-200 mm and 15.3 % increase in the 201-300 mm total length category from pretreatment to post-treatment. This may indicate high survival rates for smaller bluegill and an increased forage base for largemouth bass; thus, the low P rate may be just as efficient for fish growth as the high P rate. However, because very few tagged fish were retrieved, individual growth rates of fish were not determined.

I did not sample for fish diets. I suggest that future studies should focus on bluegill and largemouth diets to focus on which prey resources are efficiently being consumed with different pond management approaches. Also future studies should focus on pond management approaches sampling entire fish population by draining ponds for more accurate estimates for fish growth rate and production.

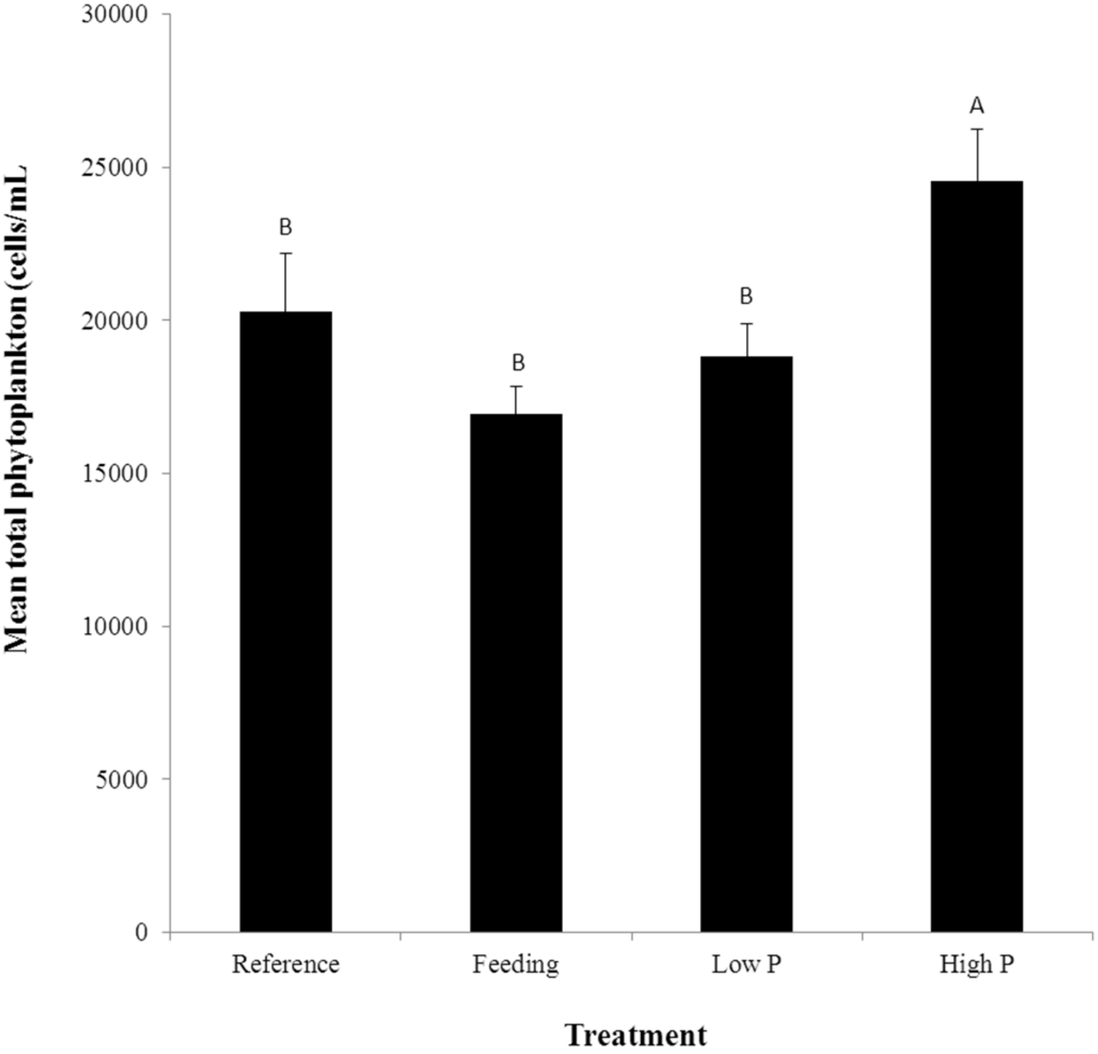

Figure 3.1 Mean total phytoplankton cells (±SE) for treatments in pond experiment conducted in north central Mississippi, 2011. The y-axis error bars are representative of standard error. Significant differences among treatments are represented by letters above y-axis error bars.

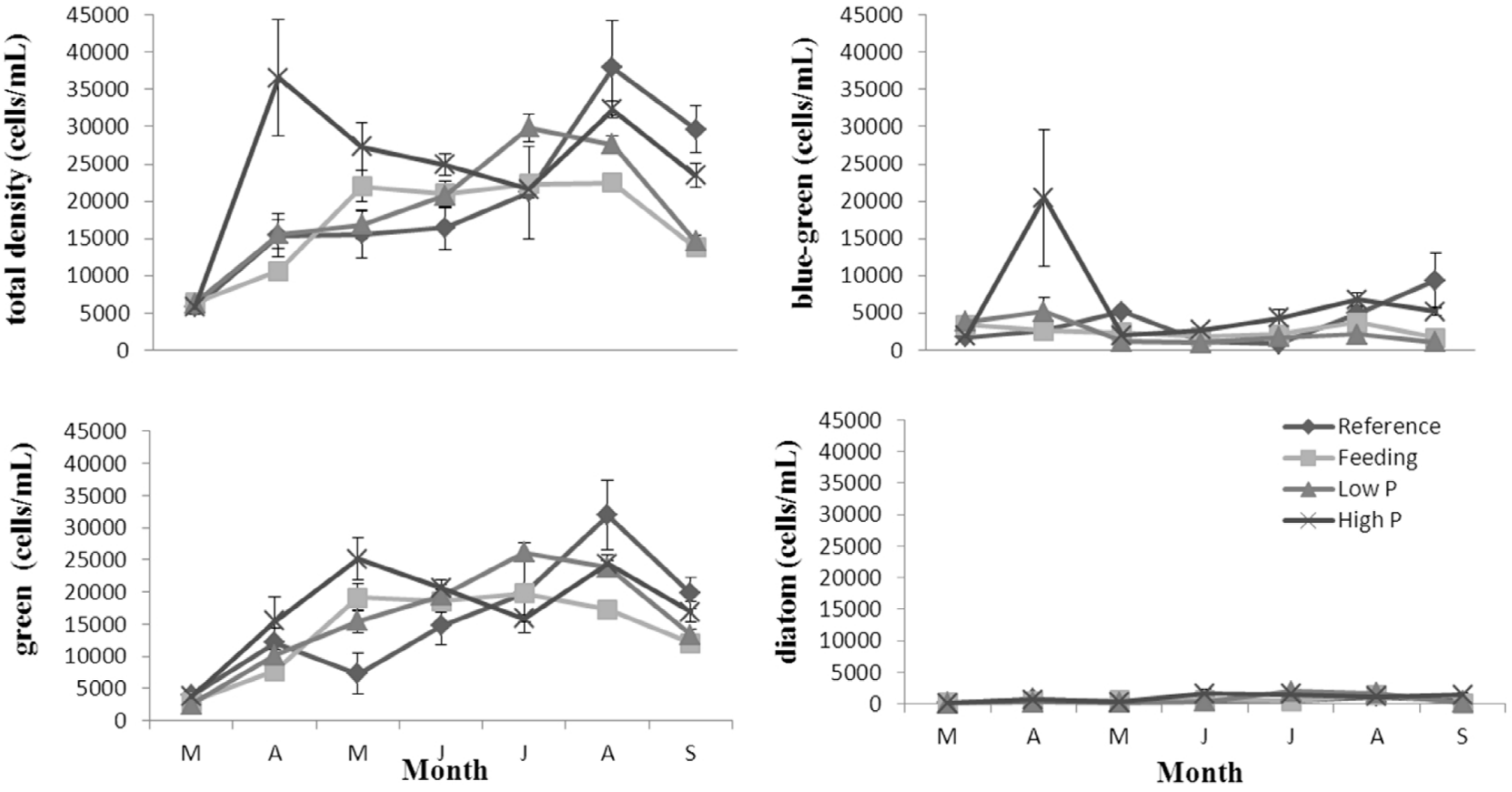

Figure 3.2 Mean total, blue-green, green and diatom phytoplankton (cells/mL) (±SE) for treatments over time in pond experiment conducted in north central Mississippi, 2011. The y-axis error bars are representative of standard error.

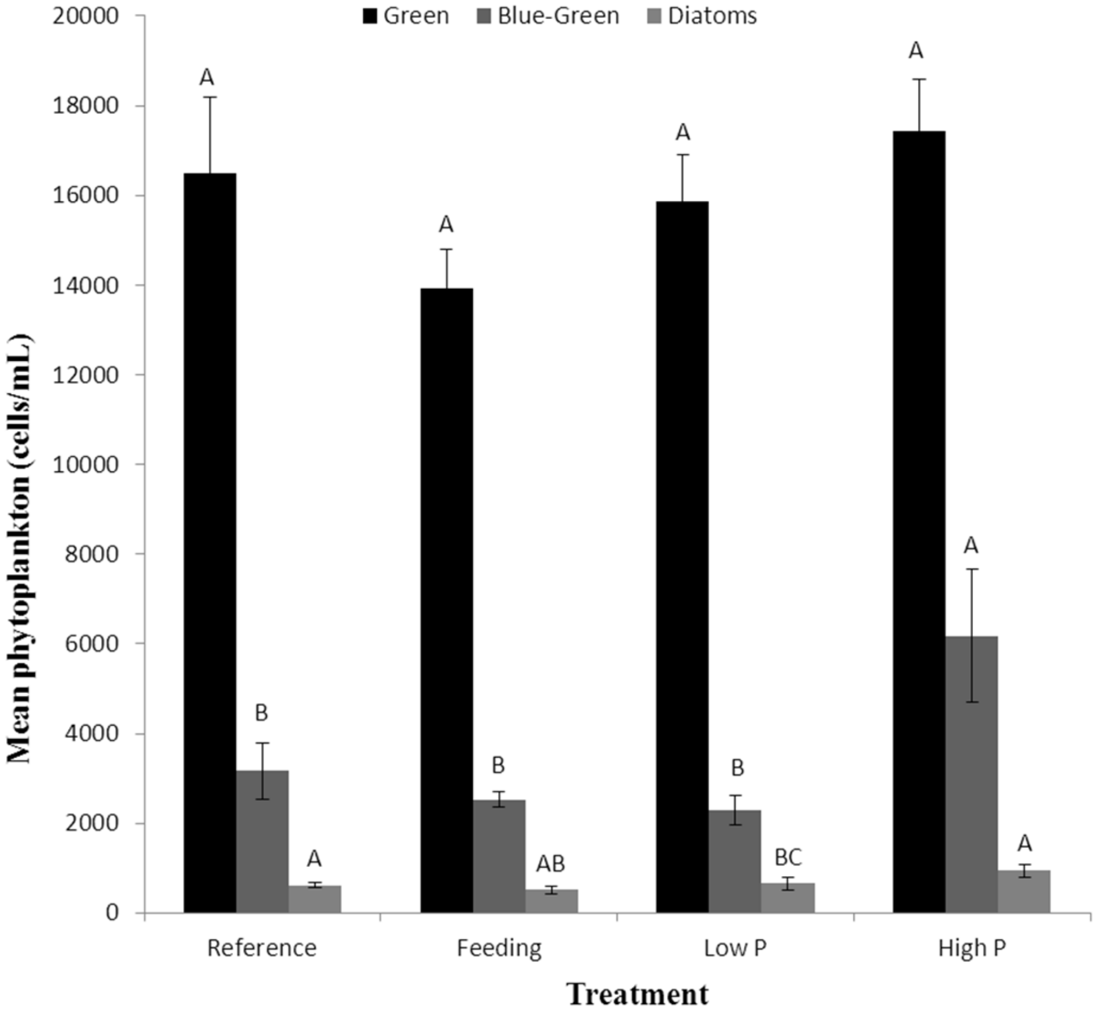

Figure 3.3 Mean phytoplankton cells/mL (±SE) for green, blue-green, and diatoms for treatments in pond experiment conducted in north central Mississippi, 2011. The y-axis error bars are representative of standard error. Significant differences among treatments are represented by letters above y-axis error bars.

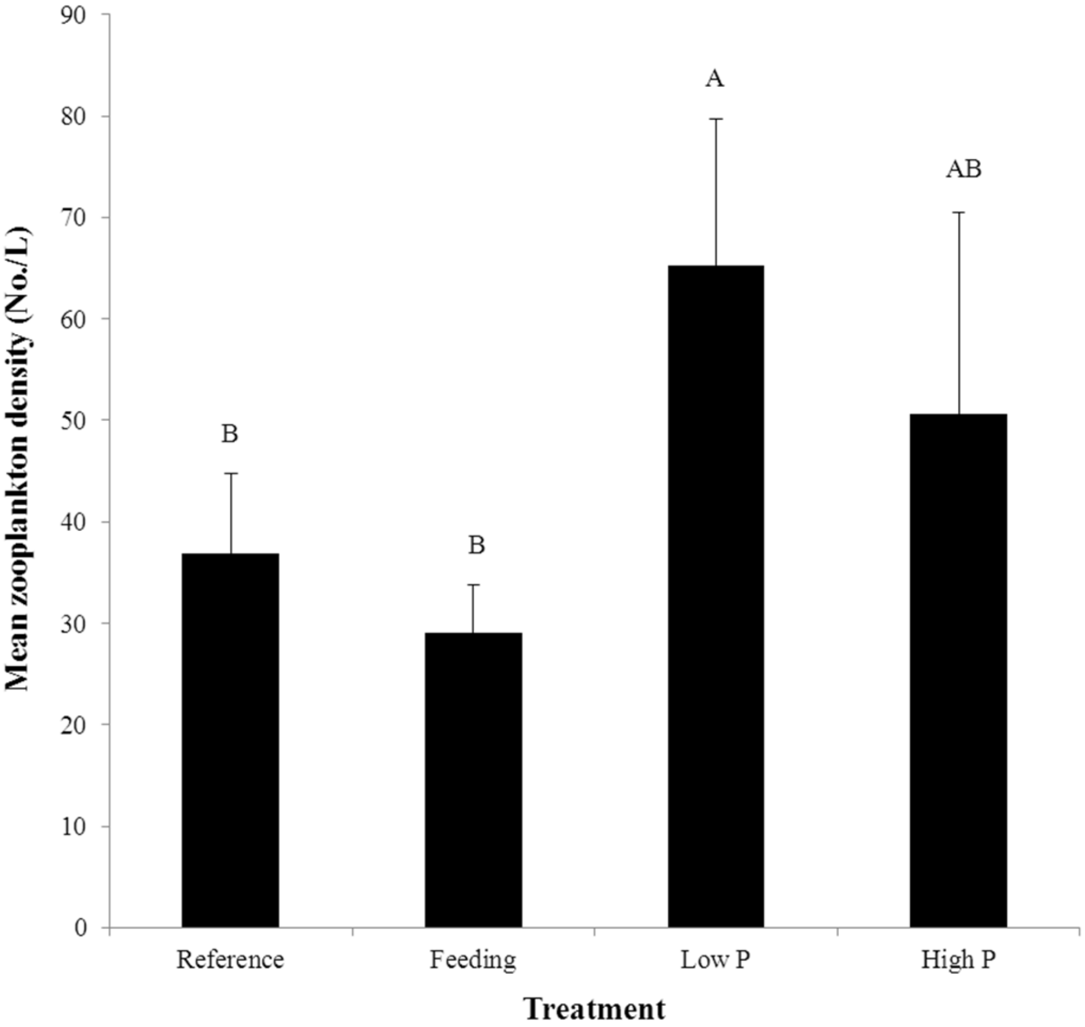

Figure 3.4 Mean zooplankton No./L (±SE) for treatments in pond experiment conducted in north central Mississippi, 2011. The y-axis error bars are representative of standard error. Significant differences among treatments are represented by letters above y-axis error bars.

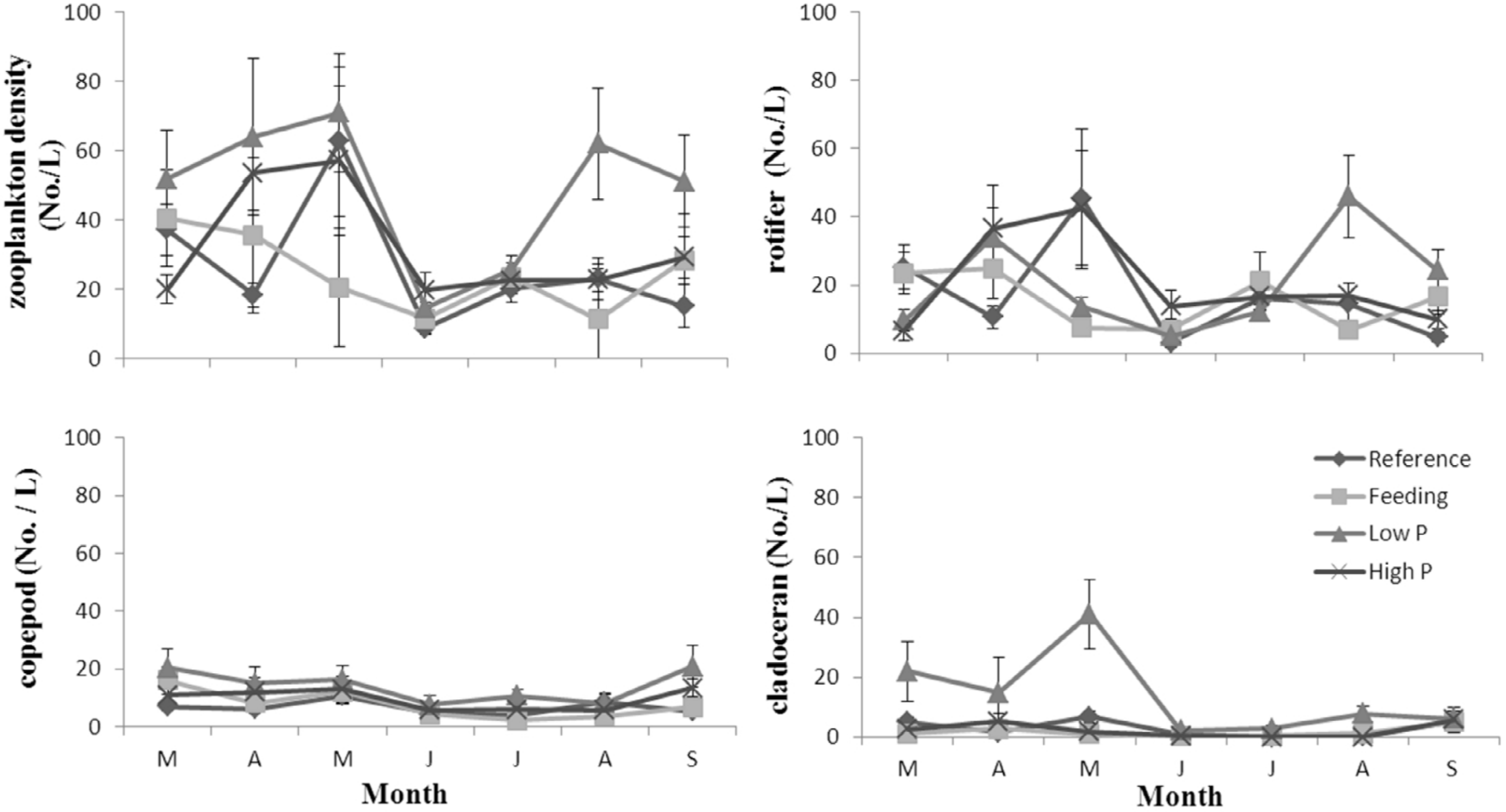

Figure 3.5 Mean zooplankton total, rotifer, copepod and cladoceran density (No./L) (±SE) for treatments over time in pond experiment conducted in north central Mississippi, 2011. The y-axis error bars are representative of standard error.

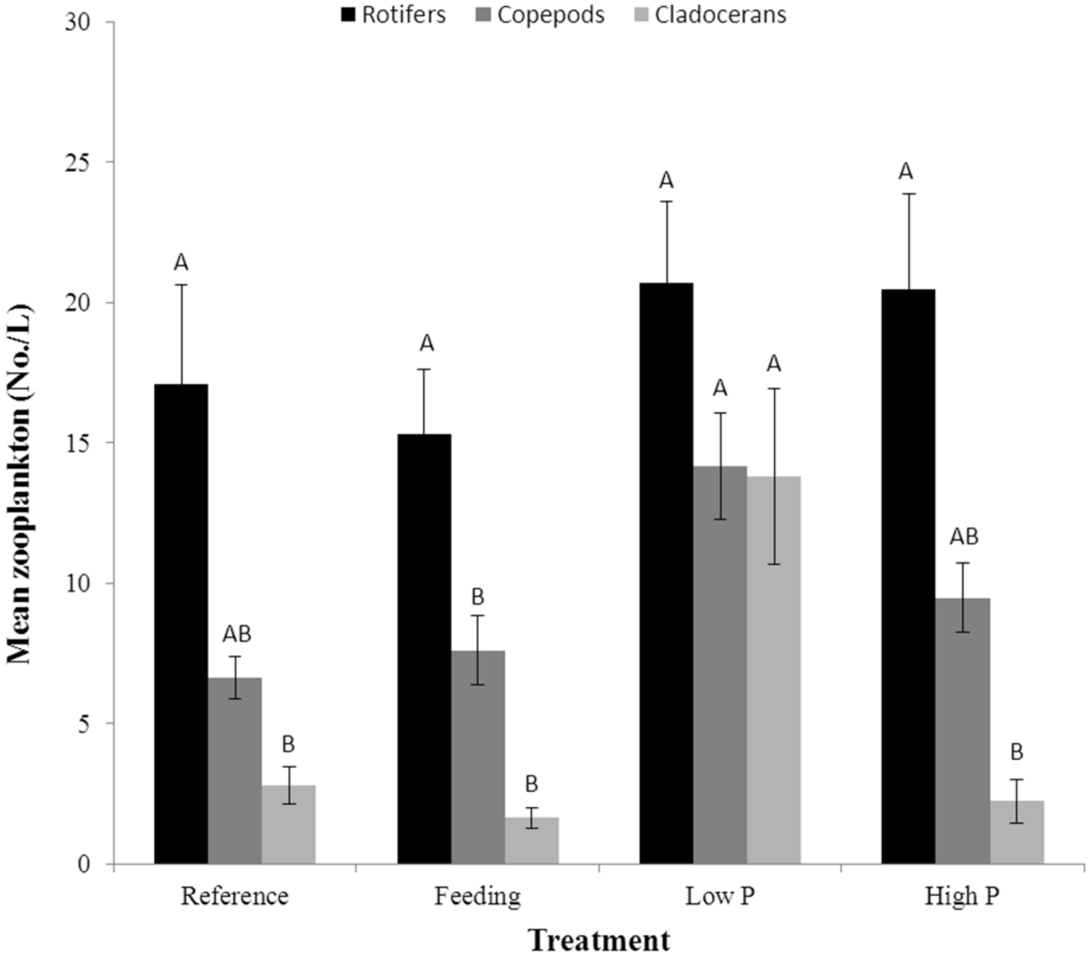

Figure 3.6 Mean zooplankton no./L (±SE) for rotifers, copepods and cladocerans for treatments in pond experiment conducted in north central Mississippi, 2011. The y-axis error bars are representative of standard error. Significant differences among treatments are represented by letters above y-axis error bars.

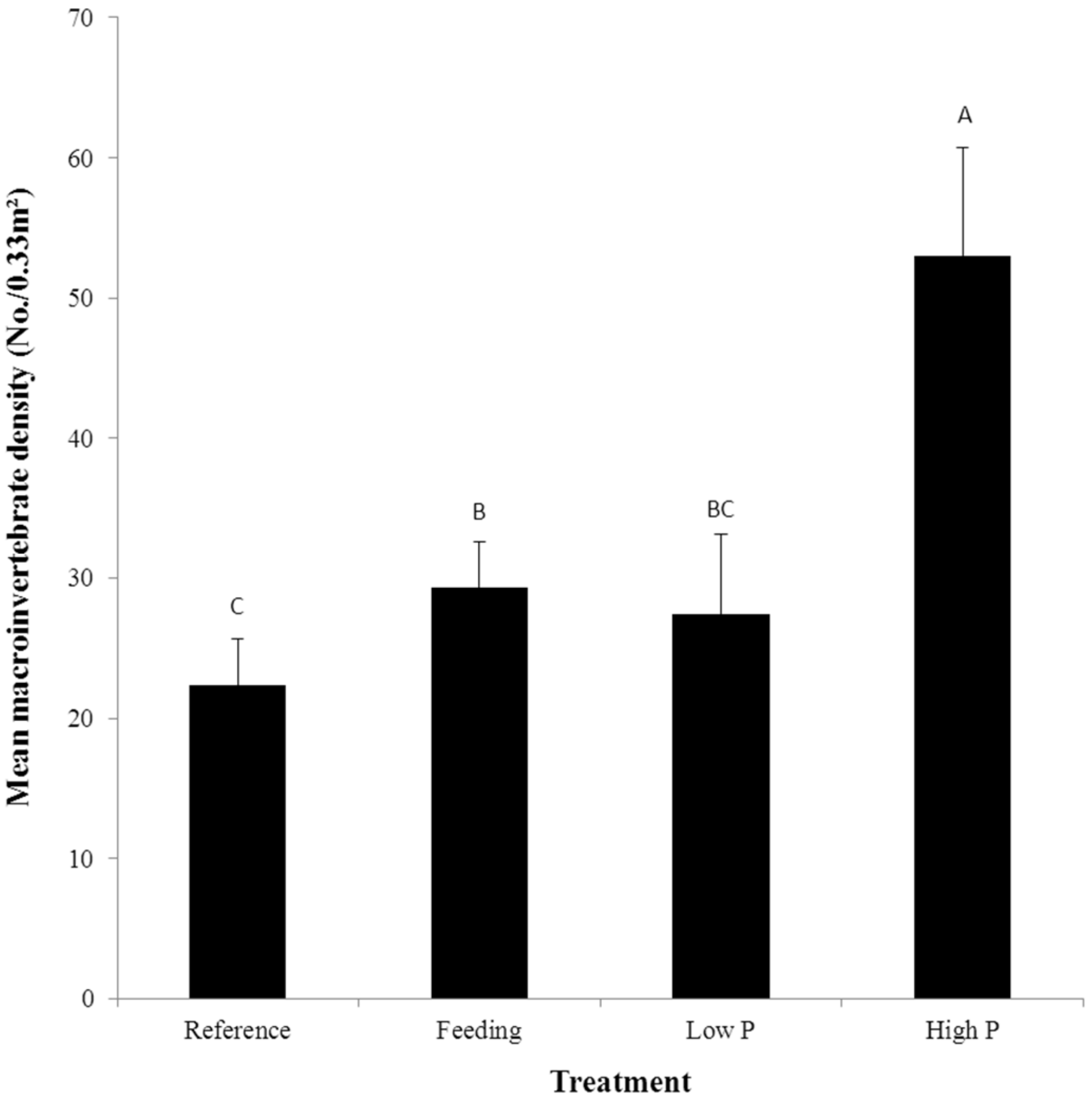

Figure 3.7 Mean macroinvertebrate density (±SE) for treatments in pond experiment conducted in north central Mississippi, 2011. The y-axis error bars are representative of standard error. Significant differences among treatments are represented by letters above y-axis error bars.

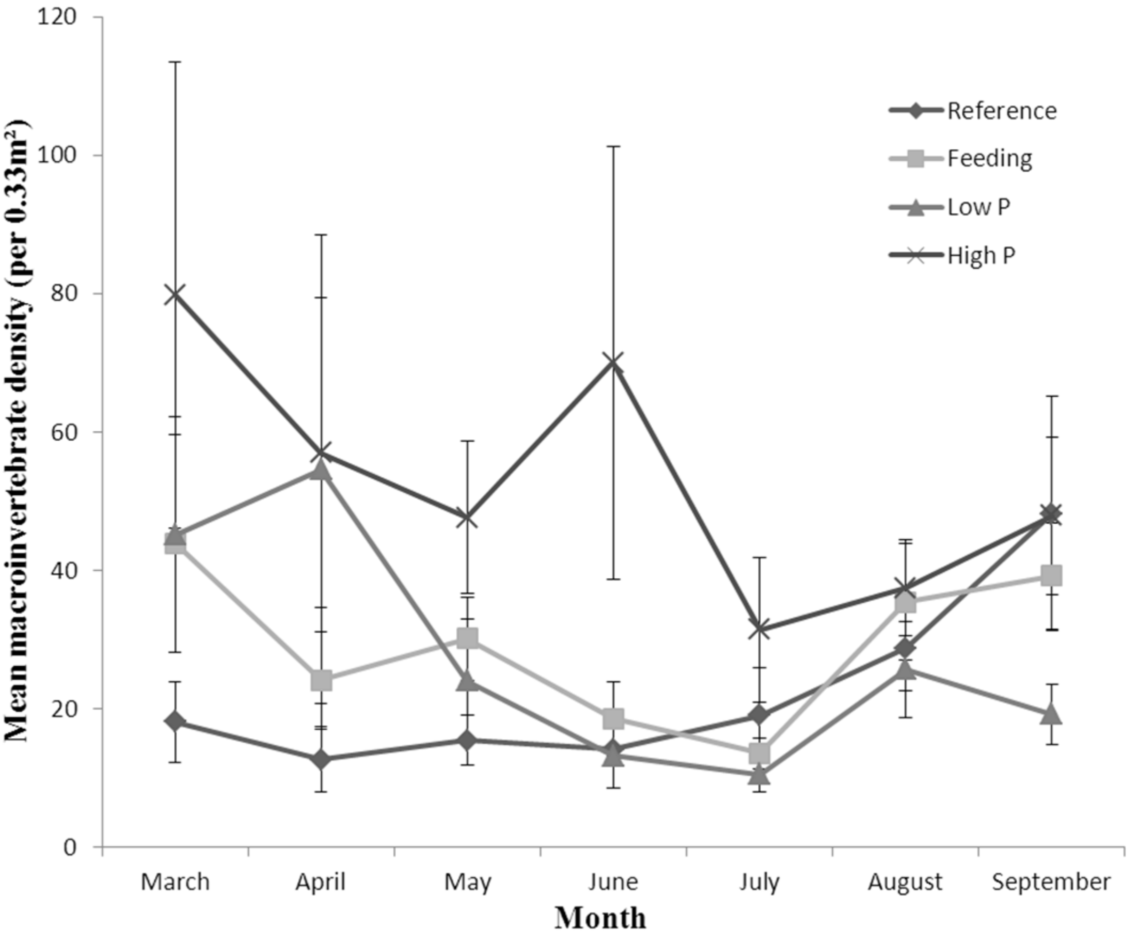

Figure 3.8 Mean macroinvertebrate density (±SE) for treatments over time in pond experiment conducted in north central Mississippi, 2011. The y-axis error bars are representative of standard error.

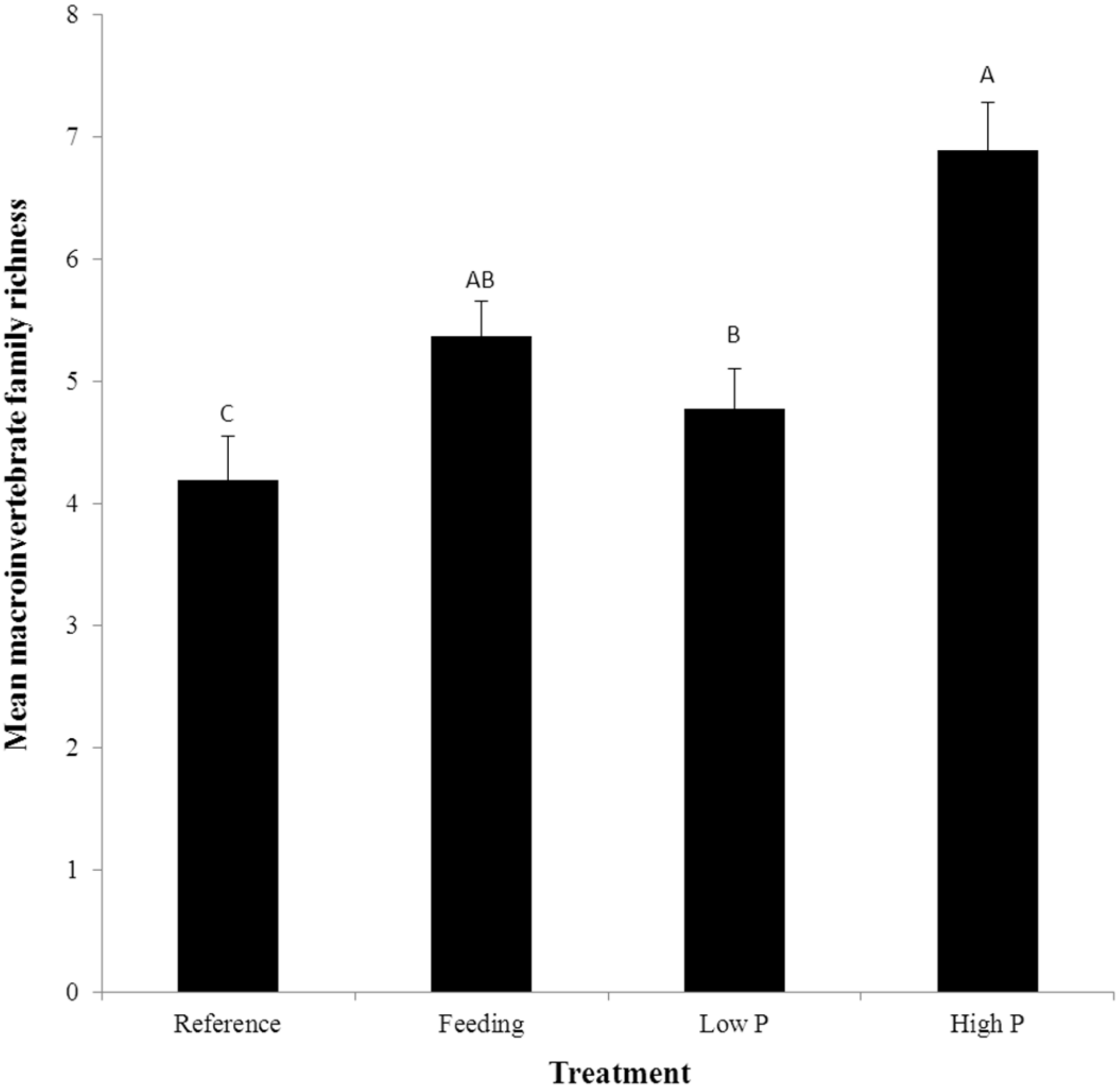

Figure 3.9 Mean macroinvertebrate family richness (±SE) for treatments in pond experiment conducted in north central Mississippi, 2011. The y-axis error bars are representative of standard error. Significant differences among treatments are represented by letters above y-axis error bars.

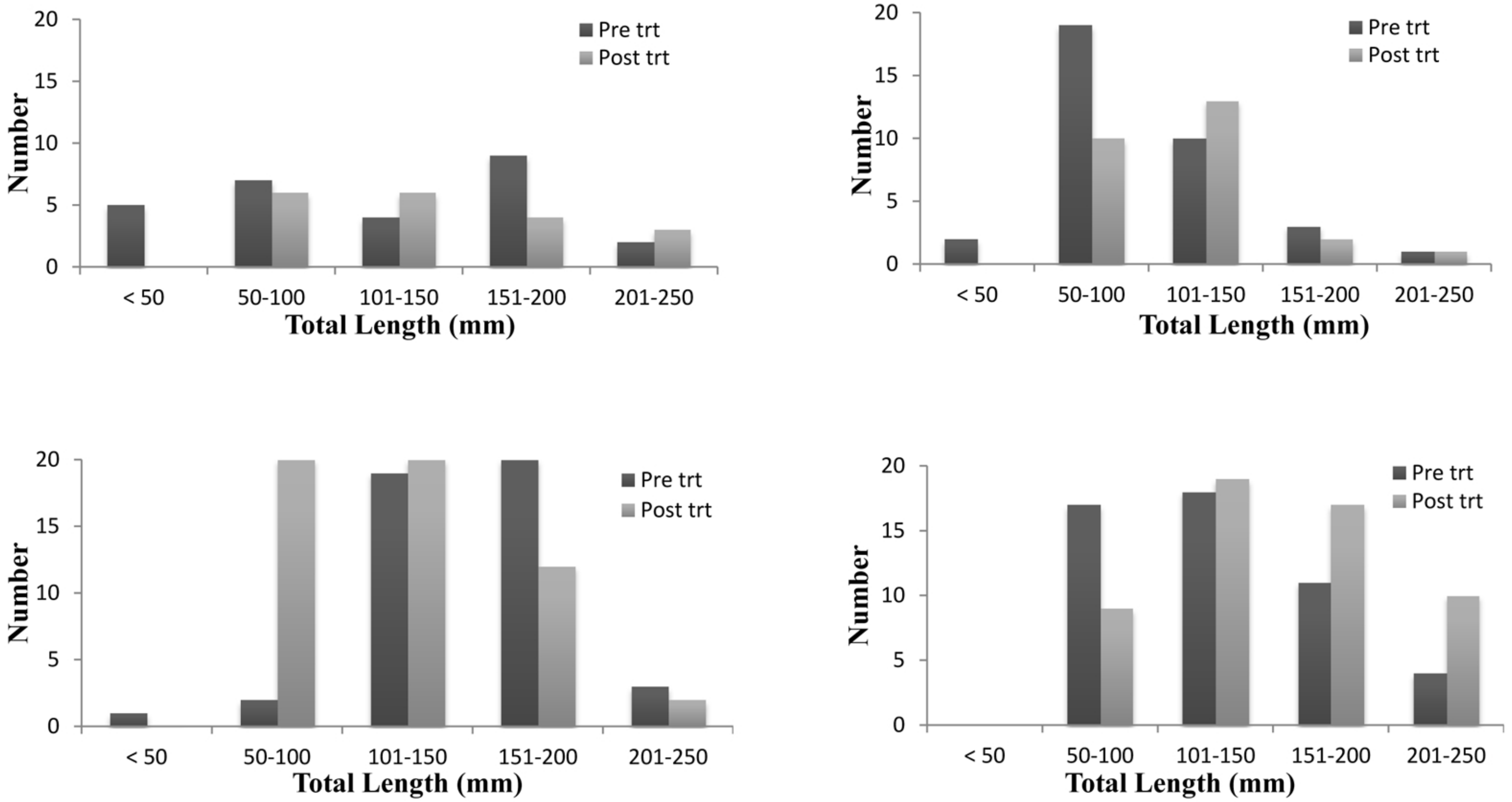

Figure 3.10 Total number of bluegill reference (top left), feeding (top right), low P (bottom left), and high P (bottom right) treatments in six length categories for pretreatment and post-treatment in pond experiment conducted in north central Mississippi, 2011.

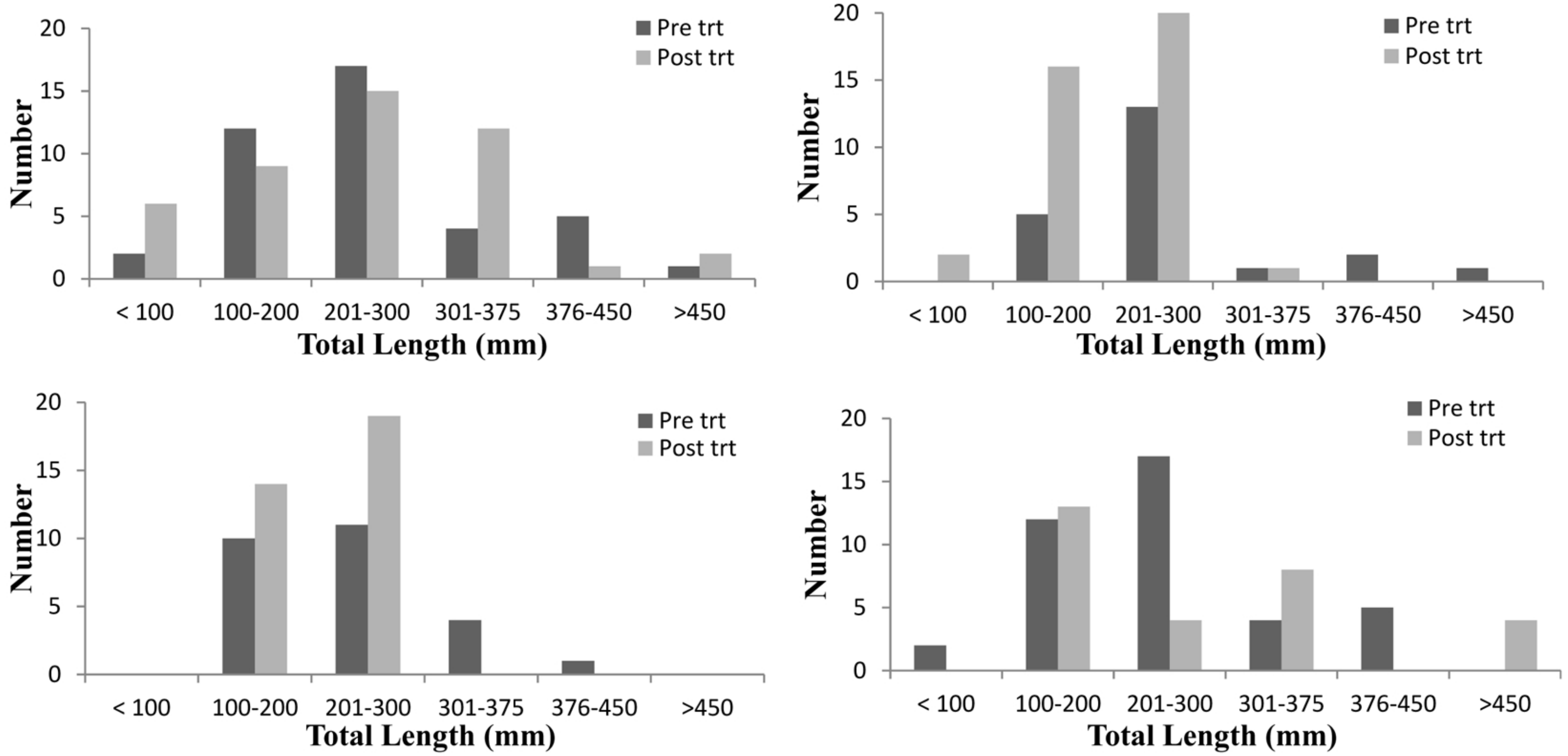

Figure 3.11 Total number of largemouth bass for reference (top left), feeding (top right), low P (bottom left), and high P (bottom right) treatments in six length categories for pretreatment and post-treatment in pond experiment conducted in north central Mississippi, 2011.

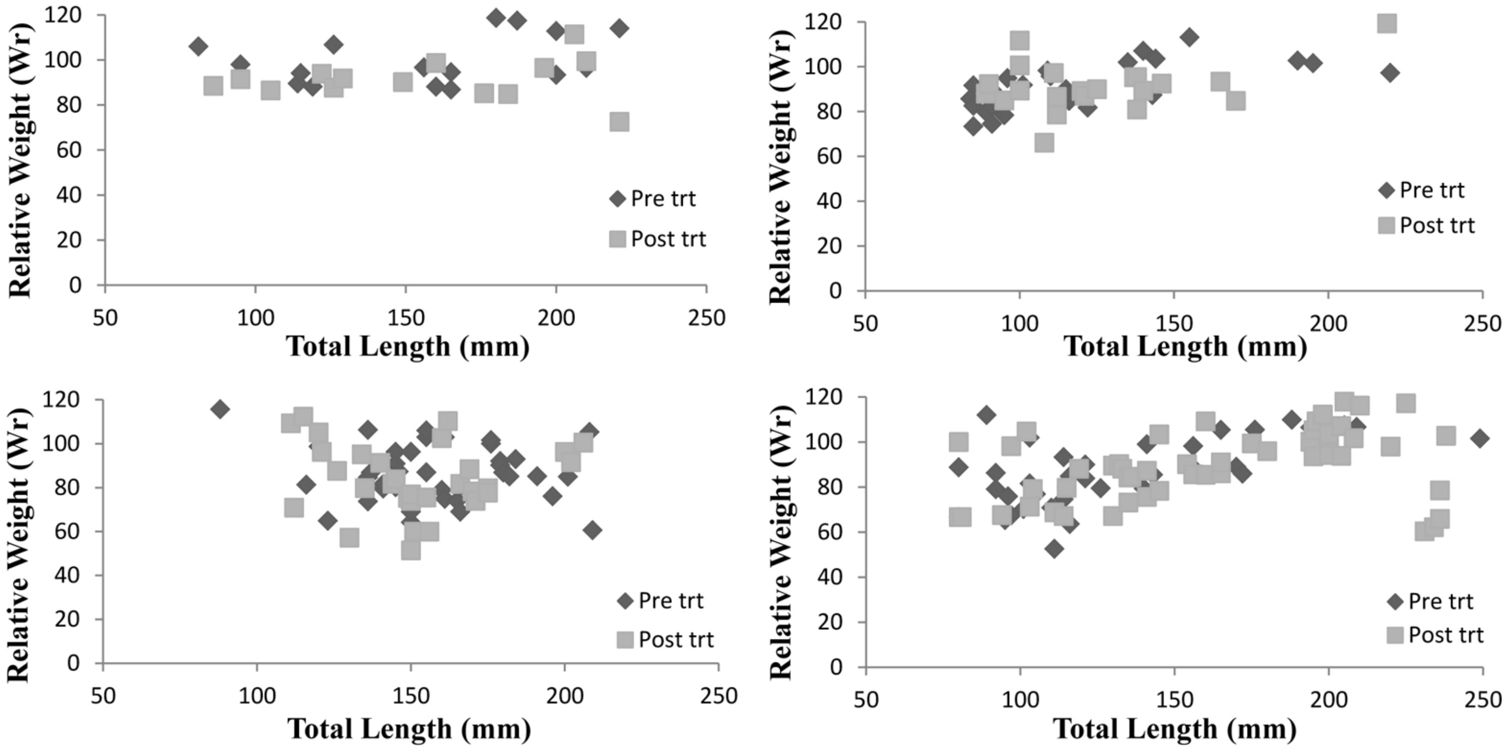

Figure 3.12 Overall relative weight of bluegill for reference (top left), feeding (top right), low P (bottom left), and high P (bottom right) for pretreatment and post-treatment in pond experiment conducted in north central Mississippi, 2011.

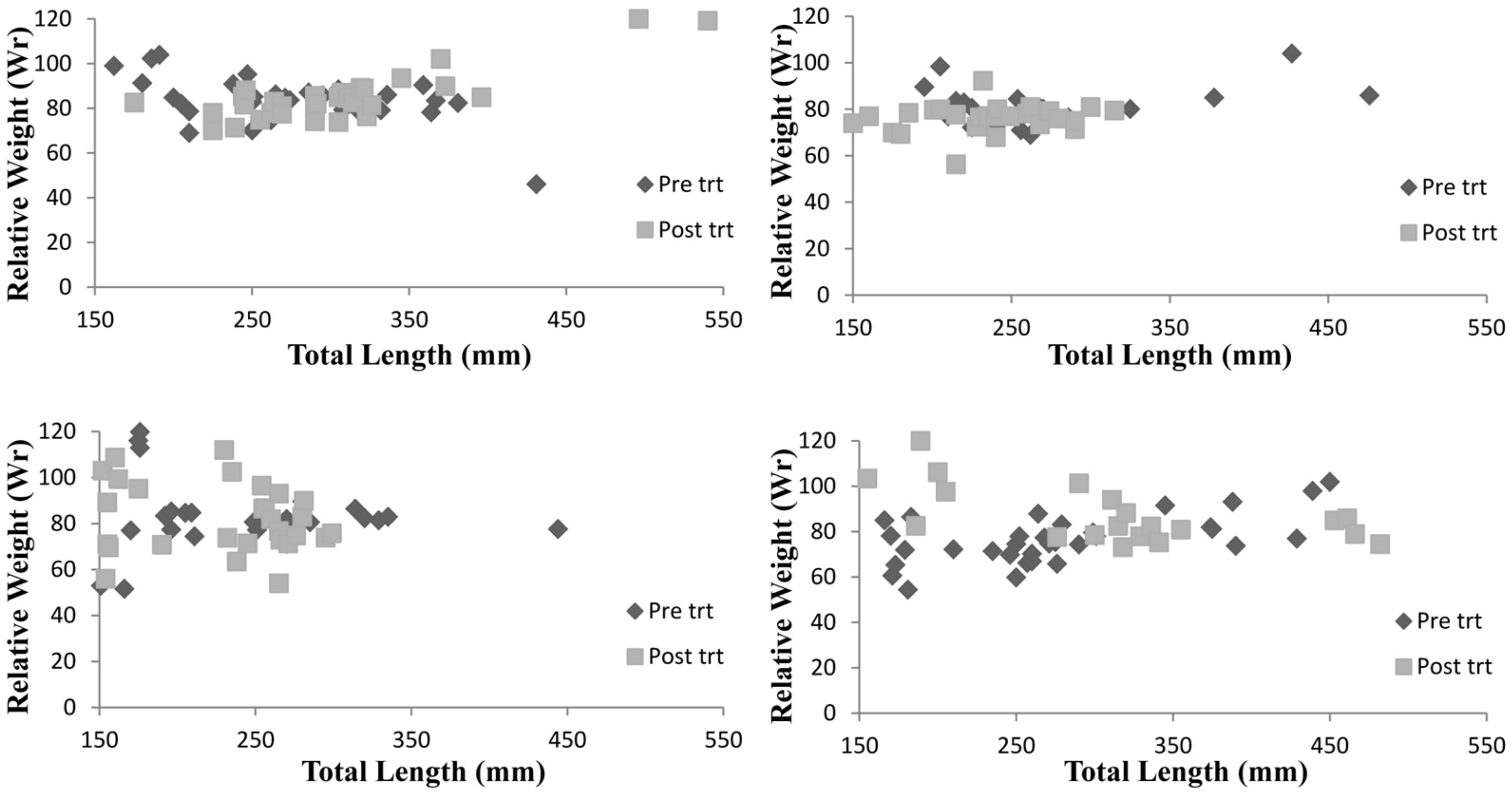

Figure 3.13 Overall relative weights of largemouth bass for reference (top left), feeding (top right), low P (bottom left), high P (bottom right) for pretreatment and post-treatment in pond experiment conducted in north central Mississippi, 2011.

CHAPTER IV

COSTS ASSOCIATED WITH POND MANAGEMENT

Introduction

Managing ponds and small impoundments frequently incurs costs. Type of management techniques and preferences for the pond often determines how much is spent annually. It is important to know what materials will be needed as well as how much they cost before pond owners decide on how to manage their pond. Water quality parameters, aquatic macrophytes and phytoplankton biomass are important components in a pond ecosystem and can influence economic costs of pond management.

Water quality parameters such as total alkalinity, temperature, dissolved oxygen, pH, chlorophyll *a*, and secchi depth can influence how management is conducted and can also play a role in the occurring costs. Acidic ponds with total alkalinity levels less than 20 mg/L are typically recommended to apply agriculture limestone to raise alkalinity to buffer water against rapid changes in pH and increase availability of nutrients in the water column (Boyd 1990; Boyd and Tucker 1998) which incurs more costs. Extremely high pH and chlorophyll *a* concentrations and extremely low dissolved oxygen levels and secchi depths can have negative impacts on fish populations and often result in fish kills.

Aquatic macrophytes are an important part of pond ecosystem. They can provide many benefits to an aquatic ecosystem such as refuge, shelter and various feeding opportunities for fish and invertebrates (Dibble et al. 1996). However, populations of aquatic macrophytes can reach nuisance levels and add costs for eradication efforts such as chemical, or biological (Wiley et al. 1984). Aquatic macrophyte infestations can reduce sportfishing yields by hindering foraging efficiency and pose as an obstacle for recreational users (Colle and Shireman 1980; Savino and Stein 1982; Wiley et al. 1984) Also, excessive nutrients from run-off, livestock, and fertilizing may cause nuisance filamentous algae blooms in which algaecides will incur more costs.

Understanding the positive and negative impacts of water quality, aquatic macrophytes and phytoplankton biomass in ponds is paramount to management efforts. Although aquatic vegetation can have many benefits, it may have many negative aspects. An internet survey for Texas ponds and small impoundments revealed that aquatic vegetation was the most common problem for pond owners (Schonrock 2005). Excessive growth of aquatic macrophtyes needs to be managed because it can reduce condition and growth of largemouth bass and bluegill (Colle and Shireman 1980; Wiley et al. 1984) and also can interfere with fishing. Largemouth bass growth was predicted by Colle and Shireman (1980) to significantly decrease in a system with 40% or greater total coverage of aquatic plants than a body of water with less than 40% aquatic vegetation. Bluegill growth has been shown to improve when aquatic vegetation was removed and the littoral zone had between 20 and 40% of vegetation (Olson et al. 1998). However, most pond owners consider aquatic macrophytes a nuisance and are willing to pay to partially or fully eradicate aquatic vegetation in their ponds.

Cost of fertilizer, feed, herbicide, and algaecides may influence or determine a pond owner’s decision. Different ways to manage a pond for fish have different costs and efficiencies. Shireman and others (1986) found that fertilization costs were

$608/hectare/year and herbicide costs, for aquatic vegetation percentages of 0, 40, and 70, ranged from $417/hectare/year to $1,339/hectare/year over a four-year period. The costs of managing a pond for fish production need to be determined before a pond owner makes a decision.

It is important to study and identify responses of common pond management approaches such as supplemental feeding, fertilizing, and no management on the water quality, aquatic macrophytes, and chlorophyll *a* as well as the costs associated with these management approaches to better manage and utilize ponds more efficiently.

My goal was to conduct a field study to investigate how common pond management approaches influence pond conditions as well as economic costs of each pond management approach in ponds located in north central Mississippi. I evaluate treatment effects on pond conditions by measuring differences in physiochemical variables such as temperature, dissolved oxygen, and pH as well as indicators of phytoplankton biomass such as secchi depth and chlorophyll *a*. I also evaluated treatment effects on aquatic plant frequency pre and post treatment. In addition, I evaluate costs associated with different pond management approaches by obtaining economic costs of materials, algaecides and herbicides.

Methods

The experiment was conducted in 12 privately-owned ponds in Oktibbeha county, except for two ponds located in Clay county in north central Mississippi. Total alkalinity, reported as mg/L CaCO3, was measured using a Lamotte colorimetric test kit (Chestertown, MD, USA).

The following physiochemical variables were measured in each pond: temperature, dissolved oxygen, pH, total phosphorus, chlorophyll *a* and secchi disk transparency. A water quality multi-probe (Manta Eureka™, Austin, Texas) was used to measure temperature, pH and dissolved oxygen. Total phosphorus was analyzed by ascorbic acid method 10210 using TNT plus ™ 843 and was calorimetrically determined on a DR 5000 spectrophotometer (Hach 2008). Total phosphorus was measured before applying fertilizer to see how much was needed to achieve a phosphorus level of 0.3 mg P/L for low P treatment and 0.6 mg P/L for high P treatment. Data readings were collected at three random points for each pond. The multi-probe was lowered to the bottom to take the first reading then pulled upwards every meter to take other readings and also stopped at 0.5 meters for surface readings at each point for each pond to get a mean for the water column. *In vivo* chlorophyll *a* (chl *a*) was measured with an AquaFluor™ handheld fluorometer (Turner Designs, Sunnyvale, CA) to estimate algae density for each treatment (Wersal and Madsen 2011). Secchi disk transparency was measured at three different locations by visual observation method (Carlson and Simpson 1996). Secchi disk transparency and multi-probe sampling occurred between 9:00 a.m. and 2:00 p.m. on consecutive days at the end of each month. A point-intercept survey was conducted on a 20 meter grid (Madsen 1999), to assess the aquatic plant communities within each pond before and after study. Trimble Yuma™ (Sunnyvale, California) tablet computer, with an internal global positing system (GPS), was used to navigate to each point.

When pond owners complained of aquatic vegetation problems, herbicides or algaecides were applied depending on plant type. Chemical control was applied with either diquat (Reward®, Syngenta, Greensboro, North Carolina), glyphosate (Rodeo®, Monsanto Company, St. Louis, MO) or chelated copper (Cutrine Plus®, Applied Biochemists, Germantown, Wisconsin) depending on the target plant. Costs were calculated by documenting cost of materials from reputable sources (Table A.5). Costs of feed, herbicides, algaecides, fertilizer and amount of materials used for each task were documented.

Data Analysis

Chlorophyll a and secchi depth were tested for normality with a Shapiro-Wilk test and were not, so a Friedman nonparametric analysis of variance (ANOVA) with repeated measures was used to determine differences for these variables. Temperature, dissolved oxygen, pH, were transformed as necessary and followed a normal distribution as determined by Shapiro-Wilk tests and further analyzed by one-way analysis of variance (ANOVA) with repeated measures. Statistically significant values were assessed using a Tukey's multiple comparison test using SAS version 9.2 (SAS Institute, Cary, NC).

Results

Temperature (°C) differed significantly ($F = 27.6$, $P = 0.01$) among treatments. Temperature was significantly less in feeding treatment than both low P and reference treatments (Figure 4.1). Temperature peaked in July for all ponds. The interaction between pond treatment and month was significant ($F = 2.42$, $P = 0.001$) for temperature (Figure 4.2). Dissolved oxygen (mg/L) differed significantly ($F = 18.82$, $P < 0.001$) among treatments (Figure 4.3). Dissolved oxygen for reference treatment ponds were significantly greater than feeding and high P treatments. Also, low P treatment was significantly greater than feeding treatment. Mean dissolved oxygen concentration was least for July feeding ponds at 4.2 mg/L and greatest for May low P ponds at 9.5 mg/L (Figure 4.4). The interaction between pond treatment and month was significant

(F = 2.75, P < 0.001) for dissolved oxygen (Figure 4.4). Secchi depth (m) differed significantly (Friedman test, P< 0.001) among treatments (Figure 4.5). High P treatment had significantly lower secchi depths than other treatments. Reference ponds had relatively high secchi depths although lower secchi depths were observed in July, August, and September due to two of the ponds developing late algal blooms at this time. Interaction between pond treatment and month was significant (Friedman test, P = 0.01) for secchi depth (Figure 4.6). Chlorophyll *a* (µg/L) differed significantly (Friedman test, P< 0.001) among treatments (Figure 4.7). High P treatment had significantly greater chlorophyll *a* than other treatments and feeding treatment was significantly greater in chlorophyll *a* than low P treatment. The interaction between pond treatment and month was significant (Friedman test, P < 0.001) for chlorophyll *a* (Figure 4.8). Reference ponds had low chlorophyll *a* concentration for April, May, June but relatively high concentrations for July, August, and September. This corresponded to lower secchi depth visibilities for reference ponds in these months. The pH differed significantly (F = 30.18, P< 0.001) among treatments (Figure 4.9). Feeding treatment had significantly lesser pH values than other treatments. The interaction between pond treatment and month was not significant (F = 0.97, P = 0.49) for pH (Figure 4.10). Mean pH ranged between 6.5 and 9.0, which is a desirable range for fish production (Boyd 1990).

The greatest cost came from reference treatment in the Marcum pond at $1,242.48 for herbicide and algaecide treatment and second greatest came from high P treatment in the Tyner pond at $911.91 for initial materials, herbicide, and two algaecide treatments (Table 4.1). Main nuisance aquatic plant problems that pond owners were having came from filamentous algae (*Pithophora spp*.), water primrose (*Ludwigia spp*.), and brittle naiad (*Najas minor*) and also occurred the most economic costs for herbicide and algaecide treatments (Table 4.2, Table 4.3).

Discussion

Pond management strategies can affect water quality and aquatic plants, both of which can affect economic costs. Water quality problems with temperature, dissolved oxygen, chlorophyll a, secchi depth, and pH can pose threats to fish in ponds. However, this study found no substantial problems with water quality but had some fluctuations. Also, costs fluctuated for all ponds and for each pond management strategy.

In reference ponds, there was no cost or management with feed or fertilizer; however, in July an algal bloom in two out of the three ponds was observed. Increased water clarities toward the beginning of the year allowed for aquatic plants to grow and increase nutrient fluxes in July combined to influence growth of nuisance filamentous algae, submersed plant and emergent plant growth to occur substantial costs with herbicide and algaecide in the Marcum reference pond. However, on the other end of the spectrum increased nutrients from high fertilizer level in the Tyner pond lead to increases in nuisance filamentous algae and submersed plants to occur substantial costs with herbicide and algaecide. Although feeding incurred greatest initial costs of materials, no herbicide or algal treatments were needed in this study. Low fertilizer level seemed to be most economical strategy with $28.60 for materials and $66.00 for herbicide spot treatment with glyphosate for emergent plants.

High fertilized ponds had mean secchi disk visibilities ranging from 0.55 m to 0.86 m over the treatment period and low fertilized ponds had mean secchi disk visibilities ranging from 0.82 m to 1.4 m. High fertilized ponds secchi depths are close to the 0.45 m to 0.6 m secchi depth visibility recommended by Brunson et al. (1999) for ideal phytoplankton blooms, but are still somewhat greater and far from the 0.3 m to 0.45 m secchi disk visibility recommendation by Boyd (1990). However, other fertilization experiments have experienced greater secchi depth visibilities above 0.45 m (Wudtisin and Boyd 2005). Nonetheless, future research on secchi disk visibilities for adequate phytoplankton blooms for zooplankton and fish production should be evaluated.

Pond owner preferences toward aquatic vegetation can influence the economic costs of ponds. Some pond owners want vegetation in their pond and realize the importance and benefits from aquatic macrophytes, also some pond owners prefer to fish in and around the vegetation to improve catch rates. However, many pond owners prefer not to have vegetation in their pond or have relatively few areas with macrophytes growing. Pond owners who do not prefer aquatic vegetation and chose to fertilizer their pond, need to ensure that no submersed, floating, emergent or marginal plants are in the pond before fertilizing. Fertilizing will encourage growth of existing aquatic plants and acquire more costs for herbicides and algaecides. This study provides potential costs and outcomes from common pond management strategies, thus future studies should focus on costs for pond owner preferences such as trophy bass, trophy bluegill, or just good balance population for both. Also, other studies could focus on pond restoration or pond construction costs for pond owner preferences.

Table 4.1 Costs of initial materials for pond experiment conducted in north central Mississippi, 2011.

Pond	Treatment	Initial Costs	Total Costs (materials, algaecide, and herbicide)
Dibble	Reference	$0.00	$0.00
Marcum	Reference	$0.00	$1,242.48
Pryor 3	Reference	$0.00	$0.00
Gillis	Feeding	$153.95	$153.95
Pennel	Feeding	$153.95	$153.95
Smith 2	Feeding	$153.95	$153.95
Maples	Low fertilizer	$28.60	$94.60
Mlsna	Low fertilizer	$28.60	$28.60
Pryor 1	Low fertilizer	$28.60	$28.60
Tyner	High fertilizer	$57.20	$911.91
Willcutt	High fertilizer	$57.20	$57.20
Smith 1	High fertilizer	$57.20	$57.20

Table 4.2 Point intercept survey for aquatic plants before treatments for pond experiment conducted in north central Mississippi, 2011.

Pond	Treatment	Sampling pts.	Common name	Species name	% Frequency
Dibble	Reference	17	-	-	0
Marcum	Reference	25	water primrose	*Ludwigia spp.*	32.0
		25	filamentous algae	*Pithophora spp.*	16.0
Pryor 3	Reference	26	leafy pondweed	*Potomageton foliosus*	69.2
		26	American pondweed	*Potamogeton nodosus*	7.7
Gillis	Feeding	22	variable leaf pondweed	*Potamogeton diversifolius*	27.3
		22	water primrose	*Ludwigia spp.*	18.2
Pennel	Feeding	16	waterleaf	*Hydrolea spp.*	6.3
Smith 2	Feeding	22	leafy pondweed	*Potomageton foliosus*	54.5
Maples	Low fertilizer	20	water primrose	*Ludwigia spp.*	5.0
Mlnsa	Low fertilizer	20	water primrose	*Ludwigia spp.*	25.0
Pryor 1	Low fertilizer	23	leafy pondweed	*Potomageton foliosus*	56.5
Tyner	High fertilizer	20	brittle Naiad	*Najas minor*	55.0
		20	coontail	*Ceratophyllum demersum*	30.0
Willcutt	High fertilizer	20	-	-	0
Smith 1	High fertilizer	16	-	-	0

Table 4.3 Point intercept survey for aquatic plants after treatments for pond experiment conducted in north central Mississippi, 2011.

Pond	Treatment	Sampling pts.	Common name	Species name	% Frequency
Dibble	Reference	17	white water lily	*Nymphaea odorata*	5.9
Marcum	Reference	25	water primrose	*Ludwigia spp.*	20.0
		25	filamentous algae	*Pithophora spp.*	48.0
		25	brittle naiad	*Najas minor*	24.0
		25	smart weed	*Polygonum spp.*	8.0
Pryor 3	Reference	26	leafy pondweed	*Potomageton foliosus*	76.9
		26	American pondweed	*Potamogeton nodosus*	19.2
Gillis	Feeding	22	variable leaf pond weed	*Potamogeton diversifolius*	40.9
		22	water primrose	*Ludwigia spp.*	18.2
Pennel	Feeding	16	waterleaf	*Hydrolea spp.*	12.5
Smith 2	Feeding	22	leafy pondweed	*Potomageton foliosus*	59.1
Maples	Low fertilizer	20	water primrose	*Ludwigia spp.*	5.0
Mlnsa	Low fertilizer	20	water primrose	*Ludwigia spp.*	20.0
Pryor 1	Low fertilizer	23	leafy pondweed	*Potomageton foliosus*	73.9
Tyner	High fertilizer	20	brittle naiad	*Najas minor*	85.0
		20	coontail	*Ceratophyllum demersum*	20.0
		20	filamentous algae	*Pithophora spp.*	85.0
Willcutt	High fertilizer	20	water primrose	*Ludwigia spp.*	5.0
Smith 1	High fertilizer	16	-	-	0

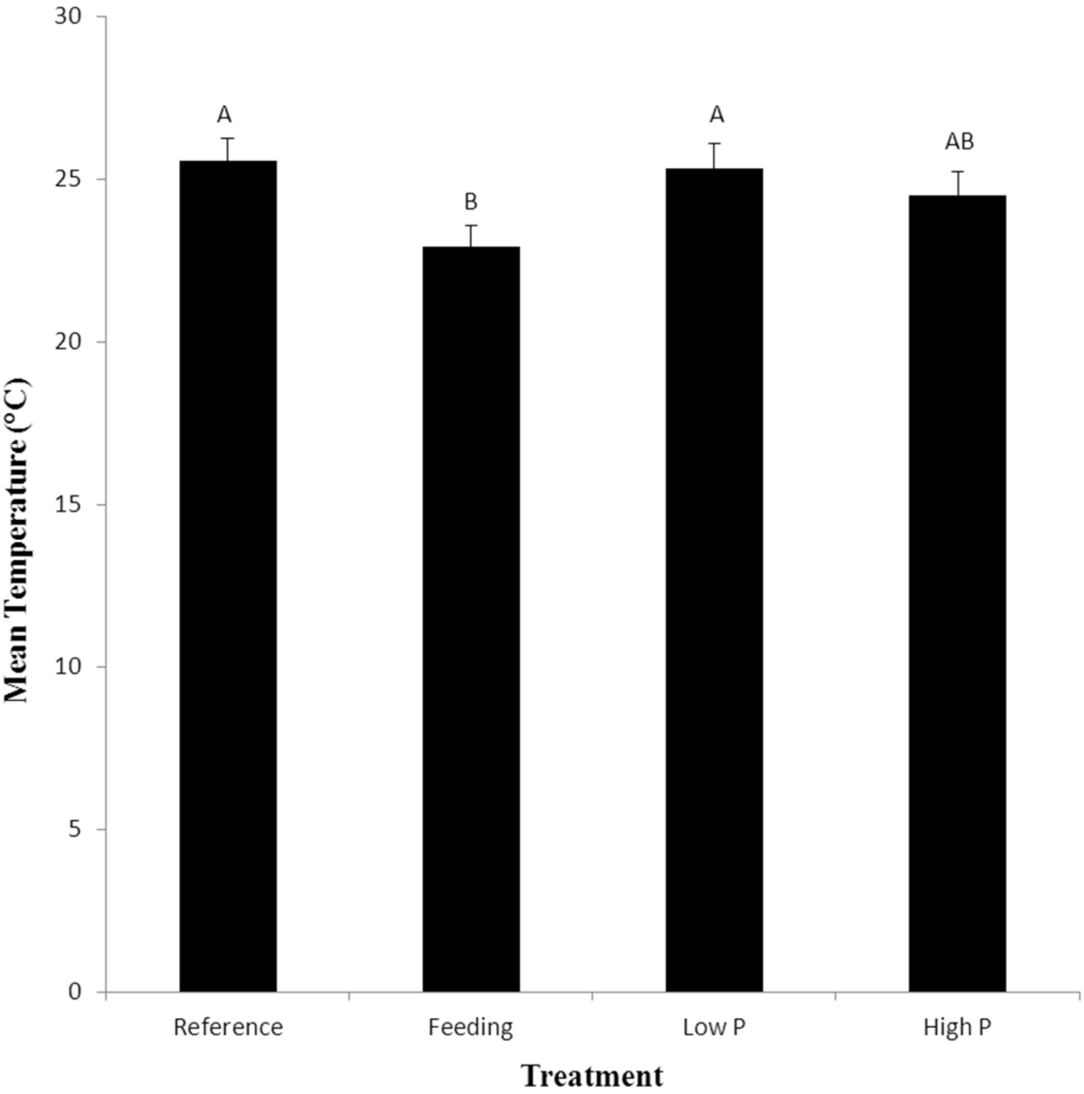

Figure 4.1 Mean temperature (°C) (±SE) for treatments in pond experiment conducted in north central Mississippi, 2011. The y-axis error bars are representative of standard error. Significant differences among treatments are represented by letters above y-axis error bars.

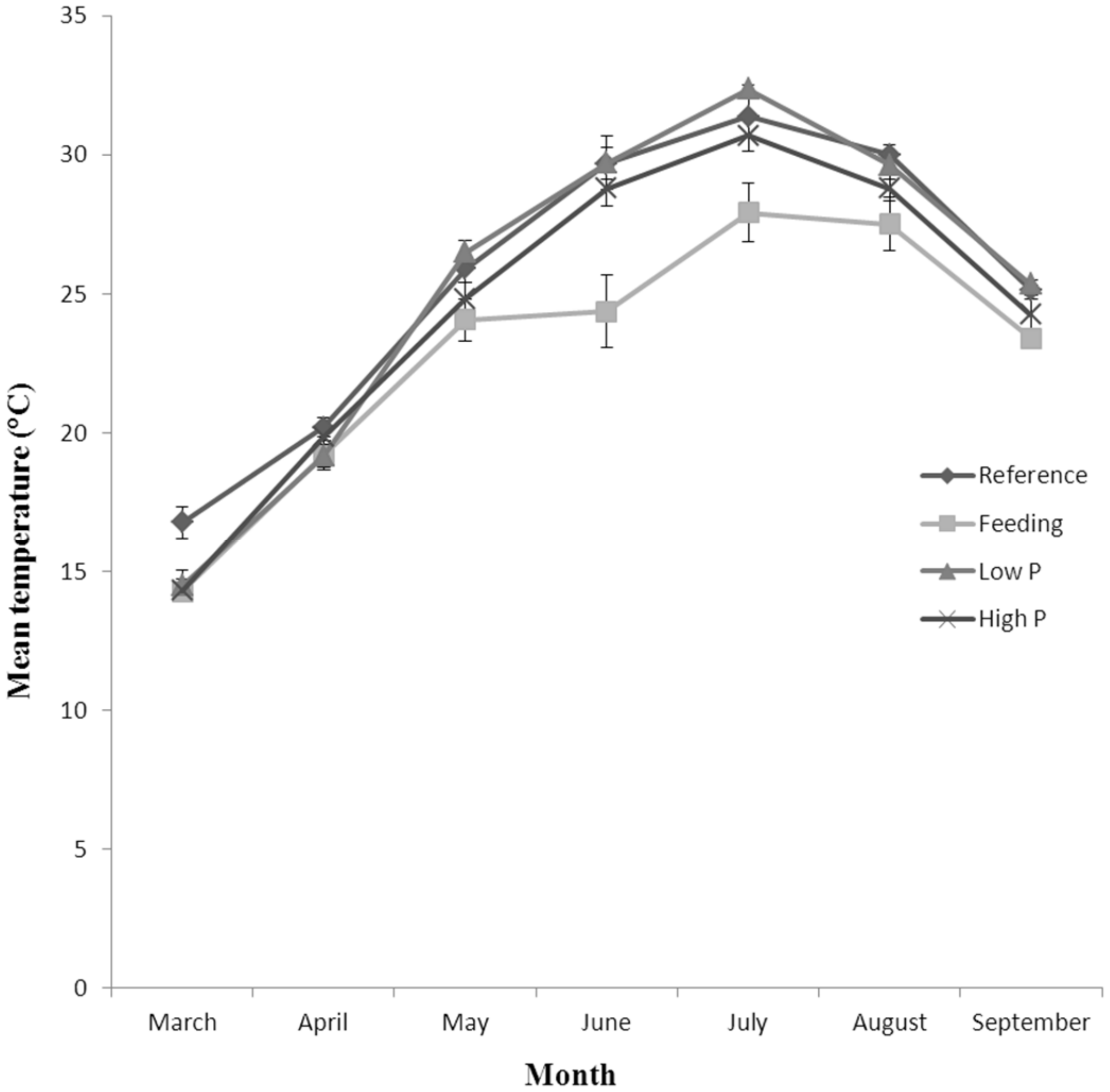

Figure 4.2 Mean temperature (°C) (±SE) for treatments over time for pond experiment conducted in north central Mississippi, 2011. The y-axis error bars are representative of standard error.

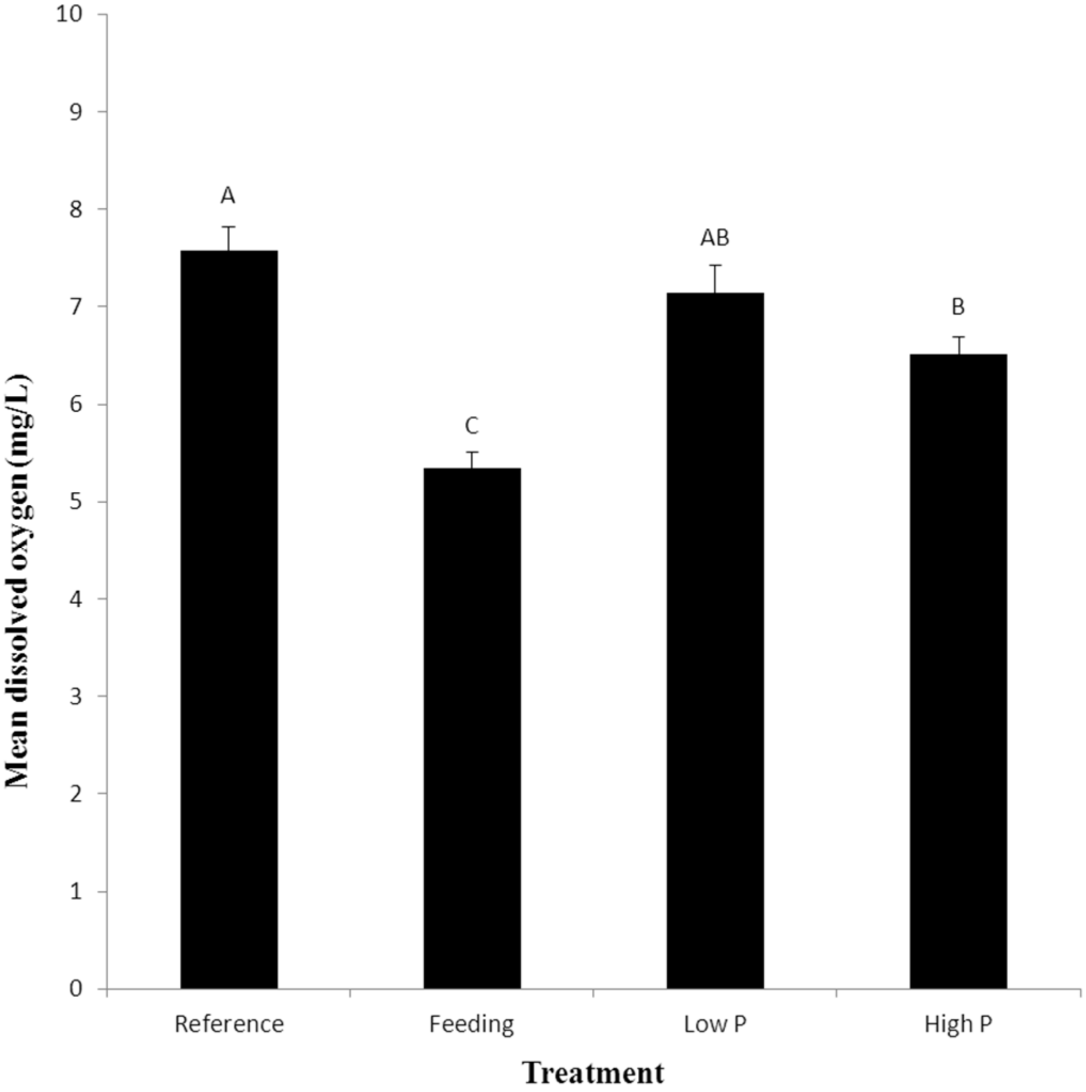

Figure 4.3 Mean dissolved oxygen (mg/L) (±SE) for treatments in pond experiment conducted in north central Mississippi, 2011. The y-axis error bars are representative of standard error. Significant differences among treatments are represented by letters above y-axis error bars.

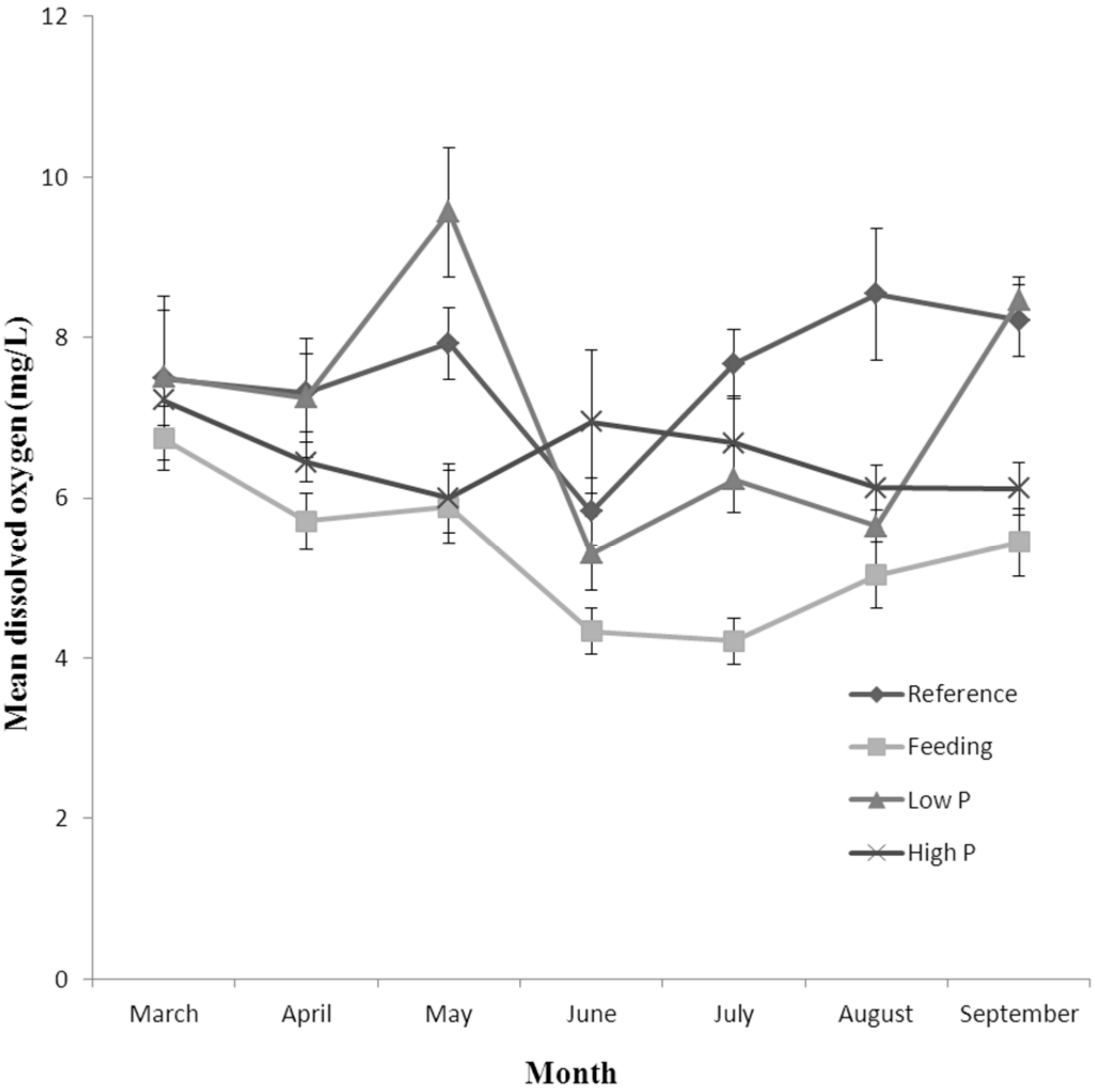

Figure 4.4 Mean dissolved oxygen (mg/L) (±SE) for treatments over time in pond experiment conducted in north central Mississippi, 2011. The y-axis error bars are representative of standard error.

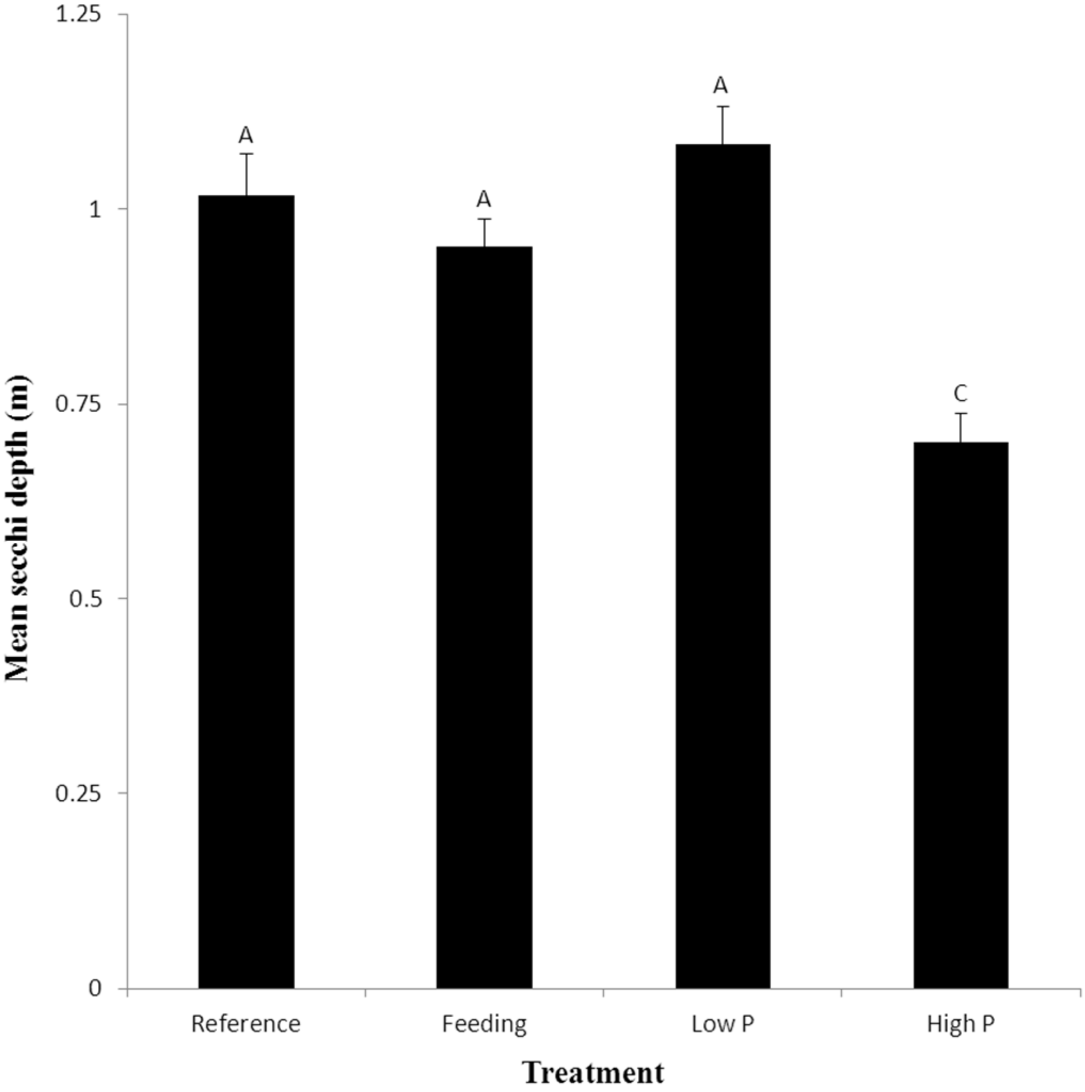

Figure 4.5 Mean secchi depth (m) (±SE) for treatments in pond experiment conducted in north central Mississippi, 2011. The y-axis error bars are representative of standard error. Significant differences among treatments are represented by letters above y-axis error bars.

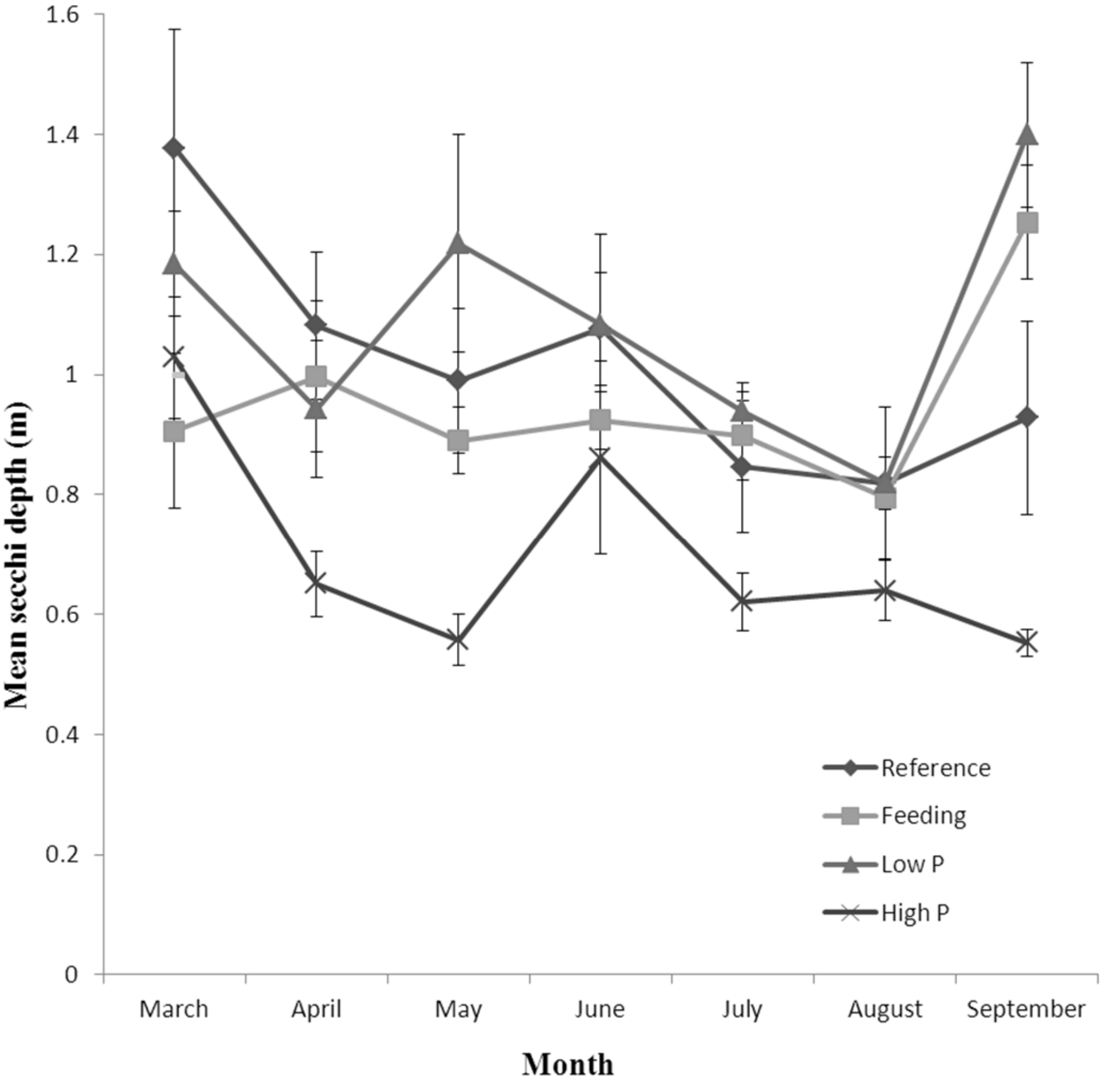

Figure 4.6 Mean secchi depth (m) (±SE) for treatments over time in pond experiment conducted in north central Mississippi, 2011. The y-axis error bars are representative of standard error.

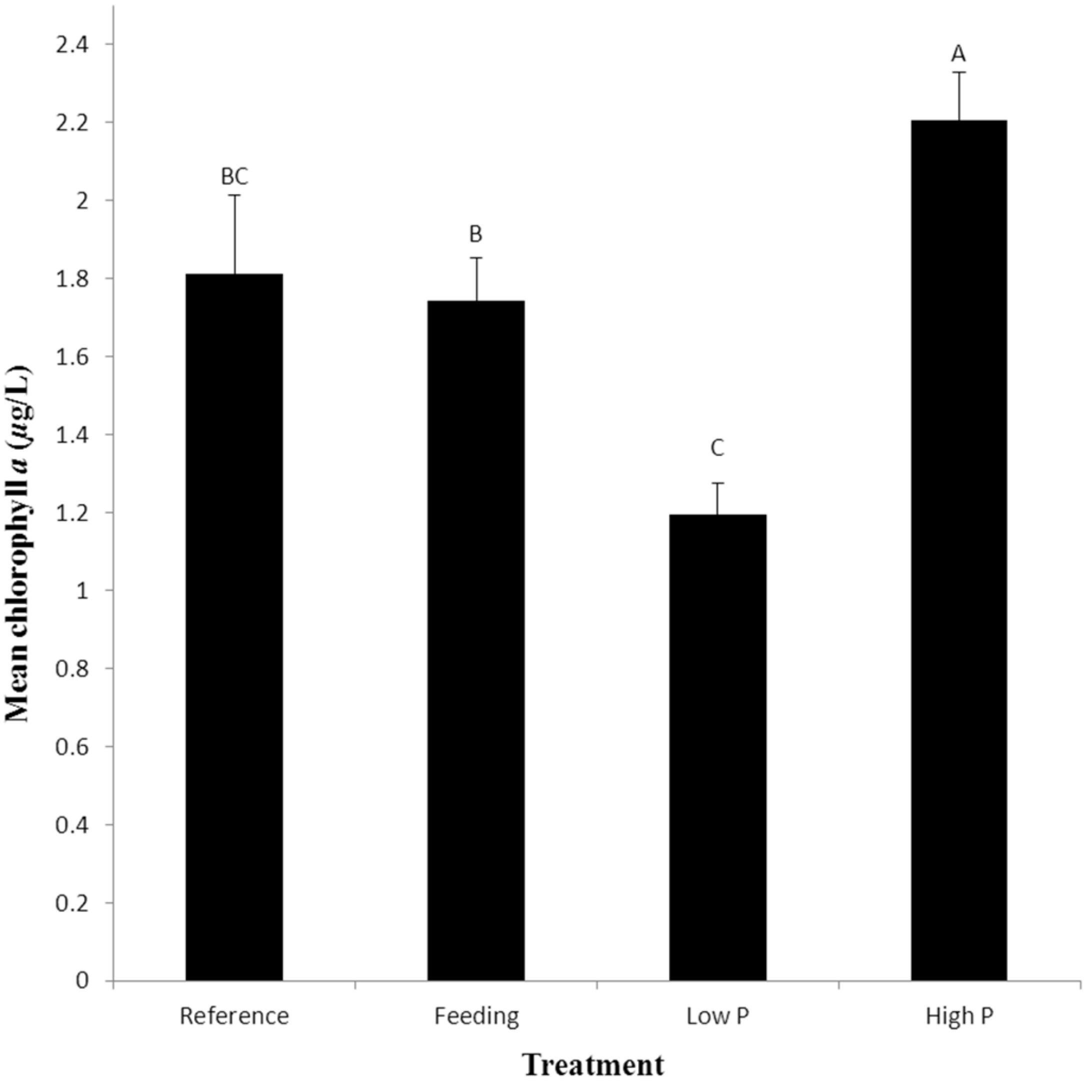

Figure 4.7 Mean chlorophyll *a* (µg/L) (±SE) for treatments in pond experiment conducted in north central Mississippi, 2011. The y-axis error bars are representative of standard error. Significant differences among treatments are represented by letters above y-axis error bars.

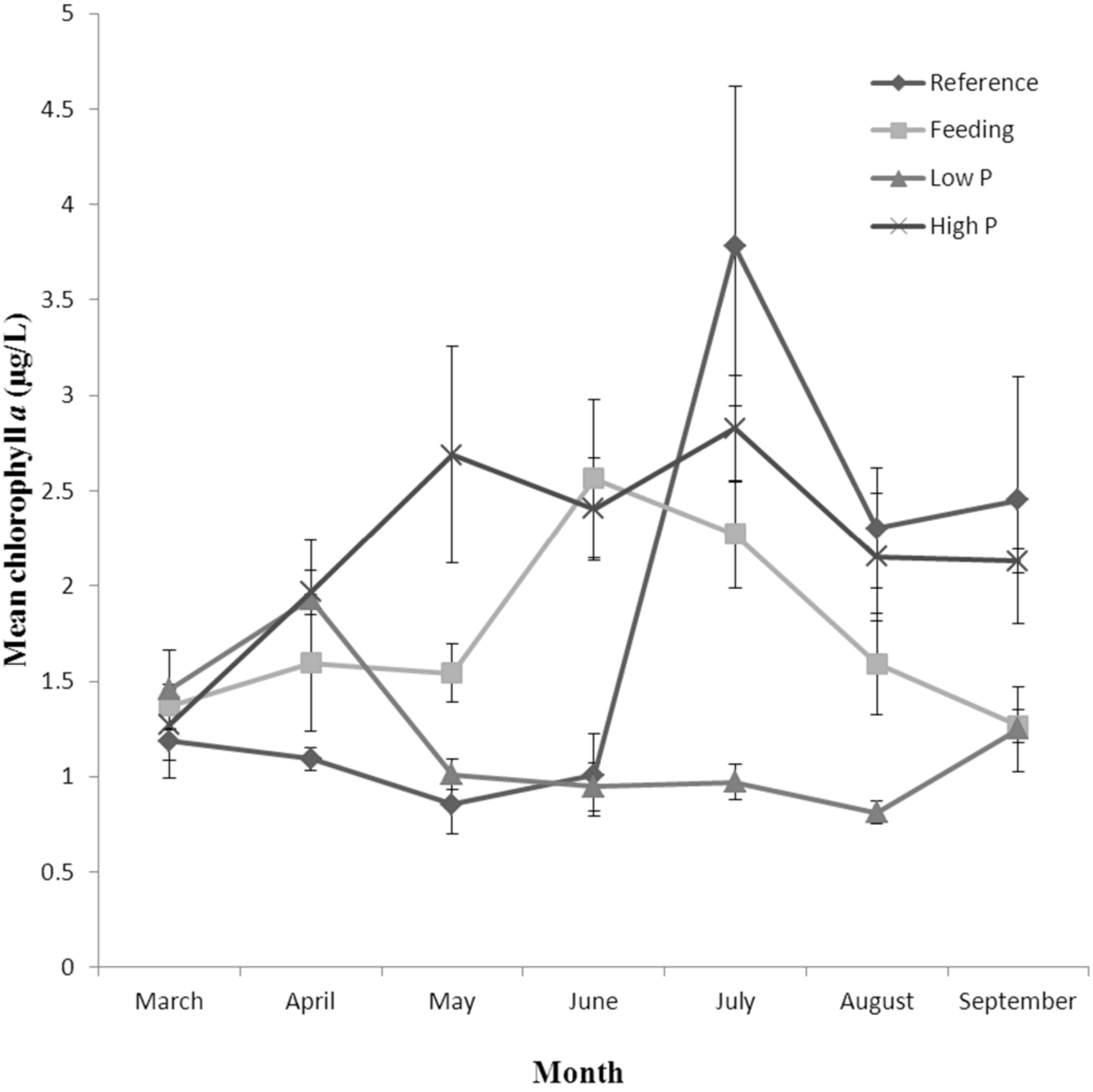

Figure 4.8 Mean chlorophyll *a* (µg/L) (±SE) for treatments over time in pond experiment conducted in north central Mississippi, 2011. The y-axis error bars are representative of standard error.

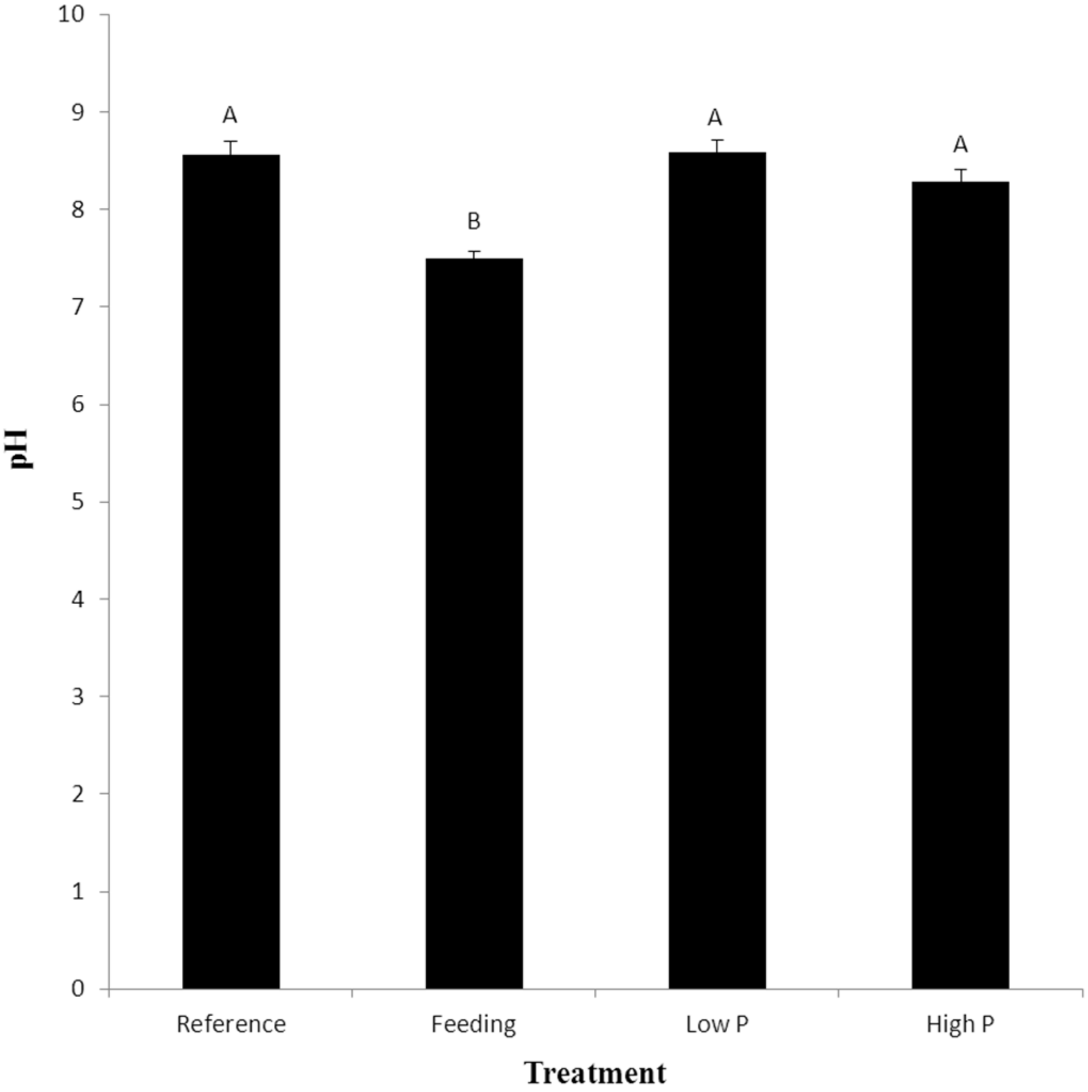

Figure 4.9 Mean pH (±SE) for treatments in pond experiment conducted in north central Mississippi, 2011. The y-axis error bars are representative of standard error. Significant differences among treatments are represented by letters above y-axis error bars.

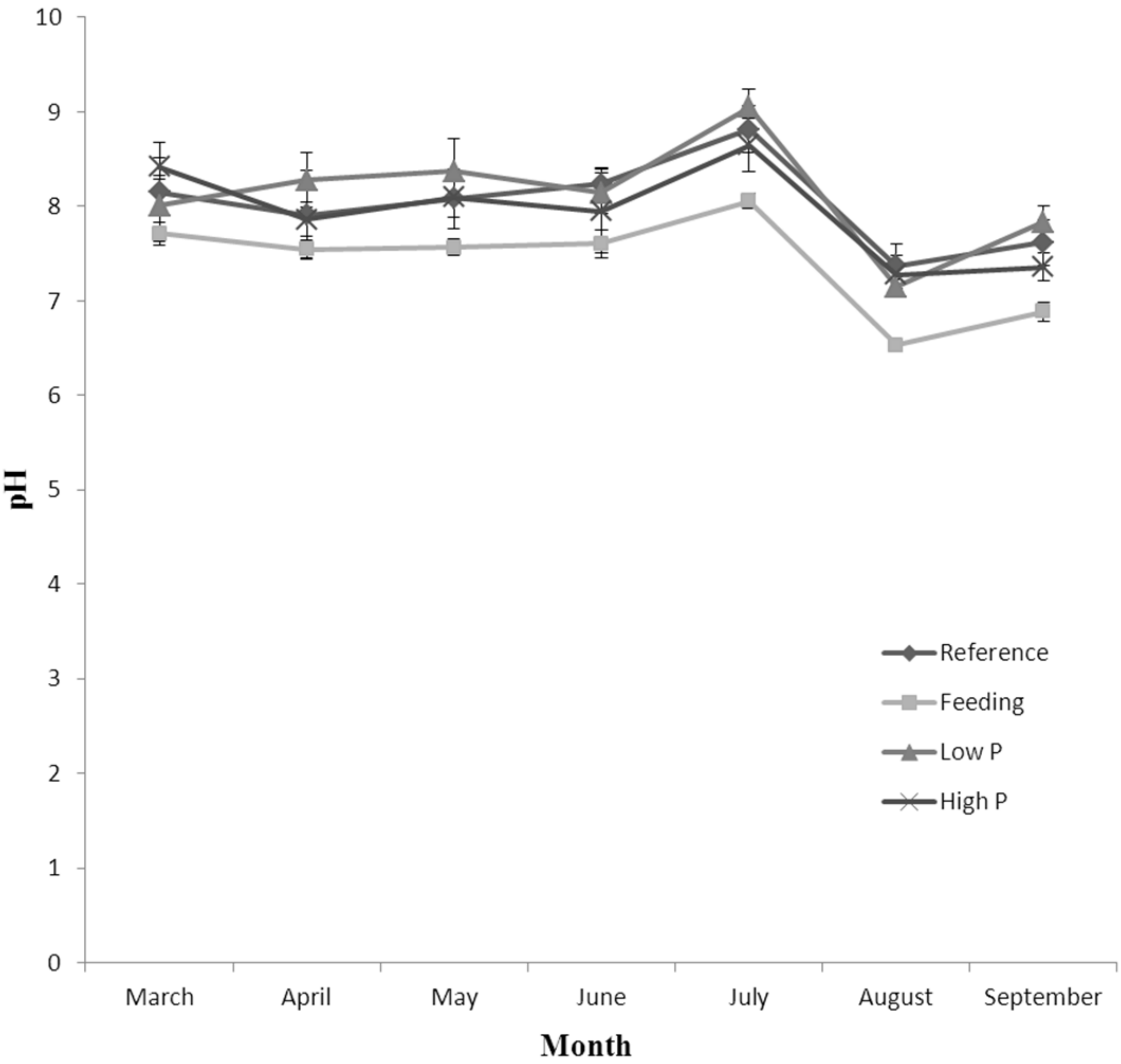

Figure 4.10 Mean pH (±SE) for treatments over time in pond experiment conducted in north central Mississippi, 2011. The y-axis error bars are representative of standard error.

CHAPTER V

SYNTHESIS

Ponds and small impoundments are important for our future recreational fisheries throughout the United States and continue to grow in numbers every year. Sound research that facilitates a better understanding of pond ecology and identifies practical and efficient economics is paramount at improving best manage practices used in Mississippi ponds and small impoundments. This research adds to fertilization programs throughout the southeastern United States and further the knowledge of pond ecology.

State and federal agency fishery managers as well as private pond owners manage ponds by different strategies. However, the variety of management strategies available to the pond manager has differential effects on trophic levels within ponds, as well as costs associated with each strategy. The overall goal of my study was to investigate how different approaches in pond management influenced trophic levels as well as to obtain economic costs of different management approaches.

Two experiments were conducted to first evaluate phosphorus concentration levels (mg P/L) on sunfish growth and second to use two of these concentration levels to evaluate at a larger scale in privately owned ponds. Nuisance aquatic plant problems were observed with the high fertilization level resulting in more costs for algaecides and herbicides. Pond managers may be able to use a high fertilization level but are likely to have to excessive aquatic plant growth including filamentous algae problems. For best management practices the lesser fertilization level of 0.3 mg P/L is more likely to result in less aquatic plant problems and less economic costs to the pond owner while still efficiently maintaining zooplankton production.

This research shows that pond owner preferences on aquatic vegetation also play a role on costs. Emergent vegetation was considered nuisance by some pond owners and incurred costs; however, emergent vegetation can play vital roles in aquatic ecosystems, providing refuge and food resources for zooplankton (Nurminen and Horppila 2002), macroinvertebrates (Schramm and Jirka 1989) and fish (Bryan and Scarnecchia 1992). This research brings insight to pond owners on how much algaecides and herbicides cost as well as how much is needed.

Current liquid fertilizer rate recommendation for Mississippi is based on soil region and varies from ½ gallon to 1 gallon per acre or no fertilizer needed in the delta region (Neal and Clardy 2010). Results from my research helps refine fertilization programs in ponds by first evaluating phosphorus levels (TP) before fertilization and second to obtain pond volume to better estimate amount of fertilizer needed. Many privately owned ponds have different sizes and average depths which can influence how much fertilizer is needed. Also, this study focused fertilizing at a concentration rate instead of surface acre rate. Checking phosphorus level before fertilizing allows the pond owner to accurately assess how much is needed without over fertilizing. This study focused on one growing season from March to September, future studies should focus on multiple years and their effects on the trophic levels as well as costs associated.

Also, current recommendation for secchi disk visibility for fertilizer programs in Mississippi is 0.45 meters to 0.59 meters and if secchi disk visibility reaches 0.6 meters it is time for another application of fertilizer (Neil and Clardy 2010). However, keeping phytoplankton levels at this range of secchi disk visibility may not be necessary for adequate zooplankton production. Greater secchi disk visibilities than the recommended maximum of 0.45 meters by Boyd 1990 have been observed in other fertilization experiments for bluegill (Wutisin and Boyd 2005). Secchi disk visibility of 0.45 meters to 0.6 meters needs to be investigated more thoroughly as greater secchi disk visibilities than 0.6 meters may be viable for zooplankton production and therefore fish production and results in less fertilizer applications throughout the year. Also, more accurate results are needed to assess bluegill and largemouth bass total length increases and relative weight increases from pond management approaches. Future studies on effects of pond management approaches on fish growth should either begin by stocking same size fish or by draining ponds at the end of study to accurately assess significant differences in growth and production.

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APPENDIX A

SUMMARY OF PRODUCT PRICE, FERTILIZER, SUPPLEMENTAL FEED, HERBICIDE, ALGAECIDE AMOUNT AND COSTS FOR POND EXPERIMENT CONDUCTED IN NORTH CENTRAL MISSISSIPPI, 2011

Table A.1 Fertilizer amount and costs for pond experiment conducted in north central Mississippi, 2011

Pond	Treatment	Acre	Mean depth (ft)	Acre-ft	Total (gallon)	Cost (gallon)	Total cost
Maples	Low fertilizer	5.9	5.4	31.86	3.07	$17.60	$28.60
Mlsna	Low fertilizer	1.1	5.8	6.38	0.93	$5.31	$28.60
Pryor 1	Low fertilizer	1.28	4.8	6.14	2.10	$12.01	$28.60
Tyner	High fertilizer	3.0	4.1	12.3	6.80	$38.90	$57.20
Willcutt	High fertilizer	1.9	6.6	12.6	8.52	$48.73	$57.20
Smith 1	High fertilizer	2.45	3.8	9.3	5.53	$31.63	$57.20

Table A.2 Supplemental feed amount and costs for pond experiment conducted in north central Mississippi, 2011.

Pond	Treatment	Amount (lbs.)	Costs per 50lb	Feed cost	Auto feeder
Gillis	Feeding	261	$12.50	$75.00	$78.95
Pennel	Feeding	261	$12.50	$75.00	$78.95
Smith 2	Feeding	261	$12.50	$75.00	$78.95

Table A.3 Herbicide amount and costs for pond experiment conducted in north central Mississippi, 2011.

Pond	Treatment	Herbicide	Amount	Cost (gallon)	Total cost
Marcum	Reference	Rodeo (Glyphosate)	2 oz	$19.50	$19.50
		Reward (Diquat)	8 gal.	$97.83	$782.64
		Dyne-Amic (Surfactant)	2 oz	$46.50	$46.50
Maples	Low fertilizer	Rodeo (Glyphosate)	4 oz	$19.50	$19.50
		Dyne-Amic (Surfactant)	4 oz	$46.50	$46.50
Tyner	High fertilizer	Reward (Diquat)	3 gal.	$97.83	$293.49

Table A.4 Algaecide amount and costs for pond experiment conducted in north central Mississippi, 2011.

Pond	Treatment	Algaecide	Amount	Cost (gallon)	Total cost
Marcum	Reference	Cutrine-plus	12 gal	$32.82	$393.84
Tyner	High fertilizer	Cutrine-plus	14.4 gal	$32.82	$561.22

Table A.5 Product price list for pond experiment conducted in north central Mississippi, 2011.

Product	Price	Source
Fish feeder	$78.95 each	Oktibbeha County Co-op
Floating catfish feed	$12.50 per 50lb bag	Oktibbeha County Co-op
Liquid 10-34-0 fertilizer	$28.60 per 5 gallon bucket	Oktibbeha County Co-op
Cutrine Plus (Chelated Copper)	$32.82 per gallon	Helena Chemical Co. & Cygnet Enterprises Inc.
Reward, (Diaquot)	$97.83 per gallon	Helena Chemical Co. & Cygnet Enterprises Inc.
AquaPro, Aquaneat (Glyphosate)	$50.01 per gallon, $55.10 per 2.5 gallon	Helena Chemical Co. Cygnet Enterprises Inc.
Rodeo (Glyphosate)	$19.50 per gallon	Helena Chemical Co.
Dyne-Amic, Sun energy (Surfactant)	$46.50 per gallon	Helena Chemical Co. & Cygnet Enterprises Inc.