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Effects of Grass Carp in Midwest Reservoirs

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Effects of Grass Carp use in Midwest reservoirs

by

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DEDICATION

The following work is dedicated to my parents Christopher and Annette Mammoser who have always pushed me to be and do the best I can, supporting me through everything.

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ABSTRACT

Aquatic vegetation control is an ongoing issue for many waterways across the United States. Iowa's landscape is naturally highly productive making this issue of nuisance levels of vegetation a common occurrence. Initial options for managing aquatic vegetation were to use mechanical or chemical methods but excessive cost and time necessitated the decision to use Grass Carp starting in 1973. In response to management concerns related to Grass Carp stocking into Iowa's public lakes, recent changes in aquatic management approaches have been undertaken. Three lakes in Iowa representing different management scenarios in the use of Grass Carp as a management tool for aquatic vegetation were chosen. Red Haw Lake is void of Grass Carp, Mormon Trail Lake has a medium density of Grass Carp (9.5/ha) and Greenfield Lake has a high density of Grass Carp (33.5/ha). Aquatic vegetation and water chemistry were sampled in June-August 2007-2012. Benthic macroinvertebrates, young of year Bluegill and Largemouth Bass were sample in 2011 and 2012 to understand how changes in aquatic vegetation caused by Grass Carp change their communities and characteristics.

Grass Carp can have a strong influence on vegetation diversity and abundance through their selective grazing. Varying densities of Grass Carp alters the intensity of their effect on the vegetation within the system. Benthic macroinvertebrate communities are changed by vegetation abundance. Characteristics of Bluegill and Largemouth Bass spawning activity is most closely linked to water temperature and the intensity to photoperiod. Young of year Bluegill and Largemouth Bass growth is effected by vegetation abundance but competition and food supply also have an influence on it. Vegetation management is not simply adding or removing Grass Carp. Often the issue is caused by more than this singular factor. Rather a more holistic watershed approach is required to achieve the desired result.

CHAPTER 1. GENERAL INTRODUCTION

The utility of aquatic vegetation, namely macrophytes, in fishery management has often been influenced by ongoing conflicts within a specific fishery. For instance, macrophytes are often referred to as 'weeds' when they limit access to water bodies that results in frustration among anglers, i.e., fishing access to the fishery as well as slow growing sport fish through reduced feeding rates and predator forage efficiency (Crowder and Cooper 1982; Bettoli et al. 1992). In contrast, the importance of macrophytes to the health of aquatic ecosystems has been documented by numerous studies (Crowder and Cooper 1979; Savino and Stein 1982; Durocher et al. 1984; Bettoli et al. 1992). In highly altered landscapes, such as the Midwest, rural and urban influences can contribute excess nutrients and soil loss creating aquatic systems inundated with vegetation and plagued with algal blooms. These anthropogenic changes cause eutrophication of lakes, altering aquatic vegetation species and abundance (Scheffer et al. 2001; Egertson et al. 2004).

Swingle (1957) first proposed that the exotic species, Grass Carp *Ctenopharyngodon idella*, from Eastern Asia be introduced into the United States for macrophyte control. During the 1960s there was strong public pressure to find a biological control for macrophytes instead of traditional chemical control, particularly after the book Silent Spring by Rachel Carson (Mitchell and Kelly 2006). Six years after Swingle's proposal, the first Grass Carp were brought into the United States at Auburn University to begin research into their ability to control macrophytes (Bain 1993). Since their introduction, Grass Carp have been recorded in 45 states, including Iowa. Introduction methods varied widely from both legal and illegal stockings (Nico et al. 2012) to escape from aquaculture facilities, and subsequent movement of those introduced populations to other locations (Courtenay et al. 1984).

Even during the first stocking of Grass Carp many fishery managers had significant concerns because of the potential for reproduction and dispersal of self-sustaining populations of this exotic species (Bain 1993). In response to these concerns a private fish hatchery developed triploid Grass Carp in 1983 (Malone 1984). The U.S. Fish and Wildlife Service determined that these triploid Grass Carp were functionally sterile and therefore prohibition of release based on population control concerns were no longer valid (Clugston and Shireman 1987). However, there are still other potential issues with using Grass Carp as biological controls for macrophytes since macrophytes are sometimes viewed as essential habitat for different fish species (Tonn and Magnuson 1982). Many agencies have continued to stock Grass Carp, both diploid and triploid, in water bodies perceived to have excessive macrophyte populations (Nico et al. 2012).

Grass Carp at previously prescribed stocking densities of 25 fish/ha can cause a major reduction to complete elimination of macrophytes (Van Dyke et al. 1984; Klussman et al. 1988; Cashatt 2008). A significant change in macrophytes can cause a cascade of both direct and indirect effects to the ecosystem. The most apparent direct effect is the decrease in macrophyte habitat heterogeneity due to selective foraging by Grass Crap (Dibble and Kovalenko 2009). Even if there is not a complete elimination of macrophytes the community often shifts towards those species that are less palatable (Vinogradov and Zolotova 1974; Hanlon et al. 2000; Pipalova 2006). Grass Carp are selective generalists and foraging activity eliminates plant species in order of decreasing palatability (Van Dyke et al. 1984; Leslie et al. 1987).

Habitat heterogeneity mediates mechanisms within aquatic systems; decreased heterogeneity can cause a variety of indirect effects including changes in trophic interaction, distributions (Werner and Hall 1979; Savino and Stein 1982; Mittelbach 1988; Diehl 1993), community compositions, species diversity and abundance to change (Gilinsky 1984).

Homogeneous macrophyte beds support fewer numbers and lower diversity of epiphytic macroinvertebrates (Brown et al. 1988), a critical food source for many juvenile fish (Keast 1984; Diehl and Kornijow 1997; Persson and Crowder 1997).

A spatially complex system supports predator avoidance, ontogenetic shifts (Werner et al. 1977; Lodge et al. 1988), and a greater number of niche spaces, which can allow the coexistence of competitors as well as the persistence of predators and their prey (Crowley 1978). Systems that have macrophyte infestations can be too spatially complex leading to decreased fish growth and altered population dynamics (Miranda et al. 1984; Savino and Marschall 1992; Diehl 1993) through reduced food availability and/or decreased feeding efficiency (Crowder and Cooper 1982; Savino and Stein 1982; Anderson 1984). Intermediate complexity of macrophytes allows for long term persistence of both predators and prey (Savino and Stein 1982).

In the 1970s many lakes in Iowa were plagued with excessive macrophytes to the point that fishing and other recreational activities were difficult or impossible (Mitzner 1978). Initial management options for these macrophytes centered around mechanical or chemical methods, but excessive costs and personnel time necessitated the decision to use Grass Carp (Mitzner 1978). Red Haw Lake was the site of the first Iowa introduction of Grass Carp in 1973 to assess their effectiveness to control macrophytes (Mitzner 1978). At the conclusion of the study in 1978, Grass Carp had decreased macrophyte density to non-nuisance levels and Mitzner (1978) deemed the experiment a management success. Since the first introduction of Grass Carp into Iowa’s waterways as biological control agents of macrophytes, there has been an increase in the number of lakes in the turbid phase, perceived effects on the centrarchid populations, and observations of Grass Carp living 30 years, far beyond what was originally considered possible. Considering these observations and an increased focus on a watershed approach to lake management problems resulted in the Iowa Department of Natural Resources decision to limit the use of Grass Carp in public waterways (IDNR 2013).

Three lakes, Red Haw, Mormon Trail and Greenfield, were selected to study how varying levels of Grass Carp biomass directly affects macrophyte abundance and diversity, and how centrarchid spawning periodicity and growth are influenced. This study builds on previously collected macrophyte data to better understand how the different Grass Carp management scenarios affect the lake's ecosystem.

Goal and Objectives

Goal

Assess the effects of varying Grass Carp biomass on Midwest reservoirs.

Objectives

1. Observe effects of differing Grass Carp densities on macrophyte diversity and abundance, and associated benthic macroinvertebrate populations.
2. Assess the effects of water temperature on spawning periodicity using daily growth rings of Bluegill and Largemouth Bass.
3. To determine how the effects of Grass Carp densities on aquatic vegetation diversity and abundance, and ultimately on the growth rates of YOY Bluegill *Lepomis macrochirus* and Largemouth Bass *Micropterus salmoides*.

Background

Red Haw, Mormon Trail and Greenfield Lakes located in south-central Iowa provide an opportunity to study the role of Grass Carp biomass as a tool to manage macrophytes. Water quality parameters among the lakes were similar at the beginning of the study. Each of these lakes has a unique history involving Grass Carp.

Red Haw Lake is a 29-ha reservoir with steep sides and a maximum depth of 12 m located in Lucas County, Iowa (Mitzner 1978). From early May to September the lake stratifies leaving the hypolimnion devoid of oxygen (Mitzner 1978). In 1973 prior to the introduction of Grass Carp, Largemouth Bass, Bluegill, and Crappie *Pomixis spp.*, were the predominant fish species with Redear Sunfish *Lepomis microlophus*, Green Sunfish *Lepomis cyanellus*, Warmouth *Lepomis gulosus*, Channel Catfish *Ictalurus punctatus,* Bullhead *Ictalurus spp.*, Yellow Perch *Perca flavescens*, and Golden Shiner *Notemigonus crysoleucas* also inhabiting the lake (Mitzner 1974).

Grass Carp were stocked into Red Haw Lake in July 1973 to assess their effectiveness as a macrophyte control tool (Mitzner 1978). At the time, 95% Red Haw Lake’s shoreline was ringed with macrophytes; covering 3.33 ha of the lake at an estimated weight of 76 metric tons (Mitzner 1974). By 1978, macrophytes covered a maximum of 5.24 ha and had an estimated weight of 8.1 metric tons at the August peak (Mitzner 1979). Even though macrophytes covered a larger area, 5.24 ha in 1978 versus 3.33 ha in 1973, the result was a significantly lower macrophyte density. At the end of the study in 1978 Mitzner (1978) came to the conclusion that macrophytes were at non-nuisance levels and the stocking of Grass Carp was deemed a success.

In 2001 and 2002 Red Haw Lake was renovated, removing all fish, while the dam and spillway were repaired. The restored fish community now consists of Largemouth Bass, Bluegill and Redear Sunfish with small numbers of Crappie and a few Green Sunfish and Black Bullheads *Ameiurus melas* that were first detected in 2010 (M. Flamming, Iowa Department of

Natural Resources Fisheries Biologist, personal communication). An increasing focus on watershed approaches to lake management problems resulted in Grass Carp not being reintroduced into Red Haw Lake (IDNR 2013a).

Mormon Trail Lake is a 14-ha reservoir located in Adair County, Iowa (IDNR 2011), having a maximum depth of 9.8 m and stratifying in the summer (Cashatt 2008). The fish community consists of Largemouth Bass, Bluegill, Crappie, Redear Sunfish, Walleye *Sander vitreus*, Channel Catfish, Grass Carp and small numbers of Green Sunfish, Common Carp *Cyprinus carpio*, and White Suckers *Catostomus commersoni*. Walleye and Catfish populations in Mormon Trail Lake are supported by stocking programs (Cashatt 2008).

Greenfield Lake is a 22-ha reservoir with a maximum depth of 7.3 m, stratifies in the summer and is located in Adair County, Iowa (IDNR 2011). Largemouth Bass, Bluegill, Crappie, Channel Catfish, Grass Carp and Walleye are the most common species with small numbers of Green Sunfish and Common Carp in the lake; both the Channel Catfish and Walleye populations are supported by stocking (Cashatt 2008). Greenfield Lake also has two SolarBee (SolarBee®, Medora Corporation, Dickinson, North Dakota) systems and is treated with copper sulfate several times a year; both the installations and the copper sulfate treatments are done to reduce algal growth within the lake since it is a reserve water source for the town of Greenfield (Cashatt 2008).

Both Mormon Trail and Greenfield Lakes were part of this study to begin to better understand how the manipulation of Grass Carp biomass affects a system. These lakes were selected for their similarity in location, water quality, fish community and because both lakes were initially stocked with Grass Carp at approximately 25 fish/ha in 1980. Despite all these similarities these two lakes experienced different perceived management outcomes (Cashatt 2008). Fishers at Greenfield Lake continued to view the lake as having an apparently good fishery although there has been a loss of macrophytes. In contrast, fishers at Mormon Trail Lake, which had nearly complete elimination of macrophytes from 1980-1998, consider the fishing to be poor (Cashatt 2008). Given these perceived differences in the fisheries, a total of 50 Grass Carp were removed from Mormon Trail Lake during 2000 and 2001. The removal of Grass Carp, accounted for 27-52% of Grass Carp biomass, reducing densities from 13/ha to 9.5/ha in Mormon Trail Lake. In contrast, Greenfield Lake's Grass Carp population was left alone as a control at 33.5/ha (Cashatt 2008).

Each of the three study lakes currently has different management scenarios for macrophytes. Red Haw Lake being devoid of Grass Carp, Mormon Trail Lake is classified as having mean density (9.5/ha) and Greenfield Lake has a high density (33.5 fish/ha). This study will build on previously collected macrophyte data to better understand how different Grass Carp biomass affects the benthic community and subsequently the fish populations of an Iowa reservoir

Thesis Organization

This thesis is organized into five chapters. Included are a general introduction and conclusion chapters, along with three individual studies. Chapters two through four are formatted according to the American Fisheries Society North American Journal of Fisheries Management. Each chapter is followed by a literature cited section and table and figures section.

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CHAPTER 2. GRASS CARP FOR CONTROLLING AQUATIC VEGETATION: IOWA'S EXPERIENCE

A paper to be submitted to *North American Journal of Fisheries Management*

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Abstract

The highly productive Iowa landscape continues to have on going issues with excessive aquatic macrophytes in the state's waterways. Initial options for managing these macrophytes were to use mechanical or chemical methods but excessive costs and time necessitated the decision to use Grass Carp starting in 1973. In response to management concerns related to Grass Carp stockings into Iowa's public lakes, later changes in aquatic vegetation management approaches were undertaken that included watershed and alternative control measures. Macrophyte abundance and diversity were measured in three Iowa reservoirs located in southern Iowa. The three lakes represent different management scenarios in the use of Grass Carp as a management tool for aquatic macrophytes. Macrophytes and water chemistry were sampled in June-August from 2007-2012 in all three lakes; aquatic invertebrates were sampled in 2011 and 2012. The lake without Grass Carp had increased plant diversity over this time period while the lake that had moderate densities of Grass Carp had decreased plant diversity; the lake stocked with the highest number of Grass Carp had low, but variable plant diversity and low abundance over this time period. The benthic macroinvertebrate data in this study support the idea that excessive macrophytes can suppress benthic macroinvertebrate abundance. The role of nutrient regimes specific to each lake influenced the static state of each lake and resulted in a limiting effect of Grass Carp presence on the actual ecological balance in individual lakes.

Introduction

Aquatic macrophytes play an important role in the health of aquatic ecosystems by providing habitat and food, stabilizing the substrate, and utilizing nutrients (Carpenter and Lodge 1986). Juvenile fish, in particular, rely heavily on macrophytes for refuge and food (Savino and

Stein 1982; Keast 1984). Along with providing this greater food source, macrophytes further benefit a system through oxygenation of the water (Carpenter and Lodge 1986).

Centrarchids have particular affinity for aquatic vegetation beds. For instance, age-0 Bluegill *Lepomis macrochirus* abundance is positively associated with macrophyte density (Hayse and Wissing 1996; Dewey et al. 1997). Young Bluegills select the highest macrophyte density in the presence of predators (Mittelbach 1988; Pothoven and Vondracek 1999) and move into open water in their absence (Mittelbach 1988). Macrophyte beds that are patchy in nature provide the best habitat for young fish by providing shelter in close proximity to open water that have a higher abundance of zooplankton (Weaver et al. 1997).

While macrophyte beds may not be the most energetically profitable habitat for larval fish they are increasingly important for young fish once they switch to macroinvertebrates as prey. Macrophytes support the periphyton-grazer system leading to high densities and diversity of macroinvertebrates (Carpenter and Lodge 1986). However, dense macrophytes can suppress benthic macroinvertebrate productivity (Wiley et al. 1984; Weaver et al. 1997). Nevertheless, the rise in epiphytic macroinvertebrates that dwell in the macrophyte beds can make up for the loss of benthic macroinvertebrates whereby the total biomass is increased (Wiley et al. 1984; Klussman et al. 1988; Kirkagac and Demir 2004). Other studies have concluded that both benthic and epiphytic macroinvertebrates decrease with a reduction or elimination of macrophytes (Vinogradov and Zolotova 1974; Fedorenko and Fraser 1978).

Excessive macrophyte populations can cause negative issues to the water quality and fishery. Dense macrophyte beds can cause oxygen depletion leading to potential fish kills (Lovell et al. 2012) as well as reducing food availability and/or decreasing feeding efficiency (Crowder and Cooper 1982; Savino and Stein 1982; Anderson 1984). For example, Largemouth Bass *Micropterus salmoides* have a reduced capture rate of prey as stem density increases (Savino and Stein 1982; Schneider 1999) resulting in abundant prey species (Crowder and Cooper 1979). When Largemouth Bass struggle to capture prey due to highly complex habitat, piscivory is delayed which then leads to reduced first year growth (Bettoli et al. 1992). Prey fish, i.e., Bluegill, that seek refuge in dense macrophytes can have decreased growth due to the lack of predation increasing intraspecific competition (Mittelbach 1988). Intermediate levels of macrophytes produce habitat structure that is optimal for growth of predators, while still ensuring an adequate prey base (Savino and Stein 1982). Over abundant macrophytes do not just affect the fishery through a stunted fish population, but can severely restrict angler access to the fishery (Mitzner 1978).

The theory of alternative stable states proposes that shallow lakes that are nutrient poor tend to be clear water macrophyte dominated systems (Morris et al. 2003); at intermediate nutrient concentrations lakes can exist in either state depending on perturbations (May 1977), and at high nutrient levels lakes tend to exist in a turbid phytoplankton dominated state (Morris et al. 2003). A variety of stressors, e.g., nutrients, on an ecosystem control the stability of that specific system; increasing stressors on a lake increases the probability of a regime change from one stable state to another (Hobbs et al. 2012). An increase in nutrients in lakes over time will cause a shift from the clear water macrophyte dominated to turbid phytoplankton state (Scheffer and Carpenter 2003). The shift to a turbid phytoplankton state back to a clear water macrophyte state will not happen unless a dramatic perturbation occurs in which external conditions, e.g., nutrients, are significantly reduced (Hobbs et al. 2012). Even if external input of nutrients are reduced, the internal nutrient cycling may be too strong to overcome and allow a regime change from the turbid phytoplankton to the clear water macrophyte state for a significant length of time (Hobbs et al. 2012).

Iowa's landscape is naturally and anthropogenically highly productive causing ongoing issues with macrophytes in the state's waterways. The excessive amounts of macrophytes in many of Iowa's lakes made fishing and other recreational activities difficult or impossible (Mitzner 1978). Initial management options for these macrophytes were to use mechanical or chemical methods, but excessive costs and personnel time necessitated the decision to use Grass Carp *Ctenopharyngodon idella* (Mitzner 1978).

In the years since 1973 when Grass Carp were first introduced into Iowa's waterways as biological control agents for macrophytes, observations included an increasing number of lakes in the turbid phase, perceived negative effects on sunfish populations, and observations of Grass Carp living far longer than originally considered possible, i.e., greater than 30 years. Combined with these observations was the increased use of a watershed approach to lake management problems which resulted in new macrophytes management guidelines by the Iowa Department of Natural Resources limiting the use of Grass Carp in public water ways (Morris 2010).

The preference of macrophyte species by Grass Carp is not agreed upon in the literature with ranking palatability purely by species alone being an oversimplification (Bonar et al. 1990). Bonar et al. (1990) suggested that there are other factors that come into palatability of macrophytes, i.e., water chemistry and growth stage, along with calcium, lignin, iron and silica content. Chilton II and Muoneke (1992) illustrated how those differences can cause widely varying preference of macrophyte species by Grass Carp among water bodies. Regardless of macrophyte species preference in given water bodies the result is a more homogeneous makeup of the macrophyte community, shifting towards those species that are less palatable (Hanlon et al. 2000; Pipalova 2006).

Loss of habitat heterogeneity can cause a variety of indirect effects including changes in trophic interactions, animal distributions (Savino and Stein 1982; Mittelbach 1988; Diehl 1993), community compositions, species diversity and abundance to change (Gilinsky 1984). In contrast to complete macrophyte removal, a water body with excessive macrophyte abundance can be too spatially complex leading to decreased fish growth and altered population dynamics (Savino et al. 1992; Diehl 1993). Numerous studies found Grass Carp to be an all or nothing solution to controlling macrophytes (Pipalova 2006) and that their longevity is considerably longer in the Midwest than what was previously thought.

Grass Carp have been used in Iowa since the early 1970s. They were first introduced into Red Haw Lake to assess their effectiveness as a tool to control macrophytes (Mitzner 1978). In 1973, 530 Grass Carp were stocked into Red Haw Lake and an additional 250 in 1974 for total of 26/ha, a level identified as best for macrophytes control. By the end of the study in 1978, Mitzner (1978) came to the conclusion that macrophyte density had decreased to non-nuisance levels and the stocking of Grass Carp was deemed a management success. Grass Carp were then stocked throughout the state, including Mormon Trail and Greenfield Lakes. In 1980, Mormon Trail Lake received 350 fish (24/ha) and Greenfield Lake was stocked with 600 fish (30/ha); Greenfield Lake then received additional stockings of 240 fish in both 1982 and 1994 (Cashatt 2008).

To date, most Iowa lakes stocked with Grass Carp have resulted in almost complete control to elimination of macrophytes (Cashatt 2008). Such was the case for the three lakes in this study. Red Haw Lake experience over 90% control (Mitzner 1978), Mormon Trail Lake essentially had complete control through 1998, and Greenfield Lake had low but measurable levels of macrophytes (Cashatt 2008). With these growing concerns and angler-perceived poor fishing in some water bodies stocked with Grass Carp, like Mormon Trail Lake, the Iowa Department of Natural Resources began their own studies into these issues (Cashatt 2008).

Red Haw Lake was completely renovated in 2001-2002 with the dam and spillway being repaired. At this time, given new cautionary notes from agency staff and published literature, the agency decision was made not to restock Grass Carp and to monitor how the reservoir recovered (M. Flamming, Iowa Department of Natural Resource Fisheries Biologist personal communication). At the same time, Mormon Trail and Greenfield Lakes were part of a study to look at how the manipulation of Grass Carp biomass affects a system (Cashatt 2008). A total of 50 Grass Carp, 22 in 2000 and 28 in 2001, were removed from Mormon Trail Lake accounting for around 33% of the biomass, while Greenfield Lake did not have any Grass Carp removed (Cashatt 2008). These events resulted in a range of 0 (Red Haw Lake), medium density (9.5/ha at Mormon Trail Lake) and high density (33.5/ha Greenfield Lake) Grass Carp. The objective of this study is to observe effects of differing Grass Carp densities on macrophyte diversity and abundance, and associated benthic macroinvertebrate populations in similar Iowa reservoirs.

Methods

Red Haw, Mormon Trail and Greenfield Lakes in south central Iowa provided an opportunity to study the role of Grass Carp as a management tool for the control of macrophytes. Each one of these reservoirs has had different management strategies applied to them with different outcomes.

Red Haw Lake is a 29-ha reservoir with steep sides and a maximum depth of 12 m and is located in Lucas County (Mitzner 1978). It stratifies from early May to September and the hypolimnion is devoid of oxygen for most of the summer (Mitzner 1978). In 1973, before Grass Carp were first stocked in July (Mitzner 1974), Largemouth Bass, Bluegill, and Crappie *Pomixis spp*., were the predominant fish species but Warmouth *Lepomis gulosus,* Redear Sunfish *Lepomis microlophus,* Green Sunfish *Lepomis cyanellus,* Channel Catfish *Ictalurus punctatus*, Bullhead *Ictalurus spp*., Yellow Perch *Perca flavescens*, and Golden Shiner *Notemigonus crysoleucas* also inhabited the lake (Mitzner 1978).

Grass Carp were stocked in Red Haw Lake to assess their effectiveness as a tool to control macrophytes (Mitzner 1978). At the time, Red Haw Lake had 95% of its shoreline ringed with macrophytes, covering 3.33 ha of the lake at an estimated weight of 76 metric tons (Mitzner 1974). By 1978, macrophytes covered a maximum 5.24 ha and had an estimated weight of 8.1 metric tons at its August peak (Mitzner 1979). Even though the macrophytes covered a larger area, 5.24 in 1978 versus 3.33 ha in 1973 when the Grass Carp were first stocked, the result was a much lower density and improved control. The conclusion of this study was that none of the macrophyte species were considered to be at nuisance levels and the Grass Carp stocking was deemed a success.

The current fish community, post renovation, consists primarily of Largemouth Bass, Bluegill, and Redear Sunfish with small numbers of Crappie, and few Green Sunfish and Black Bullheads *Ameiurus melas* that were first detected in 2010 (IDNR 2013).

Mormon Trail Lake is a 14-ha reservoir located in Adair County. It stratifies in the summer, has a maximum depth of 9.8 m. The fish community consists of Largemouth Bass, Bluegill, Crappie, Redear Sunfish, Walleye *Sander virteus,* Channel Catfish and small numbers of Green Sunfish, Common Carp *Cyprinus carpio* and white suckers *Catostomus commersoni*. The Walleye and Channel Catfish populations are supported by stocking (Cashatt 2008).

Greenfield Lake is 22-ha reservoir with a maximum depth of 7.3 m that stratifies during the summer and is located in Adair County. The major species in the lake are Largemouth Bass, Bluegill, Crappie, Channel Catfish and Walleye with smaller numbers of Green Sunfish and Common Carp; both Channel Catfish and Walleye populations are supported by stocking (Cashatt 2008). Greenfield Lake also has two SolarBee (SolarBee®, Medora Corporation, Dickinson, North Dakota) systems and is treated with copper sulfate several times a year. Both the installation of the aeration systems and the copper sulfate treatments are done to reduce algae growth within the lake since it is also used as a potential water supply for the town of Greenfield (Cashatt 2008).

Macrophytes were sampled in June, July and August from 2007-2012 in all three lakes; samples were not done in June 2012. Sampling of macrophytes followed the procedures established in the Aquatic Vegetation Management in Lakes Project (Clayton et al. 2007). Each lake was sampled once a month, all of the samples for a given lake were taken on a single day; or on consecutive days if more time was needed. Randomly selected locations for transects were established and sampling was done perpendicular from the shoreline.

Macrophyte samples were taken every 0.61-m depth contour, starting at shore, using a double sided garden rake (Figure 1); as described in Yin et al. (2000). Sampling occurred at the beginning of each depth contour, depth was determined by the sampling rake not sonar equipment. The double sided rake was lowered to the bottom, twisted 180°, and pulled back onto the boat. Density of the entire rake sample was visually estimated to the nearest 5%, total rake density (Figure 2). The entire rake sample was then removed from the rake head and separated out by species. Sago Pondweed *Stuckenia pectinata* and Southern Naiad *Najas guadalupensis* were combined into a single taxonomic group due to the fact that they are often confused with each other (AquaPlant) and we had doubts over proper field identification between the two species. Abundance of each species was recorded as a percent of the whole sample, to the nearest 5%. The individual percentages when added up equaled 100. Transects were completed when two consecutive samples taken were void of macrophytes and sampling had occurred to at least 2.44 m; or water depth started to decrease.

Quist et al. (2007) found that in Iowa's lakes 13 transects are needed to find 100% of the species, while 11-12 transects results in 90%. We analyzed the plant data collected from 2007 through 2010 with a resampling procedure to determine the number of transects necessary to sample a lake of a given size and be 100% or 90% sure that this sampling detected all species. Data from all months were included in our analysis (May through September). Managers can select from these two options when sampling lakes up to 200 ha for macrophytes (Table 1). Of course there are goals other than determining the number of species in a body of water, e.g., additional sampling when exotics are involved. We will be looking into doing similar analyses for differing goals (Table 1). The number of transects necessary to sample 100% or 90% of the species present in lakes were calculated for three size classes. Given that the focus of this study was to determine trends in the macrophytes, it was deemed unnecessary to expend the extra time and effort to find the remaining rare species. Therefore, a randomly selected 10 of the 13 established transects for the lakes were used in data collection during 2011 and 2012. Those same 10 transects data were pulled from the 13 for all previous years.

Species diversity was calculated for the months of June, July, and August using the Shannon Diversity Index:

$$H = -\sum_{i=1}^{s} p_i \ln p_i$$

where S is the total number of species in the community (richness), and p_i is the proportion of the *i*th species. Due to the combination of Sago Pondweed and Southern Naiad the Shannon Diversity Index would be slightly depressed if both species were present.

Species richness, number of unique species in each transect line, was obtained to access plant diversity within each lake over the 6-year study. Mean species richness was then calculated first for individual transects for each lake each month, and then mean values were calculated for the 3-month sampling period for each year. This later value was then used to compare lake differences in species richness over the 6-year study.

Total macrophyte abundance was calculated using total rake percent density. A weighted average was taken, across the 10 transects, for each depth contour. Summing the weighted averages for all depth contours and dividing by 10 gave the total macrophyte abundance or lake wide average rake density. Total macrophyte abundance was calculated for June, July, and August in 2007-2012.   Similar to the species richness data, analyses were done for abundance of the individual lakes over the 6-year study.

Water quality data was sourced from Iowa Lakes Information System (2013). Data was collected by Iowa State University Limnology Laboratory and the Iowa Department of Natural Resources. Water quality parameters were chlorophyll □, total phosphorus (TP), and total

Kjeldhal nitrogen to phosphorus ratio (TKN:P). Water quality parameters were averaged for the year (Table 2).

Benthic macroinvertebrates were collected with a 225-cm^2 Ekman dredge. Samples were taken at each lake every 2 weeks at 4 randomly selected transects in 2011 and 2012. Within each transect one randomly selected depth was sampled between 0.61 and 3.05 m at 0.61-m intervals. Samples were put through a 1.0 mm sieve bucket in the field and placed into a container with a 4% sucrose-formalin solution to fixate the specimens (Wetzel et al. 2005). Macroinvertebrates were dyed with rose bengal for better visibility, identified under a dissecting scope to family (Merritt et al. 2008), and counted.

Statistical analysis.—Mean values of species richness and abundance were compared for the three lakes over the 6-year study using a one-way ANOVA at significance level of □ = 0.1. Abundance was transformed to a normal distribution using the following formula: abundance=arcsine √percentage (Zar 1984). Lsmean values were compared when appropriate using Tukey HSD. All analyses were done using JMP® Pro 10.0.0 (2012 SAS Institute)

Results

Shannon Diversity Index measures the evenness of diversity. Each of the three lakes displayed different trends over the 6-year study (Figure 3). Red Haw Lake ranged from 0.12-1.43 and generally increased over time. Changes seen within year were minimal with no consistent trend distinguishable. Mormon Trail Lake indices ranged from 0.67-1.53 illustrating a much more consistent and high level of diversity but unlike Red Haw Lake there was a decreasing trend in the diversity. With the exception of 2008 and 2011 for Mormon Trial Lake, diversity between months within each year was very consistent. Diversity for Greenfield Lake ranged from 0.00-1.05 giving no clear trend though the years or within years, but with highly variable low levels of diversity.

Species richness in each of the lakes remained relatively low (Figure 4). Red Haw Lake never had more than four species within a transect, while Mormon Trail Lake had as many as seven and Greenfield only had as high as three. There was no significant differences between Red Haw and Greenfield Lakes, but both were significantly lower than Mormon Trail Lake ($p = 0.0024$).

Macrophyte abundance varied among the three lakes (Figure 5). Red Haw Lake had a decrease in macrophyte abundance that is opposite to the increasing diversity that was found. The shift to low abundance occurred during the years of 2008-09 and since then macrophyte abundance has stayed consistently low. For Mormon Trail Lake the exact inverse occurred. Excluding 2012, Mormon Trail Lake experienced a significant increase in abundance while diversity decreased. In 2009 macrophyte abundance increased over the summer months and then stayed consistently higher. In contrast to both Red Haw and Mormon Trail Lakes, Greenfield Lake throughout the entire study has had little to no macrophyte abundance with occasional small increases in August. Sago Pondweed *Stuckenia pectinata* was the predominant species to still exist in the shallow parts of Greenfield Lake with trace amounts of the genera *Chara* and *Sagittaria*. In contrast to species richness, there was not a significant differences in macrophytes abundance among the three lakes during this study ($p = 0.2214$).

Red Haw and Greenfield Lakes both experienced large changes in water quality while Mormon Trail Lake stayed relatively stable. During the study period Red Haw Lake had more than a doubling of chlorophyll □ and TP, 11 to 23.7 μg/L and 0.02 to 0.05 μg/L respectively resulting in lower TKN:P ratio (54.5 to 20). Mormon Trail Lake despite showing some variability in water quality values remained relatively consistent in this time period. Greenfield Lake showed dramatic changes in all categories from 2007-2012. Over the course of the study chlorophyll □ went from 23 to 52.4 µg/L, TP from 0.03 to 0.10 µg/L and TKN:P dropped from 40.2 to 10.4.

Macroinvertebrate abundance proved to be highly variable, particularly in 2011 (Figure 5). Red Haw Lake had a single peak of abundance mid-June, crashed in abundance during July, before plateauing at the end 2011. Mormon Trail Lake abundance in 2011 was ca. 2,300 macroinvertebrates/ m^2, low when compared to the other lakes. Greenfield Lake showed two peaks in macroinvertebrate abundance, one at the beginning of July and again in mid-August. A similar trend where Mormon Trail Lake remained at the lowest levels, Red Haw Lake followed, with Greenfield having the greatest macroinvertebrate abundance occurred in 2012.

All three lakes in both years had Chironomidae and Oligochaeta as the first or second most abundant macroinvertebrates, except Greenfield Lake in 2012 when Chaoboridae were slightly more abundant than Oligochaeta (Table 3). Chironomidae, Oligochaeta, Chaoboridae, and Ceratopogonidae were the predominate macroinvertebrates found with others only accounting for smaller portions or playing a minor role in only one of the lakes for a given year. Many of these other macroinvertebrates accounted for less than 1% of the total.

Discussion

It has been well documented in scientific literature that having Grass Carp in a lake will result in a more homogeneous macrophyte community (Hanlon et al. 2000; Pipalova 2006). Red Haw, Mormon Trail and Greenfield Lakes did not entirely follow this pattern suggesting something else may also be influencing the macrophyte community. During the study period there was an increase in macrophyte density although relatively minimal in Red Haw Lake; increased diversity did not occur until 2009 a full 7-8 years after Grass Carp were removed from the system. It is possible that it takes this long for a system to begin to recover after having Grass Carp for almost 3 decades.

At the same time that Grass Carp were being removed from Red Haw Lake, during dam renovations 2001-2002, Mormon Trail's Grass Carp biomass was reduced by about 33%. The goal of reducing the biomass of Grass Carp was done by agency staff to promote a resurgence of macrophytes abundance and diversity while still providing some control (Cashatt 2008). When this study began in 2007 Mormon Trail had the highest levels of macrophyte diversity around 1.5; it appears that though the reduction in Grass Carp biomass was a success, plant species diversity actually began to decrease starting in 2010. Thus, the presence of Grass Carp biomass alone does not fully explain these results as no more were stocked during this time period.

Greenfield Lake with the highest density of Grass Carp had low levels of diversity throughout the study period. Oddly though, starting in 2010, Greenfield Lake began to experience a reduction in diversity as well. Again this reduction cannot be fully explained by Grass Carp biomass since no additional fish were stocked near this time period.

Macrophyte species richness follows along with species diversity. Red Haw and Greenfield Lakes experience similar levels, while Mormon Trail Lake is significantly higher in species numbers. Similarity between Red Haw and Greenfield Lakes could be occurring for different reasons. Red Haw Lake's low species richness appears to be caused by excessive algal blooms; Greenfield Lake though is a combination of high Grass Carp densities and heavy algal blooms. In Mormon Trail Lake there now appears to be a balance between the macrophyte community and Grass Carp control. Whether this balance continues on in the future will depend on Grass Carp survival, water quality and composition of the macrophyte community.

In Iowa, lakes that are stocked with Grass Carp commonly experience almost complete macrophyte control to the point of their elimination (Cashatt 2008). It is then reasonable to expect that Grass Carp removal from the same lakes would result in re-establishment of the macrophytes community. Red Haw Lake had the opposite effect, despite having increased plant diversity, abundance significantly decreased during 2008-2009 over the study period and stayed depressed. A possible explanation may be increased nutrient loading to the lake. Total phosphorus increased from 0.02 to 0.05 mg/L, which may have caused the lake to shift from a clear-water macrophyte dominated state to one dominated by phytoplankton. Lakes with a TP concentration less than 0.025 mg/L likely exist in the macrophyte dominated state (Morris et al. 2003).

In Red Haw Lake, despite having little to no change in watershed usage except the installation of several settling ponds (R. Schultz, Iowa Department of Natural Resources Fisheries Biologist personal communication), TP concentrations increased beyond the threshold of 0.025 mg/L during 2008. Increased nutrients in Red Haw Lake directly correspond to the increase in chlorophyll □ and a reduction in macrophytes, supporting the suggestion that this lake had switched states to a more turbid phytoplankton dominated state. Algal blooms have been shown to be effective in reducing macrophytes through reduction in light availability; fisheries managers in the southeastern US have long recommended the use of fertilizers to increase algal blooms to help control macrophytes (Madsen et al. 2012).

What exactly caused the significant change in nutrients loads to Red Haw and Greenfield Lakes but not to Mormon Trail Lake in 2008 remains unknown. Site-specific differences in each watershed may be the primary driver of these differences. For instance, a number of erosional areas have been identified in the Red Haw watershed. These effects could be exasperated by the watershed ratios of the three lakes with Mormon Trail having 11.3, Red Haw with 14.0 and Greenfield with 17.0.

After the removal of around 33% of Grass Carp from Mormon Trail Lake in 2001-2002 (Cashatt 2008) macrophyte abundance was expected to increase. Macrophyte abundance did eventually increase but not until 2009, much later than expected. A significant reduction in abundance occurred in 2012. Iowa experienced an extreme drought in 2012, dropping the water levels in many reservoirs. This event is likely the cause of the reduction in macrophyte abundance. While abundance overall did increase in Mormon Trail Lake, macrophyte diversity also decreased although it may simply be yearly natural fluctuation.

Greenfield Lake having a high biomass of Grass Carp had very low to no macrophyte abundance; findings that are consistent with other studies on Grass Carp (Pipalova 2006). While it appears that Greenfield Lake had increased macrophyte diversity in July 2012 this was simply an artifact of the Shannon Diversity Index in that only two samples of macrophytes were found that month and consisted of two different species, one at each sample location.

Similar to Red Haw Lake, Greenfield Lake experienced a dramatic increase in TP concentration in 2008. From 2007-2012 TP concentrations tripled causing the TKN:P to drop by a factor of four. The use of the SolarBee units and occasional applications of copper sulfate for algae control did not affect the planktonic algae populations. Chlorophyll □ concentrations still doubled further suppressing macrophyte growth and possibly leading to the decline in diversity. It should be noted that one result of the plankton bloom in both lakes was the similar species richness between them.

This study supports the concept that macrophytes can suppress benthic macroinvertebrate abundance. Mormon Trail Lake has the highest abundance of macrophytes among the three lakes and correspondingly has the lowest benthic macroinvertebrate abundance. Greenfield Lake on the whole has the greatest macroinvertebrate abundance, but only slightly more than that of Red Haw Lake. This again follows suite in light of macrophyte abundance levels (Figure 5) for 2011 and 2012. While both Red Haw and Greenfield Lakes have minimal macrophyte abundance, Greenfield Lake does have slightly lower values.

Variability in benthic macroinvertebrate abundance over the sampling period displayed in Figure 5 shows the importance of sampling for macroinvertebrates often and throughout the season. With the cyclical nature of many benthic macroinvertebrate populations sampling only a few times increases the chances that the larger picture will be missed or miss represented.

Even with the limitation of only having one replicate for each Grass Carp density some conclusions can still be drawn. The data in this study supports what previous literature has found. Grass Carp can, in fact, have a great effect on a system through their control of macrophytes. Manipulating their biomass in a lake can cause a change in the macrophyte community, leading to cascading affects within the system, i.e., benthic macroinvertebrate populations. Though as shown in this study Grass Carp are not the only factor controlling the macrophyte community, things such as water quality also have a strong influence on which state a lake exist in.

Acknowledgements

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Tables and Figures

FIGURE 1. Double sided rake as described in Yin et al. (2000) used to collect macrophytes samples (Clayton et al. 2007).

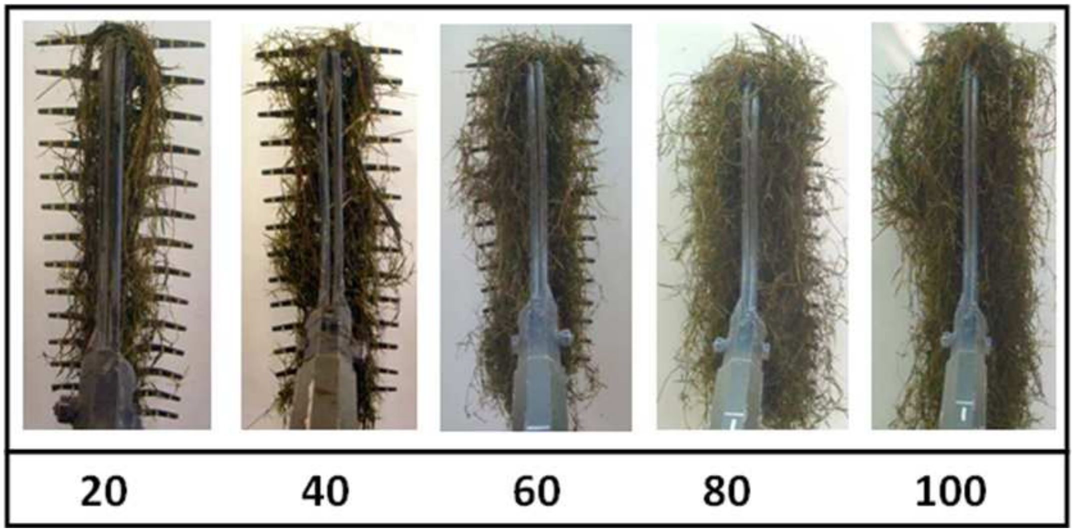

FIGURE 2. Examples of total raked densities by percentage (Clayton et al. 2007).

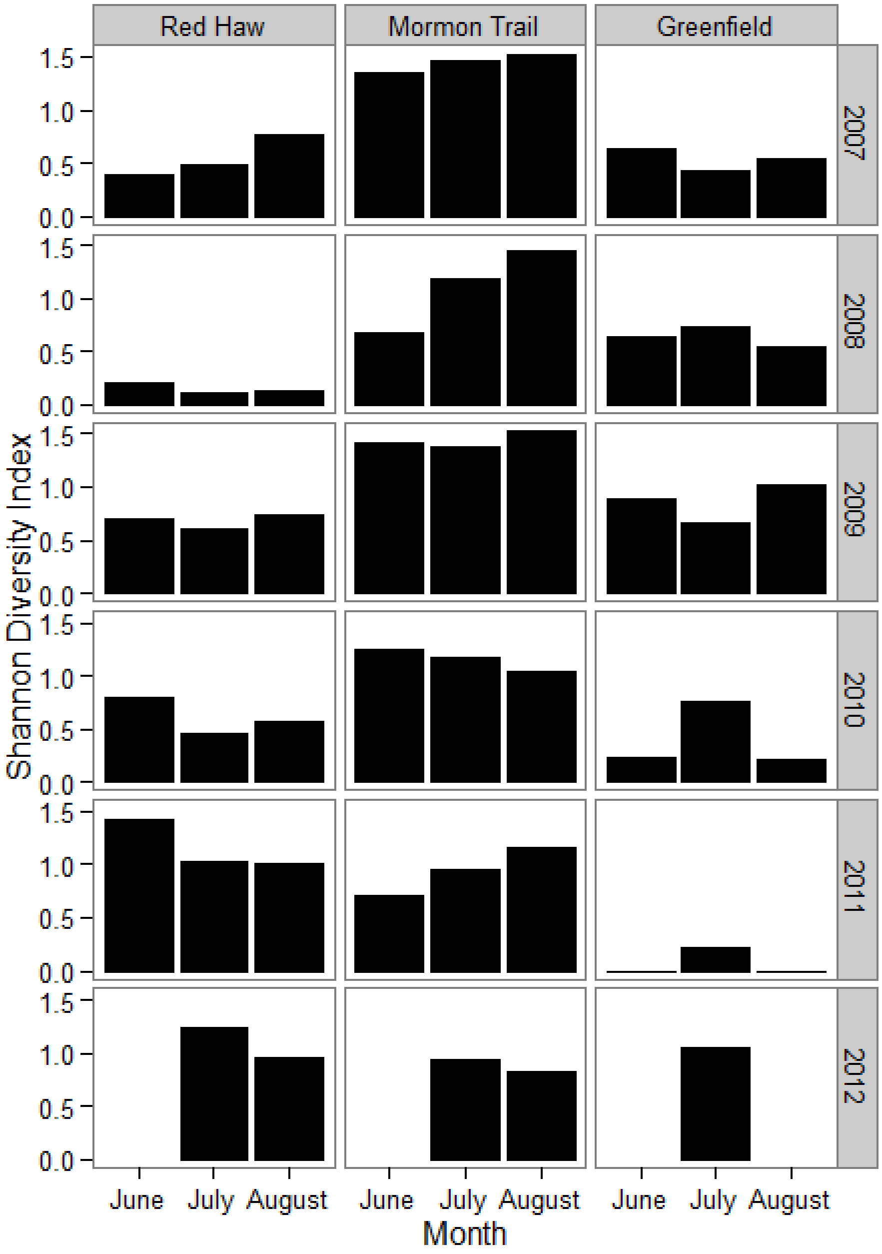

FIGURE 3. Shannon Diversity Index of macrophytes across months and years for Red Haw (Low Grass Carp Density), Mormon Trail (Medium Grass Carp Density) and Greenfield Lakes (High Grass Carp Density) in 2007-2012. Sampling did not occur in June 2012.

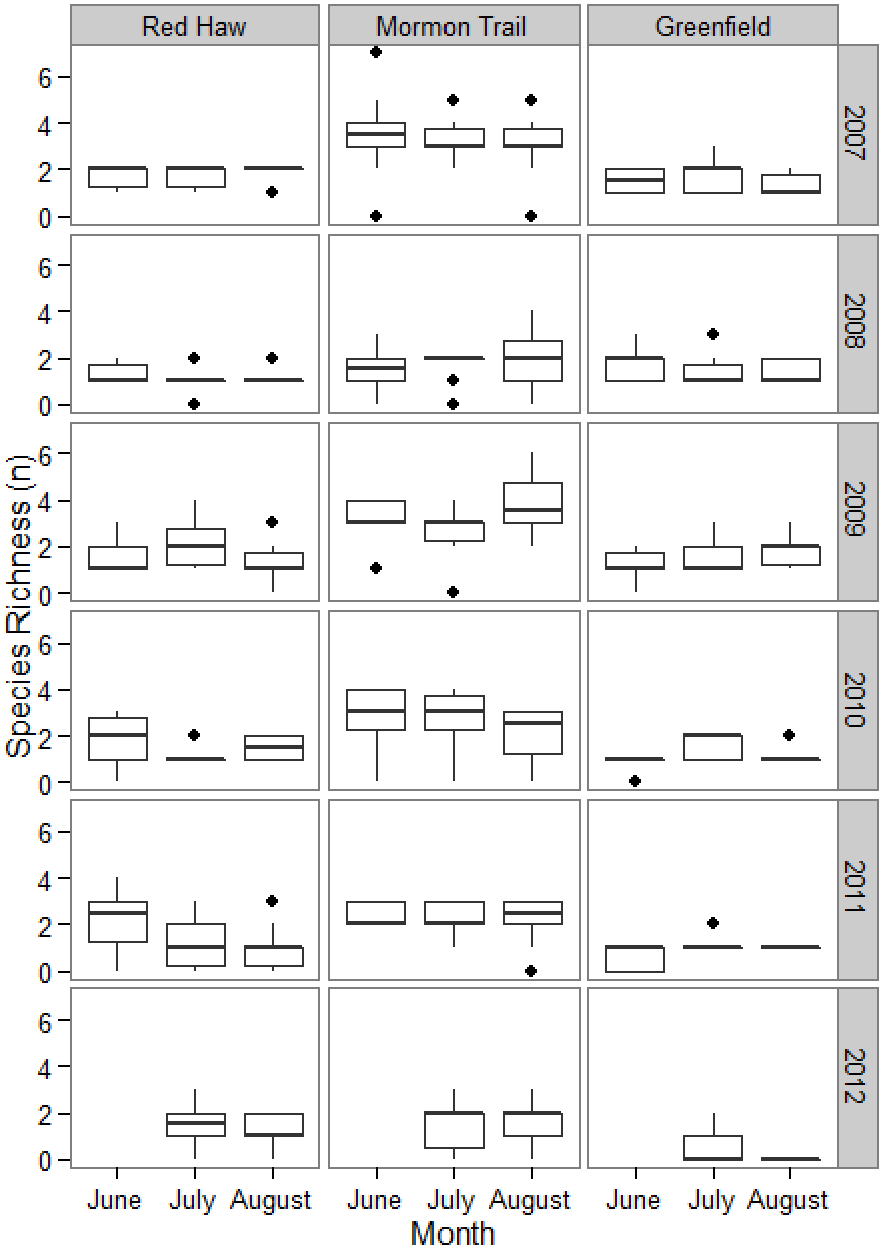

FIGURE 4. Species richness (n) of transect lines with the lake, across months and years. Red Haw (Low Grass Carp Density), Mormon Trail (Medium Grass Carp Density) and Greenfield Lakes (High Grass Carp Density) 2007-2012. Sampling did not occur in June 2012. The upper and lower ends of the boxes represent the first and third quartiles; the line in the middle corresponds to the mean. The whiskers extend to the highest value within 1.5x the inter-quartile range (IQR). Any data beyond 1.5xIQR was considered an outlier and marked as a point.

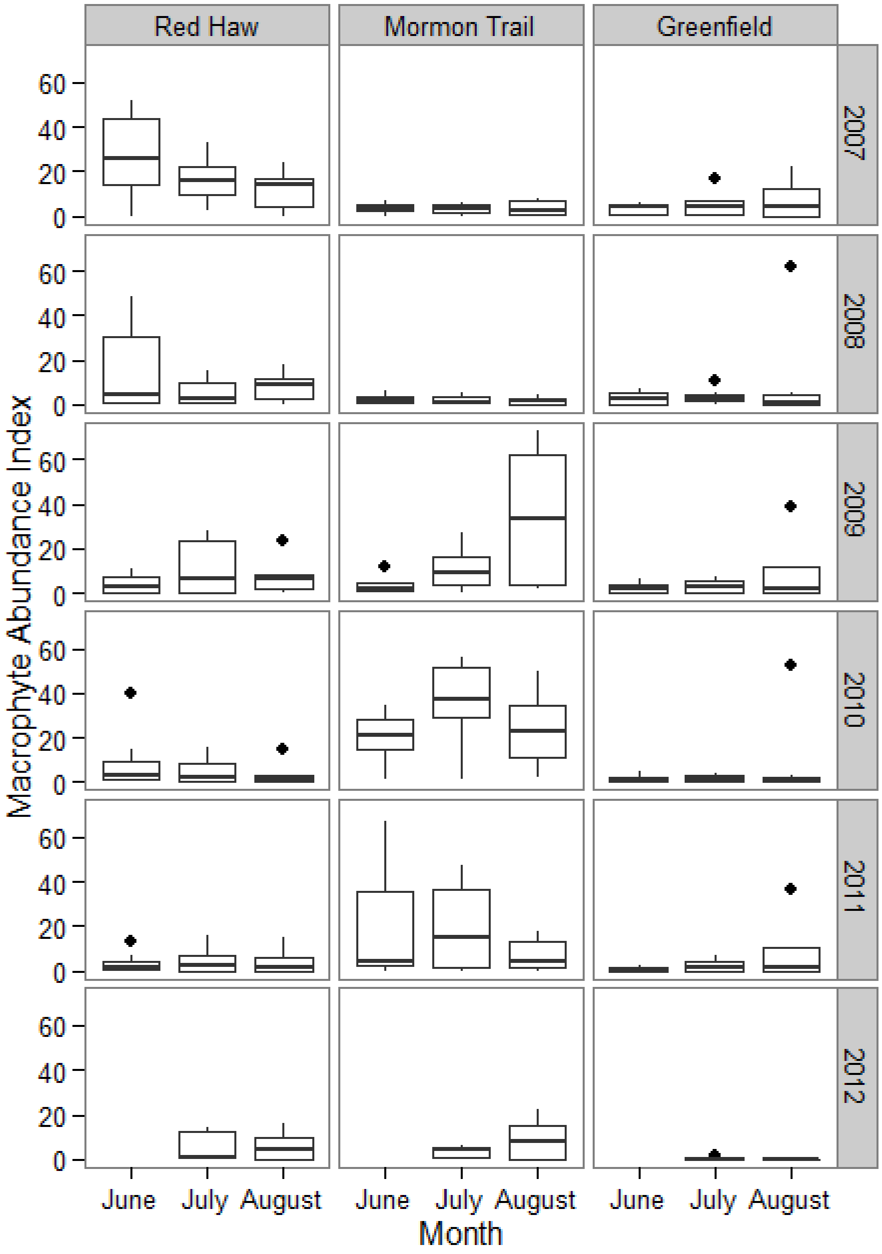

FIGURE 5. Macrophyte abundance, measured by total rake density, across months and years for Red Haw (Low Grass Carp Density), Mormon Trail (Medium Grass Carp Density) and Greenfield Lakes (High Grass Carp Density) 2007-2012. Sampling did not occur in June 2012. The upper and lower ends of the boxes represent the first and third quartiles; the line in the middle corresponds to the mean. The whiskers extend to the highest value within 1.5x the inter-quartile range (IQR). Any data beyond 1.5xIQR was considered an outlier and marked as a point.

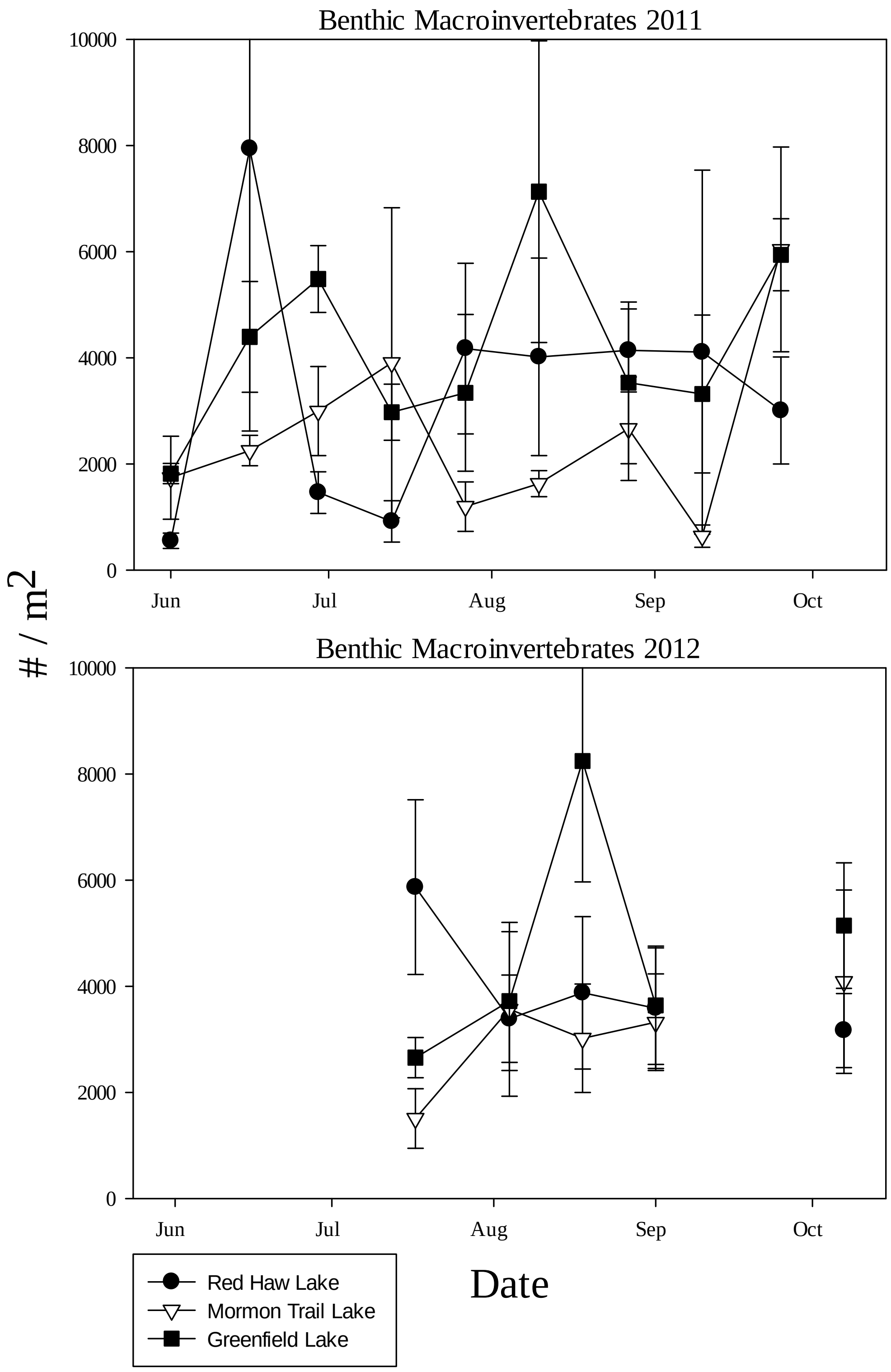

FIGURE 5. Average number ± SE benthic macroinvertebrates (#/m^2) for Red Haw (Low Grass Carp Density), Mormon Trail (Medium Grass Carp Density) and Greenfield Lakes (High Grass Carp Density) in 2011 and 2012. Sampling did not occur in June and late September 2012.

TABLE 1. Number of transects needed to find 100% and 90% of the macrophyte species richness within a lake. Original data from Quist et al. (2007).

Lake Size	N	Original	Species Richness 100%	Species Richness 90%
<40 ha	9	13	11	10
40-100 ha	2	19	15	8
101-200 ha	2	25	20	15
201-400 ha	0	29	-	-
>400 ha	0	49	-	-

TABLE 2. Average water quality data (chlorophyll *a*, cyanobacteria, total phosphorus [TP] and total Kjeldhal nitrogen:phosphorus [TKN:P]) for Red Haw (Low Grass Carp Density), Mormon Trail (Medium Grass Carp Density) and Greenfield Lakes (High Grass Carp Density) from 2007 to 2012. (Source: Iowa Lakes Information System 2013).

Lake	Year	Chlorophyll □ (µg/L)	Cyanobacteria (mg/L)	TP (µg/L)	TKN:P
Red Haw	2007	11.0	29.6	0.02	54.5
	2008	-	-	-	-
	2009	20.0	40.2	0.04	-
	2010	27.6	53.8	0.05	20.0
	2011	10.3	13.4	0.05	20.0
	2012	23.7	59.5	0.05	20.0
Mormon Trail	2007	24.7	76.0	0.03	33.3
	2008	-	-	-	-
	2009	5.0	13.3	0.02	-
	2010	20.1	19.5	0.04	50.0
	2011	36.5	14.8	0.04	25.0
	2012	17.8	24.2	0.03	33.3
Greenfield	2007	23.0	-	0.03	40.2
	2008	-	-	-	-
	2009	39.7	28.8	0.08	-
	2010	25.9	25.3	0.08	12.5
	2011	31.9	7.7	0.07	14.3
	2012	52.4	19.1	0.10	10.4

TABLE 3. Sample size (n), average ± SE benthic macroinvertebrate (#/m^2) density and the percentage of the total for Red Haw (Low Grass Carp Density), Mormon Trail (Medium Grass Carp Density) and Greenfield Lakes (High Grass Carp Density) in 2011 and 2012. Percentages accounting for less than 1% were considered to be trace (TR) amounts. N=5 in 2012 rather than 9 because sampling did not start until July 2012.

2011

	Red Haw Lake				Mormon Trail Lake				Greenfield Lake			
Family	n	#/m^2	SE	%	N	#/m^2	SE	%	N	#/m^2	SE	%
Oligochaeta	9	1017	490	30%	9	1033	390	41%	9	1839	451	44%
Chironomidae	9	1694	382	50%	9	850	132	34%	9	1875	315	44%
Ceratopogonidae	9	137	40	4%	9	34	14	1%	9	131	35	3%
Tabanidae	9	-	-	-	9	-	-	-	9	3	1	TR
Chaoboridae	9	422	248	13%	9	43	34	2%	9	193	91	5%
Limnophilidae	9	19	6	TR	9	-	-	-	9	5	2	TR
Leptoceridae	9	19	6	TR	9	62	23	2%	9	21	8	TR
Caenidae	9	20	8	TR	9	7	3	TR	9	10	6	TR
Baetidae	9	-	-	-	9	5	2	TR	9	-	-	-
Emphemeridae	9	-	-	-	9	2	1	TR	9	-	-	-
Libellulidae/Cordulidae	9	5	3	TR	9	7	2	TR	9	7	5	TR
Coenagrionidae	9	2	1	TR	9	7	2	TR	9	-	-	-
Gomphidae	9	-	-	-	9	2	0	TR	9	-	-	-
Amphipoda	9	23	16	TR	9	474	272	19%	9	95	74	2%
Megaloptera	9	15	4	TR	9	2	2	TR	9	31	11	TR
Hirudinae	9	-	-	-	9	2	2	TR	9	5	3	TR
Astacidae	9	-	-	-	9	1	1	TR	9	-	-	-

2012

	Red Haw Lake				Mormon Trail Lake				Greenfield Lake			
Family	n	#/m^2	SE	%	N	#/m^2	SE	%	N	#/m^2	SE	%
Oligochaeta	5	1569	263	39%	5	1842	400	59%	5	1007	253	22%
Chironomidae	5	1544	173	39%	5	780	276	25%	5	2324	530	50%
Ceratopogonidae	5	295	142	7%	5	69	61	2%	5	224	142	5%
Tabanidae	5	-	-	-	5	-	-	-	5	-	-	-
Chaoboridae	5	240	104	6%	5	280	179	9%	5	1062	540	23%
Limnophilidae	5	86	57	2%	5	-	-	-	5	-	-	-
Leptoceridae	5	147	97	4%	5	9	4	TR	5	2	2	TR
Caenidae	5	20	12	TR	5	5	4	TR	5	-	-	-
Baetidae	5	-	-	-	5	3	3	TR	5	-	-	-
Emphemeridae	5	-	-	-	5	3	3	TR	5	-	-	-
Libellulidae/Cordulidae	5	13	5	TR	5	9	7	TR	5	-	-	-
Coenagrionidae	5	5	2	TR	5	2	2	TR	5	-	-	-
Gomphidae	5	-	-	-	5	-	-	-	5	-	-	-
Amphipoda	5	38	38	1%	5	58	45	2%	5	-	-	-
Megaloptera	5	22	6	TR	5	27	12	TR	5	4	3	TR
Hirudinae	5	-	-	-	5	16	16	TR	5	51	15	1%
Astacidae	5	-	-	-	5	-	-	-	5	-	-	-

CHAPTER 3: CHATERTERISTICS OF BLUEGILL AND LARGEMOUTH BASS SPAWNING ACTIVITY IN MIDWEST RESERVOIRS

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Abstract

Young of year Bluegill and Largemouth Bass were sampled in three Iowa reservoirs, Greenfield, Mormon Trail and Red Haw Lakes in 2011 and 2012 using a Herzog Armadillo (Mini Missouri) Trawl. Collected fish were then aged using otoliths to determine actual spawning dates. Although these two centrarchid species have been investigated numerous times since they were first accepted as stockers in man-made reservoirs, we determined that their actual spawning dates are much earlier than previous literature suggests. Early spring water temperature combined with lake structure results in Bluegills spawning in late March instead of the commonly accepted late April spawning typically noted for this species. Largemouth Bass were found to spawn closer to traditionally accepted times from early May through mid-July.

Introduction

The variable size of larval and juvenile fish populations is reflective of both species-specific reproductive strategies, i.e., differential survival relative to number of eggs, as well as environmental conditions, e.g., water temperatures and prey availability. There are many abiotic and biotic factors that influence the reproductive successfulness of Bluegill *Lepomis macrochirus* and Largemouth Bass *Micropterus salmoides*.

Abiotic factors include water temperature (Clark and Keenleyside 1967; Stevenson et al. 1969; Beard 1982), weather (Stevenson et al. 1969), littoral condition (Schneider 1999) as well as actual lake structure. Growth also tends to be slowest in supply reservoirs with fluctuating water levels (Mayhew 1964). Biotic factors that influence reproductive success include predation (Swingle and Smith 1943), fish density (Swingle and Smith 1943), and body size (Cargenelli et al. 1995).

Variability in hatching date may also influence population dynamics including growth, recruitment, over winter survival (Post and Evans 1989; Miranda and Hubbard 1994), and actual morphological features, i.e., growth of gape size (Goodgame and Miranda1993) that indirectly influences fish growth and survival. The larger the gape size of the fish, the larger the prey items it can consume, which will yield more net energy (Goodgame and Miranda1993; Phillips et al. 1995; Post 2003). Fish with an earlier hatching date and a larger gape size could consume more energy and increase its likelihood of winter survival (Goodgame and Miranda 1993; Phillips et al. 1995; Post 2003).

Bluegill are almost exclusively colonial, multiple spawning fish (Werner 1969), with few displays of solitary nesting (Neff et al. 2004). In addition, Bluegills often spawn in periodical bouts because of the variability of survival of the larval and juvenile fish (Winemiller 2005). Bluegill will spawn at water temperatures as low as 17 °C (Clark and Keenleyside 1967; Stevenson et al. 1969) with a photoperiod of 16 h light: 8 h dark (Bryan et al. 1994; Mischke and Morris 1997; West and Hester 1966). Their spawning season is prolonged, often lasting several summer months (Beard 1982; Cargnelli and Gross 1995). Santucci Jr. and Walh (2003) in Illinois found Bluegill spawning occurring from May to August. Initial prey selection includes small zooplankton, e.g., rotifers and copepod nauplii, and then progressively larger prey as they grow (Morris and Clayton 2009).

Largemouth Bass have been recorded to spawn at temperatures around 16.0 °C (Kramer and Smith 1962; Spengler and Brown 2010) and photoperiod of 15 h light:9 h dark (Spengler and Brown 2010). Larger adult Largemouth Bass have been found to spawn at colder temperatures than smaller Largemouth Bass (Miranda and Muncy 1987; Goodgame and Miranda 1993). In similar latitudes, Largemouth Bass spawning season lasts several summer months, ranging from late April to early June (Johnson 1971; James 1946).

Largemouth Bass YOY initially consume rotifers; switch to copepods, and soon after cladocerans (Wickstrom and Applegate 1989). Young Largemouth Bass are piscivorous and begin feeding on other fish earlier than most species. Water temperature can influence feeding, growth, and developmental rates (Niimi and Beamish 1974). Optimal growth for Largemouth Bass occurs at temperatures at or above 26.6 °C (Foye 1958; Niimi and Beamish 1974).

Bluegill and Largemouth Bass spawning behaviors have been thoroughly studied (Carlander 1977; Morris and Clayton 2009). However, Bluegills may actually spawn sooner than the literature indicates, possibly as early as late March. Spawning this early could lead to miss categorizing early hatched Bluegill as age-1 rather than age-0, based on length. The goal of this study was to assess the effects of water temperature on spawning periodicity using daily growth rings of Bluegill and Largemouth Bass in Midwest reservoirs; by 1) determining spawning dates, 2) describing the timing of spawning bouts, and 3) determining if water temperature was the influences on spawning.

Methods

Research was conducted in three reservoirs: Red Haw Lake, Mormon Trial Lake, and Greenfield Lake located in South-central Iowa. Water quality parameters were similar for all lakes (Iowa Lakes Information System 2011) and maximum depth ranged from 7.3 – 12.2 m (C.A.R.D. 2008). Red Haw Lake is the largest reservoir at 39 ha, Greenfield Lake is the second-largest at 22 ha, followed by Mormon Trail at 14 ha (C.A.R.D. 2008).

Sampling was conducted during the summers of 2011 and 2012. Bluegill and Largemouth Bass YOY were collected using a Herzog Armadillo (Mini Missouri) Trawl (Innovative Net Systems, 111 Zothique Road, Milton, Louisiana). A Herzog Armadillo Trawl was selected because it separates fish and debris within the trawl using two different sized meshes. The use of these two meshes allows the smaller fish to pass through to the second bag, keeping them from getting crushed by larger fish or debris. Three trawl hauls were made at each lake once a month. Each haul was randomly selected from within three reaches. Starting at shore, towing in reverse, the trawl was pulled for 75 m in a J-shape, trawling parallel to the shoreline.

From each trawl haul, Bluegill and Largemouth Bass were sorted and a random selection of 50 fish per species (or as many as present) were measured for total length. From that group 30 fish were weighed. Selecting for fish that represented the size range, 10 fish were kept for aging. Fish were then placed into labeled bags and put on ice before being frozen in the lab.

In the lab sagittal otoliths were removed to examine daily rings for age estimation to determine spawning dates. Once removed, the otolith was secured in Buehler EpoKwick Epoxy (41 Waukegan Road, Lake Bluff, Illinois 60044). The core of the otolith was then marked by an archival ink marker, with a line extending beyond the otolith. A Buehler IsoMet low speed saw, equipped with a 0.3 mm wafering blade, was used to section the otoliths. The saw was lined up with the edge mark. After etching the otoliths with a drop of 2% HCL acid for 5-6 min the otoliths were secured to a microscope slide with super glue.

Otoliths were viewed under a Nikon Eclipse TS100 (inverted microscope) at a magnification 200X or greater by two readers who were unaware of the size and species of the fish. Daily rings were counted three times by each reader. Following Miller and Storck (1982), if the ages determined varied by less than 10% or ±3 rings then the ages were averaged. If the estimated ages varied by more the 10% or ±3 rings than the otolith was recounted and discussed, further disagreement resulted in discarding that otolith.

Using known age and length fish, simple linear regressions were built for both Bluegill and Largemouth Bass separated by sampling date and lake. Program SAS 9.3 was used to build the regressions with □ = 0.1 as the significance level. Adjusted R-squared values for the model ranged from 0.74 to 0.96 for Bluegill and 0.28 to 0.78 for Largemouth Bass. Regression equations were then applied to known length fish to estimate age.

The age determined represented the number of days post hatch until collection (Sweatman and Kohler 1991; Garvey et al. 2002; Roberts et al. 2004). Bluegill eggs hatch 2-4 d after spawning (Beard 1982) while Largemouth Bass eggs hatch 3-4 d after spawning (Kramer and Smith 1962); 3 d were added to the estimated ages to account for the time between hatching, otolith formation (Miller and Storck 1982; Roberts et al. 2004) and the time of spawning.

The new estimated ages were then compared to water temperature data from the reservoirs. In 2011 water temperature was recorded using Onset HOBO Pendant Temperature/Alarm Data Loggers (470 MacArthur Blvd., Bourne, Massachusetts 02532) from May 11th to October 6th. The temperature loggers were set at a depth of 70 cm (2.3 ft.) just off the bottom in the bays. This depth was chosen since nest depth for Largemouth Bass ranges from 25-157 cm (0.8-5.1 ft) (Kramer and Smith 1962) and 15-122 cm (0.5-4.0 ft.) for Bluegill (Swingle and Smith 1943). The statistical program *R* version 2.15.1 and □ = 0.1, the best relationship between water temperatures and precipitation was determined for this dataset.

In 2012 due to severe drought in Iowa, temperature loggers were exposed to increasingly shallow depths through the spawning season with some of the temperature loggers eventually being completely exposed. Given this issue a regression was built based on the data collect from 2011 and air temperature with precipitation from local weather stations. The stations are part of the Iowa Environmental Mesonet (Iowa State University Department of Agronomy 2001) and are located just outside of the towns of Chariton (Red Haw Lake) and Greenfield (Greenfield and Mormon Trail Lakes).

Results

There was a positive relationship between air temperature and a negative relationship to precipitation, explaining between 85-87% of the variability in the water temperature. Once completed, the regression was applied to the 2012 data to give an estimate of the water temperature in each of the three lakes (Figure 1).

Collections from trawls in both years indicated fractionated spawning of Bluegill in all water bodies with the spawning season lasting up to 151 and 159 d in 2011 and 2012, respectively. Juvenile Bluegill began to appear in trawls in late March of both years. In 2011, juvenile Bluegill first appeared in Red Haw and Mormon Trail Lakes on March 21st, but and not show up in Greenfield Lake until April 2nd. Peak density varied among lakes and between years, with different bouts of reproduction creating the multimodal patterns. Peaks were highly variable occurring from as early as the end of May to late June. All three lakes had higher peaks of juvenile Bluegill abundance in 2011 than in 2012, with the exception of Mormon Trail, which had similar peak abundance.

Trawling collections of juvenile Largemouth Bass appeared in both years in all lakes with the exception of Greenfield Lake in 2012. The spawning season lasted for 62 and 46 d in 2011 and 2012, respectively. Largemouth Bass spawning generally followed a unimodal trend. Largemouth Bass appeared as early as April 11 in Red Haw Lake in 2012. Furthermore, these fish were also discovered spawning in early to mid-May in the other lakes in 2011 and in Mormon trail in 2012. Peak juvenile density varied greatly between lakes with most peaks occurring in May. All three lakes had higher peak abundance of Largemouth Bass in 2011 than in 2012.

Discussion

Fluctuations of the water temperature resulted in a stimulus-producing repeated spawning in the lakes. This affected the length of the spawning season and the number of spawning fish of both species. A sharp drop in water temperature followed closely by a rise in temperature stimulates Largemouth Bass (Kramer and Smith 1962) and Bluegill spawning (Carlander 1977).

Although the three lakes are in the same general area of the state of Iowa, not all of the lakes fluctuated in both water temperature and spawning occurrences simultaneously; situation likely due to the differences in bathymetry between lakes. In addition water temperature effects may be overridden by other factors such as water quality and climatic conditions.

In 2011, Red Haw Lake had Bluegill show an early spawning in April with the first strong bouts in June, followed by a series of spawning bouts. In 2012, Bluegill showed a similar trend as in 2011, with three bouts of spawning, but shifted slightly earlier in the year and to a lesser magnitude.

Largemouth Bass displayed a predictable trend of spawning with a unimodal distribution peaking in middle May 2011. In 2012, the spawning occurred slightly earlier but for the same length of time. Unseasonably warm spring weather was likely the cause for the shift in spawning time. While Largemouth Bass and Bluegill spawning bouts followed similar trends in both years, they appear to have lower numbers in 2012 when compared to 2011.

In Mormon Trail Lake, Bluegill had a strong bout of spawning early in 2011; these spawning fish could have found a warmer area of the water in the large shallow bays of the lake, which range from 0-1.5 m (0-5 ft.). This early spawning bout may be the reason for the delay in the next significant bout when compared to the other lakes. Since Bluegill do devote a substantial amount of resources for early spawning attempts, Bluegill in this lake likely needed time to recover before heavy spawning occurred again in June. In 2012, Bluegill did not show a strong spawn until June. Spring 2012 had some very warm days early on, followed by a strong cold front. This drastic change in weather may have led to nest abandonment by the Bluegill, thus, causing what appears to be a delay in spawning.

Largemouth Bass had a strong bout in 2011 near the end of May, but the tail end lasted considerably into July, which is unusual. In 2012, there was never a peak abundance of Largemouth Bass in this lake. One explanation may be that Largemouth Bass in Mormon Trail Lake attempted an early spawn during the warm weather but abandoned their nests when the cold front came. This would leave only the remaining smaller Largemouth Bass to attempt to spawn, since they tend to spawn later in the year (Miranda and Muncy 1987).

Bluegill in Greenfield Lake started spawning abruptly within the same week in 2011, showing a unimodal, possibly bimodal trend. This abrupt start to spawning is different from the other lakes where these fish tended to increase spawning activity over a longer time period. With little vegetative cover and the steep sides of the lake, one could infer that all suitable spawning habitat reached the optimal spawning temperature at the same time. In 2012, Bluegill again illustrated a similar spawning trend.

Largemouth Bass in 2011 showed a predicted spawning trend of peak abundance near the end of May in Greenfield Lake. Surprisingly, no Largemouth Bass were observed in 2012; this could possibly be because of nest abandonment due to the early rise and then subsequent fall in water temperature that spring. Another possible or compounding explanation is that the weather conditions in 2012 were extreme, causing a severe drought. This drought dropped the water levels in all the study lakes with Greenfield Lake being the most affected. Greenfield Lake had dropped 0.5 m by July and a full meter by August. The water level drop made much of the limited vegetation and other cover types that were available within the lake inaccessible for spawning fish. This could have contributed to lack of juvenile Largemouth Bass caught due to predation.

Before our water temperature data were recorded, the temperature spike and sequential crash in the early spring of 2012 may have caused the Bluegill and Largemouth Bass to attempt to spawn, abandoning their nests. This would account for the overall reduced catch of Largemouth Bass and the delayed abundance of juvenile Bluegill within all lakes. While water temperature did display a significant influence on when spawning bouts occurred, the strongest ones most often coincided with photoperiod lengths of 16 h light:8 h dark and 15 h light:9 h dark, for Bluegill and Largemouth Bass respectively. Many factors play a part in determining spawning for these two species but, water temperature seems to be an overriding factor and the principal influence.

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Figure

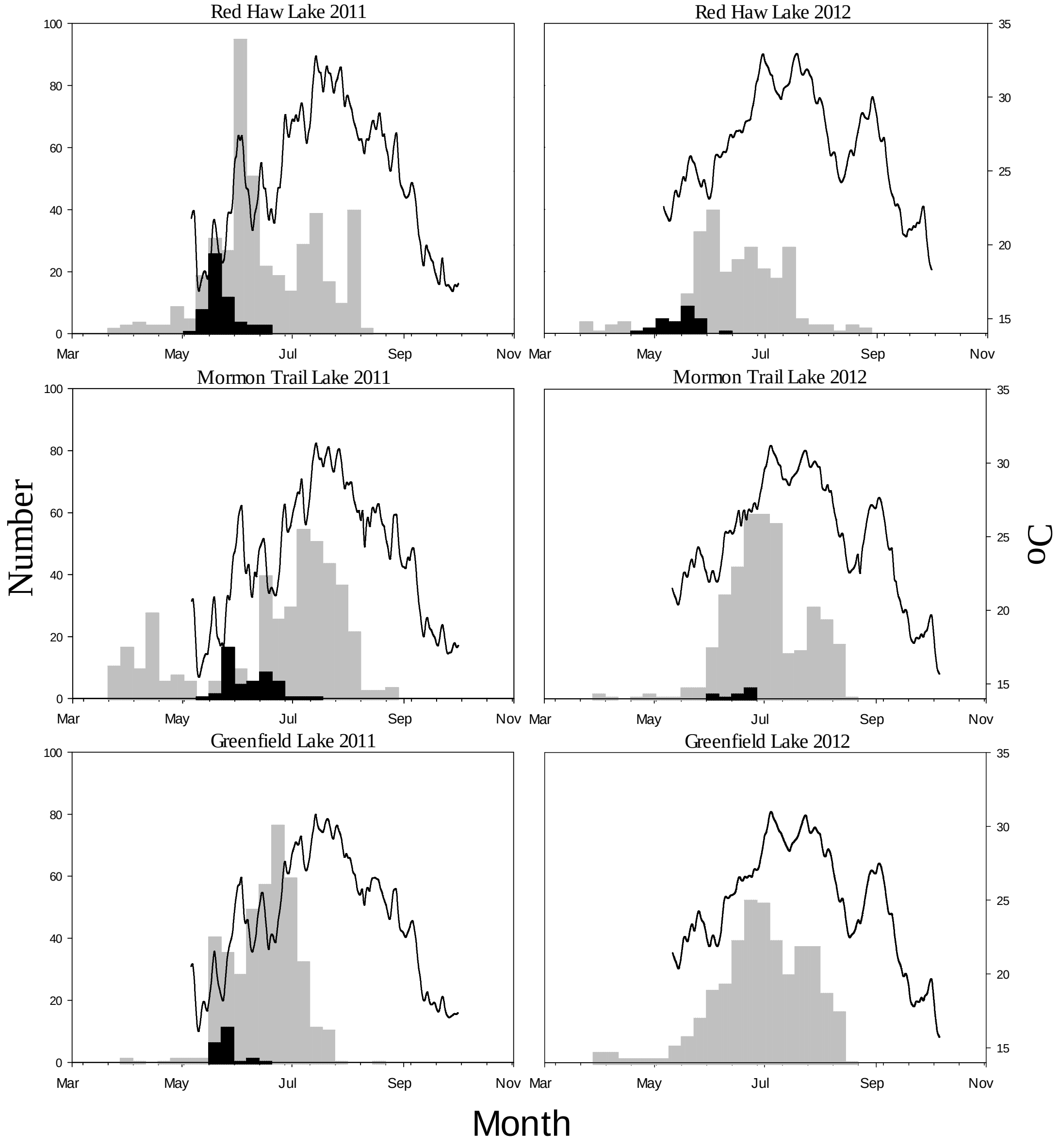

FIGURE 1. Bluegill (grey) and Largemouth Bass (black) spawn timing related to water temperature in Red Haw, Mormon Trail and Greenfield Lakes in 2011 and 2012. Relative spawning strength is indicated by the number of individuals per week in a given lake and year.

CHAPTER 4: EFFECTS OF GRASS CARP ON YOUNG OF THE YEAR FISH GROWTH

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Abstract

Growth of young of year (YOY) fish is critical to overwinter survival and therefor recruitment to the fishery. The potential for aquatic vegetation to effect fish growth is well documented. Three reservoirs in Iowa under different vegetation management strategies through varying Grass Carp densities were sampled for YOY Bluegill and Largemouth Bass growth. Grass Carp densities in these lakes were 0/ha in Red Haw Lake, 9.5/ha in Mormon Trail Lake, and 33.5/ha in Greenfield Lake. YOY Bluegill and Largemouth Bass were collect in 2011 and 2012 throughout the summer months using a Herzog Armadillo (Mini Missouri) Bottom Trawl. Collected fish were aged using otoliths to determine hatching dates. Growth rates (mm/d) were determined as a hatch week average and yearly lake average. Hatch week averages show the various trends in growth rates within each lake and year for Bluegill and Largemouth Bass. Mean yearly growth rates were general greatest in Greenfield Lake, having the highest density of Grass Carp and lowest vegetation abundance. Growth rates also seemed to be effected by food resources and competition.

Introduction

The centrarchid family continues to be the primary fishes used in managing both small ponds and reservoirs in the U.S. The importance of Bluegill *Lepomis macrochirus* and Largemouth Bass *Micropterus salmoides* for these water bodies have been recognized by fishery biologists since the early days of fishery management concepts extolled by Swingle (1950). These fishes have continued to be highly desirable for fishery management since they inhabit shallow littoral habitats that are readily accessible to shoreline anglers (Quinn and Paukert 2009).

Growth in young of the year (YOY) Bluegill and Largemouth Bass is variable due to many factors, i.e., genetics (Miranda and Muncy 1987; Aday et al. 2003), reproductive timing (Miller and Storck 1984; Miranda and Hubbard 1994; Jolley et al. 2009), and cover availability, e.g., aquatic vegetation (macrophytes) (Crowder and Cooper 1982; Miranda et al. 1984). While genetics and reproductive timing can affect growth, cover availability has a strong influence on many other aspects that influence growth such as food availability, diet shifts (Diggins et al. 1979; Miranda and Muncy 1987; Goodgame and Miranda 1993), and competition (von Geldern and Mitchell 1975; Mittelbach 1988).

Changes in cover provided by vegetation affect the growth of Bluegill and Largemouth Bass. Vegetation abundance at extremely low or high levels may decrease fish growth and alter population dynamics (Savino et al. 1992; Diehl 1993). Cover that is too spatially complex negatively impacts fish growth through reduced feeding efficiency (Crowder and Cooper 1982; Anderson 1984). In contrast, decreased vegetation can increase growth rates of both YOY Bluegills and Largemouth Bass with increased Bluegill growth primarily through reduced survivability since more are consumed by Largemouth Bass (Pothoven and Vondracek 1999). The management of vegetation in a fishery has been replete with the use of mechanical removal, chemical and biological controls (Hansen et al. 2010).

Swingle (1957) first proposed that an exotic, Grass Carp *Ctenopharyngodon idella,* be introduced into the United States for vegetation control. During the 1960s there was strong public pressure to find a biological control for problematic vegetation instead of traditional chemical control, particularly after the book Silent Spring by Rachel Carson (Mitchell and Kelly 2006). Six years after Swingle’s proposal, the first Grass Carp were brought into the U.S. at

Auburn University to begin research into their ability to control vegetation (Bain 1993). Since those initial introductions Grass Carp have been recorded in 45 states (Nico and Fuller 2005).

Water bodies stocked with Grass Carp often experience a major reduction if not a complete elimination of vegetation (Van Dyke et al. 1984; Klussman et al. 1988) and the few vegetation beds that are left are often homogeneous and made up of species that are least palatable to Grass Carp (Vinogradov and Zolotova 1974; Hanlon et al. 2000; Pipalova 2006). Homogenous vegetation beds support fewer numbers and low diversity of epiphytic macroinvertebrates (Brown et al. 1988), a critical food source for many juvenile fish (Keast 1984; Diehl and Kornijow 1997; Persson and Crowder 1997).

Young of the year Bluegill at the beginning of exogenous feeding have a mouth gape of around 250 µm (Toetz 1966). The small mouth gapes of Bluegill forces them to rely on small zooplankton as an initial food source (Morris and Clayton 2009). Numbers of YOY Bluegill have a strong relationship to vegetation density (Hayse and Wissing 1996; Dewey et al. 1997), which is primarily due to predator avoidance, e.g., Largemouth Bass (Mittelbach 1981; Mittelbach 1988). As Bluegill densities increase in vegetation beds, their growth rates often decline because the remaining juveniles must share a limited prey resource leading to interspecific competition (Mittelbach 1986; Mittelbach 1988). Slow growth of YOY Bluegill can have a significant effect on their recruitment to age-1 (Jolley et al. 2009).

Similar to Bluegill, Largemouth Bass YIY also initially feed on on small zooplankton (Wickstrom and Applegate 1989). Compared to Bluegill YOY Largemouth Bass quickly switch to larger macroinvertebrates, and then begin to consume fish by 100 mm; fish are not becoming fully piscivorous until 120 mm (Bettoli et al. 1992).

The complexity of habitat can play a large role in YOY Largemouth Bass growth. Predatory behavior shifts from actively searching at low complexity to ambushing at high complexity in an attempt to minimize energy cost (Savino and Stein 1982). Even so, increasingly complex habitat negatively affects Largemouth Basses ability to get to the prey base through providing greater refuge for their prey (Savino and Stein 1982; Bettoli et al. 1992), reducing their feeding efficiency (Savino and Stein 1982), and resulting in abundant prey species (Crowder and Cooper 1979). When Largemouth Bass struggle to capture prey in highly complex habitats piscivory is delayed (Bettoli et al. 1992); this delay in piscivory leads to reduced first year growth (Bettoli et al. 1992; Goodgame and Miranda 1993). Slower growing YOY Largemouth Bass experience higher mortality potentially creating recruitment issues (Shelton et al. 1979; Miranda and Muncy 1987).

With recruitment being critical to the long term sustainability of a fishery, growth was studied in three reservoirs in south-central Iowa. These three reservoirs, Red Haw Lake, Mormon Trail Lake, and Greenfield Lake, have similar water quality parameters (Iowa Lakes Information System 2013) while having different vegetation management through varying biomass of Grass Carp (Mammoser 2013). Red Haw Lake is the largest reservoir at 39 ha and is currently void of Grass Carp. Mormon Trail Lake has an intermediate density of approximately 9.5/ha and is the smallest of the reservoirs at 14 ha. Greenfield Lake is 22-ha reservoir and has the high density of Grass Carp, approximately 33.5/ha (Cashatt 2008). The objective of our study was to determine how the effects of Grass Carp densities on aquatic vegetation diversity and abundance, and ultimately on the growth rates of YOY Bluegill and Largemouth Bass.

Methods

Sampling was conducted during the summers of 2011 and 2012; sampling in 2012 was delayed until late summer due to unforeseen sampling issues. Bluegill and Largemouth Bass YOY were collected using a Herzog Armadillo (Mini Missouri) Trawl (Innovative Net Systems, 111 Zothique Road, Milton, Louisiana). A Herzog Armadillo Trawl was selected because it separates fish and debris within the trawl using two different sized meshes. Therefore, allowing the smaller fish to pass through to the second bag, keeping them from getting crushed by larger fish or debris. Three trawl hauls were made at each lake once a month. Each haul was randomly selected from within three reaches. Starting at shore, towing in reverse, the trawl was pulled for 75 m in a J-shape, trawling parallel to the shoreline.

From each trawl haul, Bluegill and Largemouth Bass were sorted, counted and a random selection of 50 fish per species, or as many as present, were measured for total length (mm). From that group 30 fish were weighed (g). Ten fish were randomly selected and retained for aging. Fish were then placed into labeled bags and put on ice before being frozen in the lab. Using the counts CPUE was calculated by averaging the number of Bluegill and Largemouth Bass on each sample date for the three trawls.

In the lab, sagittal otoliths were removed to examine daily rings for age estimation to determine hatching dates. Once removed, the otolith was secured in Buehler EpoKwick Epoxy (41 Waukegan Road, Lake Bluff, Illinois). The core of the otolith was then marked by an archival ink marker, with a line extending beyond the otolith. A Buehler IsoMet low speed saw, equipped with a 0.3 mm wafering blade, was used to section the otoliths. The saw was lined up with the edge mark. After etching the otoliths with a drop of 2% HCL acid for 5-6 min the otoliths were secured to a microscope slide with super glue.

Otoliths were viewed under a Nikon Eclipse TS100, inverted microscope, at a magnification 200X or greater by two readers who were unaware of the size and species of the fish. Daily rings were counted three times by each reader. Following Miller and Storck (1982), if the ages determined varied by less than 10% or ±3 rings then the ages (days post hatch) were averaged. If the estimated ages varied by more the 10% or ±3 rings than the otolith was recounted and discussed, further disagreement resulted in discarding that otolith.

Using known age and length fish, simple linear regressions were built for both Bluegill and Largemouth Bass separated by sampling date and lake. Program SAS 9.3 was used to build the regressions with □ = 0.1 as the significance level. Adjusted R-squared values for the model ranged from 0.74 to 0.96 for Bluegill and 0.28 to 0.78 for Largemouth Bass. Regression equations were then applied to known length fish to estimate age. The age determined represented the number of days post hatch until collection (Sweatman and Kohler 1991; Garvey et al. 2002; Roberts et al. 2004). Using the now expanded data set of total length at capture and age, growth rate was determined in mm/d, broken down by hatch week.

Zooplankton abundance measured in average µg/L is presented in Table 2. Zooplankton data sourced from the Iowa Lakes Information System (2013) along with macroinvertebrate data (Mammoser 2013), the growth data from all three lakes, both years, and CPUE was used in a forward selection stepwise analysis. The stepwise analysis was done in JMP® Pro 10.0.0 (2012 SAS Institute) and compared various zooplankton and macroinvertebrate densities, along with CPUE to the growth rates of YOY Bluegill and Largemouth Bass.

Results

In the 2 years of sampling YOY fish over 30,000 Bluegill and 180 Largemouth Bass were caught. Numbers of Bluegill and Largemouth Bass caught in each lake in a given year ranged from 1,234-16,026 and 0-57. Average yearly growth rates in mm/d were determined (Table 1). Bluegill in 2011 grew at 0.53, 0.63, and 0.71 mm/d in Red Haw (zero Grass Carp), Mormon Trail (medium density of Grass Carp) and Greenfield (high density of Grass Carp) Lakes respectively. As the biomass of Grass Carp in a lake increased so did the average yearly growth rates of Bluegill. There is a similar trend for 2012 with Bluegill growing 0.49 mm/d in Red Haw Lake, 0.59 mm/d in Mormon Trail Lake and 0.57 mm/d in Greenfield Lake, the exception being that Mormon Trial Lake and Greenfield Lake have almost identical daily growth rates for the year.

Largemouth Bass average daily growth rates for 2011 were 0.80, 0.87, and 1.15 mm/d in Red Haw, Mormon Trail and Greenfield Lakes respectively. Again like Bluegill in 2011, Largemouth Bass average daily growth rates for the year increased as Grass Carp biomass increased. The same trend is found in 2012 with Largemouth Bass in Red Haw Lake growing at 0.85 mm/d and in Mormon Trail at 1.04 mm/d. A growth rate for Greenfield Lake in 2012 could not be determined since no YOY Largemouth Bass were caught.

Average growth rates over the course of the year do provide a picture, but misses much of the story. With this in mind average daily growth rates were also broken down to hatch week for Bluegill and Largemouth Bass (Figure 1). For Red Haw Lake in 2011 average growth rates for Bluegills that hatched first was around 0.60 mm/d and trended upwards to a peak for those that hatched at the end of May around 0.70 mm/d. Immediately after this peak Bluegill growth rates declined to 0.50 mm/d, varying around that value and slowly trending downwards towards

0.40 mm/d for those that hatched in August. Largemouth Bass began to hatch in early May starting with a growth rate of around 0.70 mm/d. Growth rates continued to increase peaking at just under 1.00 mm/d for those Largemouth Bass that hatched mid-June. Largemouth Bass hatching was only detected for 1 week after this peak; the growth rate for these fish was around 0.75 mm/d.

Bluegill in Mormon Trail Lake during 2011 displayed no trend in daily growth rates regardless of hatch week. Rather daily growth rates remained relatively consistent ranging between 0.55 mm/d and 0.70 mm/d. Largemouth Bass began to hatch mid-May with daily rates around 0.95 mm/d, peaking the following week at 1.05 mm/d. From there a downward trend is displayed ending around 0.65 mm/d for those hatched at the end of June and mid-July.

Greenfield Lake did not have Bluegill hatch until the beginning of April, 2 weeks after the other lakes. Those first hatched Bluegill had a growth rate around 0.60 mm/d. Growth rates bounced around from there until the peak rate of just under 0.90 mm/d for Bluegill hatched mid-May. After that peak there was a precipitous decline in growths rates to 0.55 mm/d at the end of July. A single Bluegill hatched at the end of August was detected and managed to grow at 0.58 mm/d. Largemouth Bass hatched from mid-May until mid-June, these fish displayed no trend varying in growth rates from slightly more than 1.00 mm/d to just under 1.20 mm/d.

The Bluegill and Largemouth Bass hatched in Red Haw Lake during 2012 may have had similar growth rates to 2011 when averaged over the year, but displayed widely different patterns. Growth rates for Bluegill remained consistent for the year varying between 0.40 mm/d and 0.60 mm/d, becoming slightly more variable near the end of the hatching season.

Largemouth Bass, much like the Bluegill, showed consistent growth rates through their hatching season from late-April to mid-June, ranging from 0.80 mm/d to 0.90 mm/d.

Sporadic spawning effects occur in Mormon Trail Lake in 2012. Growth rates for early hatched Bluegill began around 0.40 mm/d slowly increasing to 0.60 mm/d by July. Bluegill hatched the week of July 16th are outliers for the year managing to grow at a rate of 0.82 mm/d on average. Following that week rates dropped back down to a consistent 0.50 mm/d for the remainder of the season. Largemouth Bass hatched over a much shorter 4-week period rather than the 8 weeks the year prior. They also had a much higher average growth rate for the year at 1.04 mm/d compared to 0.87 mm/d in 2011. Growth rates for all 4 weeks hovered right around that average.

Bluegill that hatched in Greenfield Lake during 2012 consistently stayed around the yearly average of 0.57 mm/d. By July and through the month of August Bluegill growth slowly declined. There are no growth rates for Largemouth Bass in 2012 due to the fact that no YOY were captured.

To further understand the mechanisms that could be driving changes in growth rates CPUE was calculated for the trawls as an estimate for YOY abundance (Figure 2). In 2011 catch rates of Bluegill remained relatively low across all three lakes. Red Haw Lake had consistent abundance of Bluegill throughout the year, but with a large spike at the end August before dropping by September. Mormon Trail Lake displayed the same trend as Red Haw Lake having peak abundance at the end August, except with lower numbers throughout the year. Greenfield Lake had a unimodal trend that started with low abundance in June, climbed through the year peaking near the end of July and slowly dropping back off. Largemouth Bass abundance displayed similar trends in all three lakes. No YOY were detected at the beginning of June; abundance peaked at the end of June dropping of significantly by the end of July remaining low the rest of the year.

Although sampling was delayed in 2012, Bluegill abundances were comparable to similar dates in 2011 for Red Haw Lake, higher for Mormon Trail Lake and drastically higher in Greenfield Lake until the end of the sampling season. Red Haw Lake did not have the same peak of Bluegill abundance in August as the year before; rather it showed a slow and precipitous decline ultimately ending with similar numbers as 2011. Mormon Trail Lake had a much higher Bluegill abundance throughout 2012 when compared to 2011. Bluegill abundance in Greenfield Lake was greater in 2012 than in 2011. Although there was a dramatic drop in fish abundance in September within Greenfield Lake, Bluegills still had a greater abundance in 2012 than in 2011. Largemouth Bass abundance in Red Haw Lake by the end of 2012 was similar to 2011 catches. Mormon Trail Lake displayed slightly lower abundance of Largemouth Bass in 2012 compared to 2011. Again no YOY Largemouth Bass were capture in Greenfield Lake.

Forward selection stepwise analysis of mean zooplankton and macroinvertebrate densities, with CPUE against mean average yearly growth rates for YOY Bluegill and Largemouth Bass for the combined 2-year data set were calculated. Parameters for YOY Bluegill growth in order of significance ($P<0.1$) were *Daphnia*, *Ceriodaphnia*, *Chydorus*, total macroinvertebrate density, CPUE of YOY Largemouth Bass, Calanoida and Cyclopoida. *Daphnia*, alone accounted for 71% of the variability and after adding *Ceriodaphnia* and *Chydorus* the variation explained increased to 94% and 99.9% respectively. The single significant ($P<0.1$) parameter for YOY Largemouth Bass growth was CPUE of YOY Largemouth Bass that accounted for 66% of the variability. Red Haw Lake had the lowest abundance of *Daphnia* in both years, having no measurable amount in 2012 (Table 2). Not only were *Daphnia* scarce within Red Haw Lake but the total number of zooplankton present was a fraction of that found in Mormon Trail and Greenfield Lakes. Red Haw Lake also had the highest CPUE of YOY Largemouth Bass in 2011 and 2012.

Discussion

The adoption of Grass Carp management tool for Iowa's lakes is well represented in these three lakes. Red Haw Lake was the first lake in Iowa to have Grass Carp introduced in 1973. A 5-year study took place, and by 1978 Mitzner (1978) had deemed the experimental stocking of Grass Carp to control nuisance levels of aquatic vegetation a success. Grass Carp were subsequently removed in 2001 while the dam and spillway were being repaired. After the success found at Red Haw Lake Grass Carp were stocked throughout the state, including Mormon Trail and Greenfields Lakes in 1980. Mormon Trail Lake was essentially void of vegetation from 1980 through 1998 and had a perceived poor fishery (Cashatt 2008). In contrast, Greenfield Lake has the highest number of Grass Carp per area, has minimal vegetation, yet the fishery seems to remain in good shape (Cashatt 2008). A study in 2001 was undertaken by the Iowa DNR to evaluate the efficiency of partial Grass Carp removal from Mormon Trail Lake to observe if it would allow some vegetation to grow and remedy the poor fishery. The uniqueness of the management events and the fact that Iowa agency biologists had initially embraced but now question the use Grass Carp as management tools for aquatic vegetation, were the reasons for selected these lakes for this study.

Differences in the density of Grass Carp within each lake caused varying levels of vegetation abundance, diversity, and richness. By the end of the study, with no Grass Carp in the past 11 years Red Haw Lake has continued to have increasing diversity. Mormon Trail Lake has similar values to Red Haw Lake and Greenfield Lake has the lowest values. Both Red Haw and Greenfield Lakes have significantly lower richness when in comparison to Mormon Trail Lake (Mammoser 2013). Vegetation abundance appeared to be highest in Mormon Trail Lake and only slightly higher in Red Haw Lake than in Greenfield Lake, but with no significant difference over the course of the 6-year study (Mammoser 2013). Despite having no Grass Carp in Red Haw Lake, the low vegetation abundance is likely caused by increased nutrient loading causing a shift to the turbid phytoplankton dominated state (Mammoser 2013).

Growth rates for Bluegill and Largemouth Bass should be fastest at low vegetation abundance and slowest at high vegetation abundance (Crowder and Cooper 1982; Anderson 1984; Pothoven and Vondracek 1999). Yearly average growth rates for YOY fishes did not follow that trend in this study (Table 1). Red Haw Lake had the slowest average yearly growth rates for both Bluegill and Largemouth Bass in 2011 and 2012.

Bluegills rely heavily on small zooplankton for the first year of growth, e.g., *Daphnia* (Toetz 1966; Morris and Clayton 2009) as shown from our stepwise analysis. Not only was *Daphnia* abundance lowest in Red Haw Lake in 2011 and 2012 but the overall density of zooplankton found was minimal. Having so little suitably sized prey to feed on likely caused the slow growth rates of YOY Bluegill within Red Haw Lake. Low measurable numbers of zooplankton in Red Haw Lake could have been caused by the overabundance of other centrarchids, out competing and leaving little for the YOY Bluegill. The slow growth shown in YOY Largemouth Bass was potentially caused by competition due to their higher abundances in Red Haw Lake. As shown by our stepwise analysis CPUE of YOY Largemouth Bass was the primary parameter to explain the variability in growth rates of YOY Largemouth Bass at 66%.

The other two anomalies in average yearly growth rates, the decrease in Bluegill growth rates in Greenfield Lake and the marked increase growth rates for Largemouth Bass in Mormon Trail Lake, are most easily explained through abundance. Greenfield in 2012 had no detectable production of Largemouth Bass YOY allowing for the YOY Bluegill population to significant increase (Figure 2) causing a drastic decrease in their growth rates when compared to 2011 from increased competition. Mormon Trail Lake had very small abundances of YOY Largemouth Bass in 2012 allowing for less competition and a greater growth rate.

Benthic macroinvertebrates, particularly chironomids and oligachaets, are key food resources to YOY Bluegill (Mittelbach 1984) and in the first part of the year for YOY Largemouth Bass (Goodgame and Miranda 1993) once both species reach sizes that can consume them. Of the benthic macroinvertebrates in these lakes chironomids accounted for 25-50% and oligachaets 21-59%, never adding up to less than 71% of the total individuals (Mammoser 2013). Total abundance of benthic macroinvertebrates seldom dropped below 2000/m^2 except for Mormon Trail Lake in 2011 (Mammoser 2013). The populations of benthic macroinvertebrates found in these lakes did not seem to have a significant influence on growth rates for Bluegill or Largemouth Bass.

There is a limitation to what conclusions could be drawn from this study since we had only one lake at each density of Grass Carp. Further research needs to look into multiple lakes with varying densities of Grass Carp to better determine how their control of vegetation affects the growth of YOY Bluegill and Largemouth Bass.

Red Haw Lake is unique in that Grass Carp inhabited the lake for 28 years before being removed (Mammoser 2013). Over the past decade the lake has existed without this exotic species. By 2009, 7 years after the removal of Grass Carp, growth rates remain at a good level for Largemouth Bass with most under 38 cm. Slow growth rates are found in other centrarchidae, Bluegill, Crappie *Pomixis spp.* and Redear Sunfish *Lepomis microlophus*, with few reaching over 20 cm (IDNR 2013). The question that comes to mind is, has Red Haw Lake begun to return to the pre-Grass Carp state, potentially having future nuisance levels of vegetation. Simply put, Red Haw Lake did not return to that state. In fact vegetation abundance has stayed at low levels (Mammoser 2013). The most likely cause of this is from the unforeseen increase in nutrient loading that this lake experienced a few years after Grass Carp removal whereby the plankton population has impacted submerged vegetation growth.

Mormon Trail Lake, since the reduction of Grass Carp biomass by about 33% in 2001-02, has had a positive reaction. Prior to the reduction of Grass Carp biomass the lake was void of vegetation and the fishery was perceived as poor (Cashatt 2008). In 2005 aquatic vegetation began to appear again and by 2012 the lake was deemed to have a good all-around fishery (IDNR 2013). Mormon Trail Lake now had quality size Largemouth Bass, Bluegill, Redear Sunfish, Crappie, Walleye *Sander vitreus*, and Channel Catfish *Ictalurus punctatus*.

Greenfield Lake is still essentially void of vegetation, having the heaviest density of Grass Carp (Mammoser 2013). Despite this, the lake consistently provides above average fishing. A survey done in 2012 found Largemouth Bass had good numbers in the 33-38 cm range. There is an abundant population of Bluegill at over 18 cm and Crappie from 16.5-23 cm. Channel Catfish range from 35.5-63.5 cm and rounding out the fishery are abundant Bullheads around 25.5 cm (IDNR 2013).

Similar to the earlier concept that simply stocking Grass Carp into a fishery to control aquatic vegetation and thereby increasing the quality of a lake's fishery; simply removing Grass Carp from a lake to increase aquatic vegetation is not valid given the results from this study. Rather we must take our knowledge and apply it to each lake or situation accordingly; often many factors contribute to the current state of a system. The management of aquatic vegetation requires a thorough analysis of aquatic vegetation populations, watershed management as well as the fishery.

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Tables and Figures

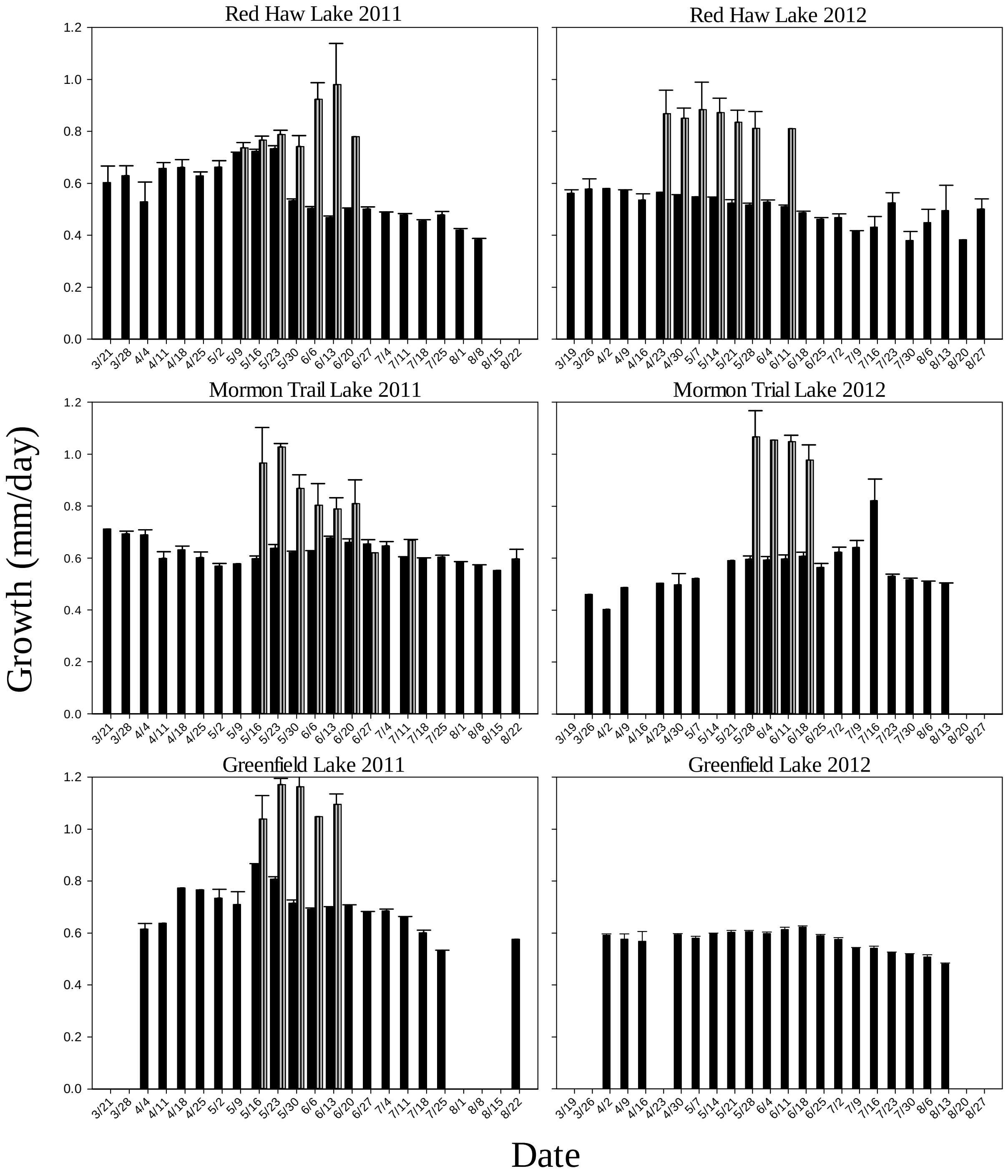

FIGURE 1. Average ± SE daily growth rate (mm/d) of Bluegill (black) and Largemouth Bass (grey) according to hatch week in Red Haw (Low Grass Carp Density), Mormon Trail (Medium Grass Carp Density) and Greenfield Lakes (High Grass Carp Density), 2011 and 2012.

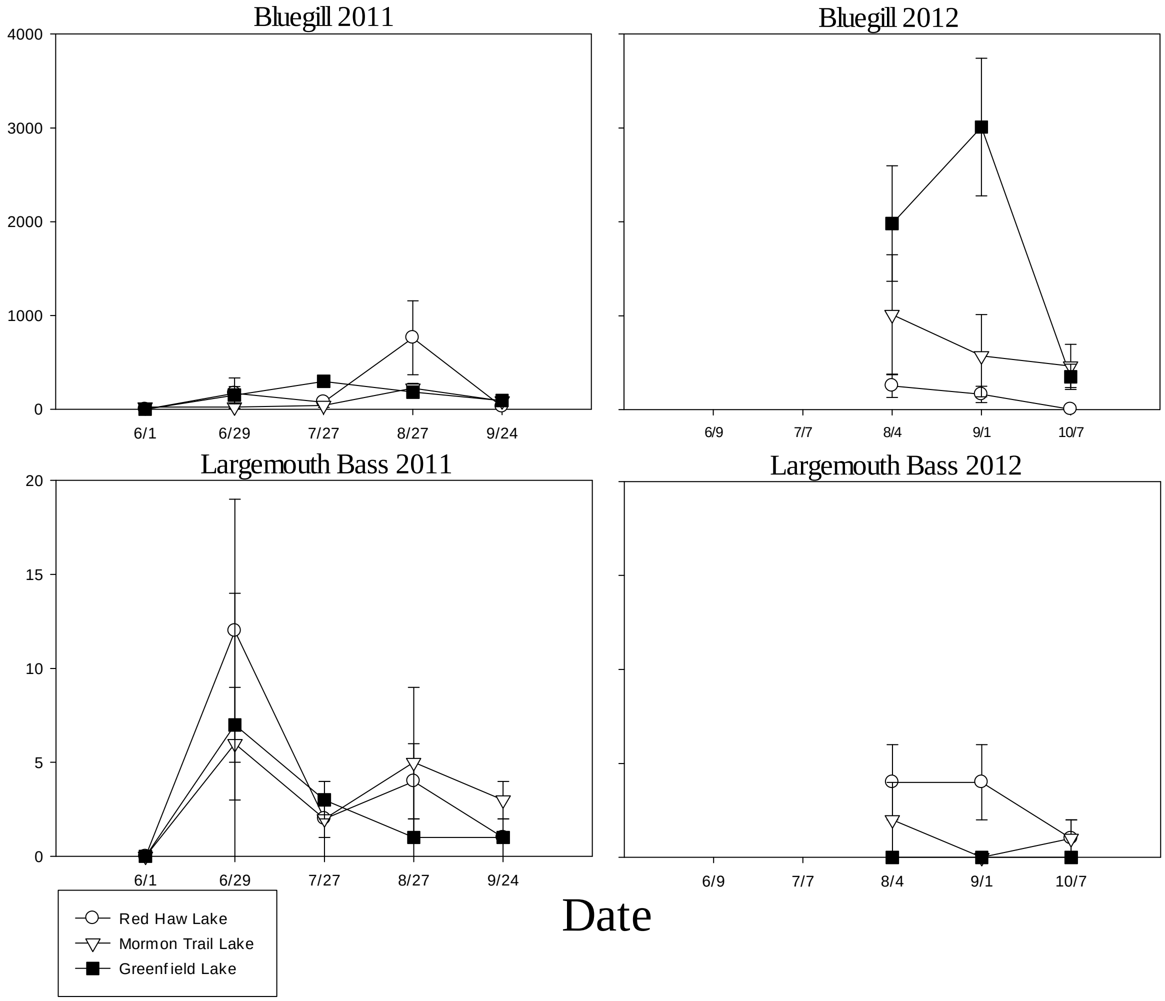

FIGURE 2. Average CPUE ± SE (#/trawl) for trawl dates in Red Haw (Low Grass Carp Density), Mormon Trail (Medium Grass Carp Density) and Greenfield Lakes (High Grass Carp Density) in 2011 and 2012. Sampling did not occur in June or July 2012.

TABLE 1. Sample size (n), average ± SE yearly growth rates (mm/d) of YOY Bluegill and Largemouth Bass with sample size (N) in Red Haw (Low Grass Carp Density), Mormon Trail (Medium Grass Carp Density) and Greenfield Lakes (High Grass Carp Density) in 2011 and 2012. No young of year Largemouth Bass were collected in Greenfield in 2012.

Bluegill

Lake	Year	n	Growth Rate (mm/d)	SE
Red Haw	2011	444	0.53	± 0.005
	2012	261	0.49	± 0.004
Mormon Trail	2011	427	0.63	± 0.003
	2012	393	0.59	± 0.007
Greenfield	2011	419	0.71	± 0.003
	2012	442	0.57	± 0.003

Largemouth Bass

Lake	Year	n	Growth Rate (mm/d)	SE
Red Haw	2011	57	0.80	± 0.017
	2012	27	0.85	± 0.024
Mormon Trail	2011	49	0.87	± 0.026
	2012	9	1.04	± 0.034
Greenfield	2011	35	1.15	± 0.021
	2012	-	-	-

TABLE 2. Average yearly growth rates (mm/d) of Bluegill (BLG) and Largemouth Bass (LMB) collected from Red Haw (Low Grass Carp Density), Mormon Trail (Medium Grass Carp Density) and Greenfield Lakes (High Grass Carp Density) followed by average µg/L of zooplankton taxa and a total average µg/L of zooplankton found (Source: Iowa Lakes Information System 2013).

Lake	Year	BLG	LMB	*Bosmina*	*Ceriodaphnia*	*Chydorus*	*Daphnia*	Calanoida	Cylopoida	Total
Red Haw	2011	0.53	0.80	0.00	0.33	0.00	16.78	5.26	2.96	25.32
	2012	0.49	0.85	0.18	1.24	0.00	0.00	0.64	4.21	6.27
Mormon Trail	2011	0.63	0.87	1.96	14.05	0.83	46.46	25.35	30.81	119.46
	2012	0.59	1.04	4.45	2.02	22.87	19.80	68.22	4.56	121.93
Greenfield	2011	0.71	1.15	0.41	47.69	0.67	42.97	26.30	12.81	130.85
	2012	0.59	-	0.00	27.35	5.50	2.80	44.77	20.49	100.90

CHAPTER 5: GENERAL CONCLUSIONS

The view fisheries managers have on aquatic plants (macrophytes), largely depends on the current state of a specific fishery. Numerous studies have documented the importance of vegetation to the health of an aquatic ecosystem (Crowder and Cooper 1979; Savino and Stein 1982; Durocher et al. 1984; Bettoli et al. 1992). In contrast, when vegetation is overabundant they are often referred to as “weeds”, limiting access to water bodies that results in frustrated anglers and those trying to enjoy to enjoy other recreational activities, i.e., slow growing fish through reduced feeding rates and predator forage efficiency (Crowder and Cooper 1982; Bettoli et al. 1992). Aquatic systems located in highly altered landscapes, like the Midwest, are often plagued with algal blooms and excessive vegetation caused by an influx of excess nutrients from urban or rural sources.

In the mid-1900s fishery managers were limited to mechanical or chemical removal of excess vegetation. Swingle (1957) first proposed the use of Grass Carp *Ctenopharyngodon idella* for vegetation control in the United States. Grass Carp were first introduced at Auburn University in 1963 and they have spread across the United States through introductions, escapes, and movement of established population (Courtenay et al. 1984; Bain 1993; Nico et al. 2012). Since Grass Carps first introduction, numerous studies have documented negative effects related to their introduction. Particularly in Iowa there has been an increase in the number of lakes in the turbid phase, perceived effects on the centrarchid populations and observations of Grass Carp living 30 years, far beyond what was originally considered possible. Taking these observations into account, the Iowa Department of Natural Resources has taken on a more watershed approach to lake management problems, resulting in a decision to limit the use of Grass Carp in public waterways (IDNR 2013a). To gain better knowledge into how Grass Carp affect reservoirs in Iowa this study looked into the effect on macrophyte and benthic macroinvertebrate abundance and diversity, as well as spawning periodicity and young of year (YOY) growth for Bluegill *Lepomis macrochirus* and Largemouth Bass *Micropterus salmoides*.

From our research done at Red Haw, Mormon Trail and Greenfield Lakes it is apparent that Grass Carp can, and do, have a strong influence on aquatic vegetation. Many studies document the ability of Grass Carp to cause a complete reduction to elimination of vegetation (Van Dyke et al. 1984; Klussman et al. 1988; Cashatt 2008). We found that at great enough densities, somewhere between 10 and 33.5/ha, Grass Carp are able to nearly eliminate all vegetation. At densities under 10 Grass Carp per ha there still appears to be some control over vegetation abundance, allowing limited growth covering around 10-40% of the littoral zone.

Vegetation abundance can also be reduced though means other than Grass Carp. In the first Iowa lake stocked with Grass Carp, Red Haw Lake, which was later renovated and had Grass Carp removed, vegetation abundance has since remained relatively low, likely caused by the significant increase in nutrients, from erosion within the watershed, and therefore increased chlorophyll □ concentrations.

Species diversity of macrophytes can be limited due to the selective feeding of Grass Carp (Van Dyke et al. 1984; Leslie et al. 1987). This proved to be the case in our study lakes. As Grass Carp density increased macrophyte species diversity decreased. Sago Pondweed *Stuckenia pectinata* was the predominant species in Greenfield Lake. The fact that Sago Pondweed is the primary species left by the Grass Carp in Greenfield Lake doesn’t agree with what most of the literature says. As explained in Bonar (1990) discrepancies in the palatability of vegetation species can often be explained by calcium, lignin, iron and silica content within the plant, which can vary between water bodies. Red Haw Lake even with having low macrophyte abundance still had the highest macrophyte species diversity by the conclusion of our study.

Macrophytes support high densities and diversity of macroinvertebrates (Carpenter and Lodge 1986). When macrophytes are nearly completely controlled by Grass Carp, numerous studies have found that while epiphytic macroinvertebrates decrease benthic macroinvertebrates increase (Martin and Shireman 1976; Leslie and Kobylinski 1985; Klussman et al. 1988; Kirkagac and Demir 2004). Not everyone agrees though, Fedorenko and Fraser (1978) came to the conclusion that epiphytic and benthic macroinvertebrates decrease with the removal of macrophytes. Our findings support what the majority of literature has found, in that as macrophyte abundance decreases, benthic macroinvertebrate abundance increases. However, the greatest species diversity, based on the number of families found, increased with increasing macrophyte abundance.

The effect of water temperature and photoperiod on timing of centrarchid spawning is well documented (Clark and Keenleyside 1967; Stevenson et al. 1969; Banner and Hyatt 1975; Jackson 1979; Beard 1982; Bryan et al. 1994). However, what role macrophyte abundance may play into spawning periodicity is not. We found that while photoperiod often did play a part in when peak spawning occurred, water temperature was an overriding factor. How macrophytes may affect the spawning periodicity is through their potential effect on the water temperature gradient throughout the littoral zone. The lack of macrophytes in Greenfield for example likely allowed the lake to warm up rather uniformly; explaining why spawning in that lake was the most uniform. The opposite may have occurred at Red Haw and Mormon Trail Lakes, having macrophytes cover part of the littoral zone could allow different areas to warm up more quickly than others, i.e., spots that have direct sunlight, accounting for the more variable spawning. One other interesting thing of note out of this section is that we collected YOY Bluegill in all three lakes in 2011 and 2012 that hatched in late March to early April. This means spawning occurred in Iowa considerably earlier in the year than previously thought.

Growth in YOY Bluegill and Largemouth Bass is influenced by many factors, i.e., genetics (Miranda and Muncy 1987; Aday et al. 2003), reproductive timing (Miller and Storck 1984; Miranda and Hubbard 1994; Jolley et al. 2009), and cover availability, e.g., aquatic macrophytes (Crowder and Cooper 1982; Miranda et al. 1984). With cover having strong influence on many other aspects that influence growth, i.e., food availability, diet shifts (Diggins et al. 1979; Miranda and Muncy 1987; Goodgame and Miranda 1993), and competition (von Geldern and Mitchell 1975; Mittelbach 1988) and being a focal point of the rest of this study we looked at how macrophytes could affect growth. Our findings at first did not entirely support the notion found by Pothoven and Vondracek (1999) that as macrophyte abundance decrease growth rates of YOY Bluegill and Largemouth Bass increase. However, the lake with the lowest macrophyte abundance, Greenfield Lake, had Bluegills and Largemouth Bass with the greatest growth rates. Compounding this issue are the relatively lower growth rates of Bluegills and Largemouth Bass in Red Haw Lake, a lake with an increasing macrophytes abundance and diversity over the study period. We later came to the conclusion that the probable cause for Red Haw Lake’s slow fish growth rates were due to extremely poor zooplankton biomass, namely *Daphnia*, which are critical to the juvenile fish. Overall we determined that macrophytes, i.e., cover, played a significant role in growth rates but so did available food resources and competition intensity.

Red Haw Lake is unique in that Grass Carp inhabited the lake for 28 years before being removed (Mammoser 2013). Over the past decade the lake has existed without this exotic species. By 2009, 7 years after the removal of Grass Carp, growth rates remain at a good level for Largemouth Bass with most under 38 cm. Slow growth rates are found in other centrarchids, Bluegill, Crappie *Pomixis spp.* and Redear Sunfish *Lepomis microlophus*, with few reaching over 20 cm (IDNR 2013b). The question that remains is whether Red Haw Lake would to return to the pre-Grass Carp state, having nuisance levels of macrophytes. Simply put, Red Haw Lake did not return to that state. In fact, macrophyte abundance has stayed at low levels (Mammoser 2013). The most likely cause of this is from the huge increase in nutrient loading experienced a few years after Grass Carp removal.

Mormon Trail Lake since the reduction of Grass Carp biomass by about 33% in 2001-02 has had a positive reaction. Prior to the reduction of Grass Carp biomass the lake was void of macrophytes and the fishery was perceived as poor (Cashatt 2008). In 2005 aquatic macrophytes began to appear again and by 2012 the lake was deemed to have a good all-around fishery (IDNR 2013b). Mormon Trail Lake now had quality size Largemouth Bass, Bluegill, Redear Sunfish, Crappie, Walleye *Sander vitreus*, and Channel Catfish *Ictalurus punctatus*.

Greenfield Lake is still currently void of macrophytes, having the heaviest density of Grass Carp (Mammoser 2013). Despite this the lake consistently provides above average fishing. A survey done in 2012 found Largemouth Bass had good numbers in the 33-38 cm range. There is an abundant population of Bluegill at over 18 cm and Crappie from 16.5-23 cm. Channel Catfish range from 35.5-63.5 cm and rounding out the fishery are abundant Bullheads around 25.5 cm (IDNR 2013b).

A limitation to this study is that for each treatment there was only one replicate per lake category. While there are never any true replicates in the natural world having several lakes with the same macrophyte management strategy and Grass Carp densities would likely provide better insight into possible scenarios under each condition. As it is this study gave a glimpse into one outcome for each treatment and some conclusions can be drawn. Much of the data and the conclusions from it support what previous literature has found. Manipulating the biomass of Grass Carp in a lake can cause significant changes to the macrophyte community indirectly affecting many other aspects of the fishery, particularly for those fishes and organism linked to macrophytes, i.e., centrarchids and benthic macroinvertebrates. Though this study and many other have documented how Grass Carp biomass can influences the macrophyte community other factors like water quality, specifically nutrient loads, can also have a strong influence on macrophytes by affecting which stable state an aquatic ecosystem is likely to exist in.

There is no one size fits all recipe to macrophyte or fisheries management. Rather we must take what we know at the time and apply it to each system and situation accordingly, reacting as we get results because often many not one factor is contributing what the current state of a system hinges on. Simple removal or control does not often work, but rather macrophyte and fisheries management requires a more holistic watershed approach.

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