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Ecology of Largemouth Bass in an Aging Reservoir: Implications for Creating a Trophy Largemouth Bass Fishery

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ECOLOGY OF LARGEMOUTH BASS IN AN AGING RESERVOIR:

IMPLICATIONS FOR CREATING A TROPHY LARGEMOUTH BASS FISHERY

BY

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This dissertation is approved as a creditable and independent investigation by a candidate for the Doctor of Philosophy in Wildlife and Fisheries Science and is acceptable for meeting the dissertation requirements for this degree. Acceptance of this does not imply that the conclusions reached by the candidates are necessarily the conclusions of the Department of Natural Resource Management.

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The work in this dissertation is dedicated to those who have had a significant influence on my life but are no longer with us to share in the completion of this journey of my life. Most importantly is my dad. My dad instilled a passion for the outdoors in me from the time I was “knee high to a grasshopper” as he liked to say. Before I was even potty-trained, I was spending countless hours in a boat, fishing with him. Not only did he teach me how to fish, but he taught me the importance of preserving the outdoors through practices such as catch-and-release or selective harvest and took the time to show me how everything in nature was connected. These experiences undoubtedly peaked my curiosity in science and ecology, instilled a passion for fisheries conservation and management in me, and ultimately led me down this career path. Unfortunately, my dad passed away unexpectedly on June 7, 2014 while I was in the middle of my last field season as a PhD student. I was blessed for the nearly 31 years I got with him, but a part of me will always be missing without him in my life. I am sure he is still walking with me on this journey, giving me hints of where to cast my line when I get lost. This one’s for you dad!!!!

Michael “Mikey” Mullenmeister, a man who I considered my second dad, passed away in October, 2011 after a long battle with cancer. I don’t know of anyone else who knew as much about fishing as Mikey. Rarely, did I ever see him go skunked. On the rare occasion he did go without catching any fish, he still had a great appreciation for the time he got to spend outside. I was lucky enough to get to spend a lot of time fishing with Mikey and learning some of his techniques and honey holes and I am grateful for the time he took out of his life to take me fishing or help me fix my boat.

Two of my uncles, Michael Breeggemann and George Breeggemann, also took the time to teach me valuable lessons about nature through the years we spent deer hunting together. Unfortunately, they also lost their own battles with cancer in previous years. Our deer woods has not been the same without you guys and I will try to carry on our traditions for years to come.

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ABSTRACT

ECOLOGY OF LARGEMOUTH BASS IN AN AGING RESERVOIR:

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There are an estimated 3-9 million small reservoirs and nearly 1,000 large reservoirs in the United States. Most of these reservoirs were built several decades ago and are experiencing symptoms of reservoir aging, including loss of habitat, sedimentation, and decreased fishery production. Furthermore, over the last several decades, there has been an increasing interest among anglers for high quality, trophy fisheries. However, little is known about exactly how the reservoir aging process affects the ecology and especially growth potential of Largemouth Bass, particularly under potential climate change scenarios. Grand Lake in TX is a 45ha ageing reservoir that was built in the 1950s and provides a great laboratory to examine how aging reservoirs affect the ecology and growth potential of Largemouth Bass. We conducted seasonal sampling using boat electrofishing to quantify population genetics, growth, condition, and survival over 3 years. We also assessed movement patterns, habitat use, and seasonal diets. This information was used to model growth potential of Grand Lake Largemouth Bass under predicted future temperatures as a result of climate change as well as different diets. We found that genetics are optimal for Largemouth Bass growth in Grand Lake. The population is composed of primarily Florida parental type Largemouth Bass (28%) and F_x hyrbids (41%), and no differences in growth were detected among the genetic parental types. Survival was also high enough to have trophy sized Largemouth Bass with

individuals observed to live to ages 9-10, and survival estimates from PIT tagged Largemouth Bass were approximately 70%. Population growth was slow for all adults ages 5 and older, with observed mean lengths at age at or below the 50^{th} percentile for ecoregion 8 of the United States. Largemouth Bass consumed an even mix of crayfish and fish during spring (May-June) and then switched over to feeding primarily on fish for the rest of the growing season. Under future predicted climate change models, Largemouth Bass will have to increase consumption by 5-20% just to meet baseline energetic demands, and if consumption remains the same as observed in 2013 and 2014, growth will decrease dramatically. Largemouth Bass were able to grow much faster on a diet of 100% shad compared to observed diets or a diet of 100% crayfish. Seasonal use areas were considered large at nearly 5ha during each of the three month summers. Use areas decreased during winter and spring. Largemouth Bass also tended to stay offshore (averaging 30-50m offshore) and use deeper water throughout most of the year, except during spring spawning. Daily movement rates and use areas were also high with mean daily use areas being 2-5ha during the summer months and total daily movement rates averaging 600-1,000m per day. Having more prey fish available in the spring could enhance Largemouth Bass growth if they switch over to feeding on these prey fish rather than crayfish. Bioenergetics simulations also revealed that consumption is going to have to increase substantially to counter the effect of global climate change, although water temperatures will be higher than the thermal optima for Largemouth Bass, limiting their growth and consumption. Systems such as aeration should be considered to reduce water temperatures closer to the thermal optima of Largemouth Bass. The lack of habitat due to reservoir aging has resulted in large daily and seasonal use areas as well as large daily movement rates for Largemouth Bass in Grand Lake. Increased habitat should allow Largemouth Bass, a habitat associate species, to forage more efficiently and thus grow faster.

CHAPTER 1: INTRODUCTION

Historically, fishing had been viewed in an almost exclusively subsistence manner in which anglers could provide food for their families. As such, fisheries managers who managed both public and private waters managed fisheries in a way that maximized fisheries production. However, in recent decades, there has been a paradigm shift in the way fisheries are viewed from a pure subsistence standpoint to a more recreational standpoint. In response to this paradigm shift, some public and private fisheries managers have tried to create trophy fisheries to appease anglers who want to capitalize on the recreational opportunities fishing provides. One example of a response to this paradigm shift was the creation of the "Toyota Share A Lunker Program" by the Texas Parks and Wildlife Department in 1986 (Texas Parks and Wildlife 2014c). The purpose for creating the "Toyota Share A Lunker Program" was to promote catch-and-release of large Largemouth Bass, *Micropterus salmoides*, in the state of Texas as well as selectively breed trophy Largemouth Bass and stock their offspring in hopes to create other trophy Largemouth Bass fishing opportunities (Texas Parks and Wildlife 2014c). Evidence of the success of the "Toyota Share A Lunker Program" include the fact that residents from 22 states other than Texas have entered a Largemouth Bass weighing more than 13 pounds into the Program (Texas Parks and Wildlife 2014a) as well the fact that the Texas state record Largemouth Bass has increased from 6.2 to 8.3 kg since 1980 (Texas Parks and Wildlife 2014b).

Fisheries managers who are trying to create trophy fisheries have four primary factors which they can manipulate in order to maximize the growth potential of their species of interest, primarily genetics, diet, habitat, and mortality. Genetics can be used to enhance the growth potential of a species of interest when different genotypes of the same species have different growth rates or when different subspecies of the same species have different growth rates. For example, Younk and Strand (1992) found that the Mississippi genetic parental type of the Muskellunge, *Esox masquinongy*, grew significantly faster and had significantly higher growth potential than the Minocqua, Shoepack, or Court Oreilles genetic parental types when grown together in two Minnesota lakes. Therefore, introduction of the Mississippi genetic parental type of Muskellunge into water bodies where the other three genetic parental types persist could enhance muskellunge growth in the introduced systems.

Additionally, two subspecies of Largemouth Bass exist: the Florida subspecies, *M. s. floridanus*, and the northern subspecies, *M. s. salmoides*. The Florida subspecies is native only to the state of Florida and small portions of Georgia and Alabama. In the warm waters of the south, pure Florida parental type Largemouth Bass and their intraspecific hybrids have been shown to grow faster and attain larger sizes than pure northern parental type Bass (e.g., Inman et al. 1977; Maceina et al. 1988). In an attempt to enhance growth rates and create additional trophy Largemouth Bass fisheries through genetic manipulation, the Florida subspecies has been stocked throughout lakes and reservoirs in the southern United States where the northern subspecies is native (e.g., Kulzer et al. 1985; Gilliland and Whitaker 1989; Dunham et al. 1992; Forshage and Fries 1995; Buckmeier et al. 2003). Evidence suggests that introducing genetic parental types with faster growth rates or larger growth potential can aid in creating trophy fisheries. As mentioned earlier, the Texas state record Largemouth Bass has increased from 6.2 to 8.3 kg since the introduction of the Florida Largemouth Bass genetics to the state of Texas

(Forshage and Fries 1995; Texas Parks and Wildlife 2014b). The Texas state record Largemouth Bass of 13.5 pounds prior to stocking Florida Largemouth Bass genetics stood for 43 years, highlighting the effects of better genetics on growth (Forshage and Fries 1995; Texas Parks and Wildlife 2014b).

High energy prey is also necessary in order to maximize growth potential and create trophy fisheries. For example, adult Walleye, *Sander vitreus,* are piscivorous and grow faster and achieve larger sizes when consuming fish for prey compared to invertebrates (e.g., Graeb et al. 2008). Throughout their range, Walleye are highly dependent upon fish as a primary food source (Starostka et al. 1996; Blackwell et al. 1999), and when age-0 Yellow Perch are in low abundance, walleye growth and condition may decline (Meerbeek et al. 2002). Additionally, Walleye growth in Upper and Lower Red Lake, Minnesota was positively correlated with strong year classes of Yellow Perch (Ostazeski and Spangler 2001). Walleye in Lake Erie select for Emerald Shiners *Notropis atherinoides* and Spottail Shiners, *N. hudsonius* during spring when these species were most abundant but switched to age-0 Gizzard Shad, *Dorosoma cepedianum,* and Alewives, *Alosa pseudoharengus,* during summer and fall (Knight et al. 1984). However, Walleye growth in Lake Erie was greater when diets consisted of mostly Gizzard Shad, a species particularly high in energy, compared to diets of Emerald Shiner and Spottail Shiner or White Perch, *Morone americana*, species which have lower energy densities (Hartman and Margraf 1992). Furthermore, research has shown that adult Walleye may actually lose weight during the growing season on a diet dominated by invertebrates (Ward et al. 2007).

Largemouth Bass, another piscivorous fish, has also been shown to grow faster on diets composed primarily of fish compared to other diets such as one comprised mostly of invertebrates. Many different studies have shown that age-0 Largemouth Bass growth is dependent upon types, sizes, and numbers of prey and that age-0 Largemouth Bass that consume a diet of primarily fish grow faster than Bass that consume diets consisting of prey other than fish (e.g., Shelton et al. 1979; Timmons et al. 1980; Adams and DeAngelis 1987). Similarly, Gutreuter and Anderson (1985) found differential growth rates of some age-0 Largemouth Bass based on availability of proper size and type of food with age-0 Bass that consumed Gizzard Shad growing faster than age-0 Bass that in ponds without availability of Gizzard Shad. In a study in a northern WI lake, Sass et al. (2006) found that Largemouth Bass consumption and growth was higher in lakes with abundant woody debris because lakes with coarse woody habitat supported high Yellow Perch populations. When coarse woody habitat was removed, Largemouth Bass were forced to consume primarily terrestrial invertebrates and growth slowed compared to areas with abundant coarse woody habitat (Sass et al. 2006).

In a discussion on the evolution of forage fish management, Ney (1981) proposed six characteristics which the most optimal forage fish species would have. These characteristics include prolific spawning (i.e., high fecundity), stable recruitment (i.e., no boom or bust cycles), trophically efficient (i.e., feed low on the food chain to minimize the energy required to produce the prey fish), vulnerability to predation throughout the life cycle of the species, no emigration, and they must be innocuous. Many prey fish species which have many of the characteristics described by Ney (1981) have been stocked in public and private waters throughout the country to maximize growth of predatory fish species. Stocked species include but are not limited to Gizzard Shad, Bluegill, *Lepomis macrochirus*, Threadfin Shad, *Dorosoma petenense*, Black Crappie, *Pomoxis nigromaculatus*, Fathead Minnow, *Pimephales promelas*, Yellow Perch, Redear Sunfish, *Lepomis microlophus*, Golden Shiner, *Notemigonus crysoleucas*, and Black Bullhead, *Ameiurus melas* (Modde 1980; Dauwalter and Jackson 2005).

Proper habitat is necessary for all life stages of a particular species in order to maximize growth potential throughout the lifespan of that species. Optimal habitat is often correlated with a species optimizing its food consumption, a factor discussed earlier. For example, Sass et al. (2006) compared changes in fish community composition, food web dynamics, and reproductive success in an isolated segment of Little Rock Lake, Wisconsin in which 75% of the coarse woody debris (CWD) was removed to a segment of the lake which was unaltered. Response metrics in both segments were quantified before and after removal of coarse woody debris. Prior to removal of CWD, the food webs in both basins were dominated by aquatic prey with 90% of Largemouth Bass diets consisting of yellow perch and the majority of yellow perch diets consisting of aquatic invertebrates (Sass et al. 2006). The food web in the control basin remained unaltered throughout the experiment (Sass et al. 2006). However, in the treatment basin, the percent composition of Yellow perch in Largemouth Bass diets decreased to 14% and Largemouth Bass showed a significant decrease in consumption and growth in the treatment basin compared to the unaltered control basin (Sass et al. 2006). Yellow Perch recruitment also dropped dramatically as recruitment in the treatment basin was 2 YOY/ha compared to 32 YOY/ha in the unaltered reference basin (Sass et al. 2006).

Habitat density can also influence foraging success of a particular species and therefore growth potential. For example, Crowder and Cooper (1982) found that Bluegill had higher consumption and growth rates at intermediate densities of macrophytes compared to low or high densities of macrophytes. In a similar study, Bettoli et al. (1992) found that when submersed aquatic vegetation covered 39 to 44% of Lake Conroe, Largemouth Bass less than 100mm total length fed primarily on invertebrates and consumed few fish. However, following removal of all submersed aquatic vegetation by Grass Carp, *Ctenopharygodon idella*, Largemouth Bass 60mm and larger consumed primarily fish prey and showed significantly faster-first year growth compared to years when submersed aquatic vegetation was present (Bettoli et al. 1992). The authors of this study concluded that habitat complexity was the primary factor regulating the size at which Largemouth Bass can switch to piscivory (Bettoli et al. 1992).

Given the fact that fish are ectotherms, water temperatures can also affect growth rates. Within the next 100 years, air temperatures are expected to rise as much as 3 °C as a result of global climate change (Eaton and Scheller 1996). As our climate warms, increased water temperatures will increase a fish's metabolic demands (Brown et al. 2004; Breeggemann et al. 2015) leading to increased consumption necessary to meet basal metabolic needs and potentially a reduction in growth (Christie & Regier 1988). Furthermore, it is likely that the effects of climate change will be most severe at the southern edge of a fish's range where temperatures are already near the upper thermal limit of tolerance (e.g., Magnuson 2001; Casselman 2002; Breeggemann et al. 2015). For example, Breeggemamn et al. (2015) showed that increased water temperatures had little effect on growth of Largemouth Bass in a lake in Nebraska (i.e., the center of the

Largemouth Bass' range), but increased water temperatures greatly reduced growth of Northern Pike, *Esox lucius*, in that same Nebraska lake. Northern Pike is a cool water species and Nebraska is at the southern end of its range, highlighting the impact climate change can have on species who are already living in environments near the edge of their tolerance. Although climate change did not significantly affect growth of Largemouth Bass in Nebraska, increased temperatures may have a stronger impact in places like Texas and the rest of the south that are already hotter.

The final factor which fisheries managers can manipulate to maximize growth is mortality. Many of the common fish species for which trophy fisheries are created can live to be a decade or older and these species need to maximize their life span to reach true trophy size. For example, bluegill can live to be 10-12 years old, Largemouth Bass can live to be 15 years old or older, and walleye can live to be 20 years old or older. Using samples collected from taxidermists, Horton and Gilliland (1993) found that Largemouth Bass in Oklahoma reservoirs must reach age-5 to reach trophy size (i.e. ≥3.6kg) and many trophy Bass were older than 10. This study highlights the need for fish to live long enough to reach trophy size. Studies have shown that angler exploitation can reduce age structure and thus size structure in Walleye populations (Baccante and Colby 1996; Staggs et al. 1990) as well as populations of other important fish species (Hilborn et al. 1995; Coble 1998; Miranda and Dorr 2000; Hilborn et al. 2001). According to Baccante and Colby (1996) very few Walleye populations can sustain exploitation rates beyond 30% without losing fishing quality. However, the level of exploitation an individual lake can sustain is highly dependent of lake type and productivity. In some highly productive Walleye fisheries in northern Wisconsin, exploitation rates as high as

35% are considered sustainable (Staggs et al. 1990). On the other hand, exploitation rates in unproductive boreal lakes in northern Ontario cannot exceed 15% without losing fishing quality (Baccante and Colby 1996).

Most often, fisheries managers influence mortality by reducing angling mortality (i.e., exploitation) through the use of regulations. For example, the state of Minnesota has a statewide minimum length limit of 1,016mm for Muskellunge and an even more restrictive minimum size limit of 1,016mm on some water bodies (Minnesota Department of Natural Resources 2014). Additionally, many states have placed special regulations on specific water bodies to create unique trophy fisheries in a single lake (Minnesota Department of Natural Resources 2014). For example, the Wisconsin Department of Natural Resources has placed a minimum length limit of 711mm and daily bag limit of one for Walleyes in Escanaba Lake, Wisconsin (Wisconsin Department of Natural Resources 2014). These regulations and other like them are put in place to create a trophy unique trophy fishing opportunities. Although many regulations are put in place to create trophy fisheries, Allen et al. (2002) used modeling to show that different regulations could be used in Florida to improve total catch of Largemouth Bass. Therefore, regulations can be used to increase catch rates as well as create trophy fisheries.

Grand Lake is a 45ha private impoundment located just east of Athens, TX. Grand Lake was built in the 1950s and is intensively managed as a trophy Largemouth Bass fishery. Grand Lake is considered a eutrophic (secchi disc readings $\leq$ 0.75 m year round) impoundment with a mean depth of 3.2 meters and a maximum depth of 7.9 meters. Northern parental type Largemouth Bass are the native parental type that was originally found in Grand Lake following construction. However, all northern parental type Largemouth Bass were removed by the Texas Parks and Wildlife Department (TPWD) using thiodan in 1972 as part of their program to evaluate the potential growth and survival of pure Florida parental type Largemouth Bass in Texas (Richard Ott, Texas Parks and Wildlife Department, personal communication). Immediately following removal of northern parental type Largemouth Bass, Grand Lake was stocked with pure Florida parental type Largemouth Bass at rate of 247 fingerlings/ha, Fathead Minnows *(Pimephales promelas)* at a rate of 27.9 kg/ha, and Threadfin Shad at rate of 50.9 kg/ha (Richard Ott, Texas Parks and Wildlife Department, personal communication). The exact stocking history of Grand Lake following 1976 (the year monitoring was ceased by TPWD) is not known because ownership has changed several times and no genetic evaluation has been conducted to assess the current genetic makeup of the Largemouth Bass population.

In order to try to create a trophy Largemouth Bass fishery, the food web of Grand Lake is intensively managed. Available prey fish include Bluegill, Redear Sunfish, *Lepomis microlophus*, Redbreast Sunfish, *Lepomis auritus*, Gizzard Shad, Threadfin Shad, *Dorosma petenense*, Mozambique Tilapia, *Oreochromis mossambicus*, Black Crappie, *Pomoxis nigromaculatus*, White Crappie, *Pomoxis annularis*, Channel Catfish, *Ictalurus punctatus*, and Black Bullhead, *Ameiurus melas*. Currently, it is not known what the primary makeup of Largemouth Bass diets are in Grand Lake. Furthermore, knowledge of available Largemouth Bass habitat in Grand Lake is lacking along with how Largemouth Bass are using the available habitat. No exploitation is taking place in Grand Lake because it is a strictly catch and release fishery and Largemouth Bass are only removed when densities are determined to be too high. Through the work outlined in this dissertation, I was able to research how each of the four factors described above affect the growth potential and creation of a trophy Largemouth Bass fishery in Grand Lake, Texas.

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CHAPTER 2: GENETIC COMPOSITION AND DIFFERENTIAL GROWTH OF GENETIC GROUPS OF LARGEMOUTH BASS IN A PRIVATE TEXAS IMPOUNDMENT

Abstract

Within the last several decades, fisheries managers have stocked Florida parental type Largemouth Bass into water bodies where the northern parental type Largemouth Bass are native with the goal of creating trophy Largemouth Bass fisheries. However, little is known about the persistence of Florida parental type Largemouth Bass in a renovated impoundment stocked only with pure Florida parental type fish when faced with the potential of reinvasion by pure northern parental type Bass. We evaluated the genetic composition of a private impoundment 40 years following renovation and stocking with only pure Florida parental type Largemouth Bass and quantified differences in growth rates of different genetic groups of Largemouth Bass found within the population. Florida Largemouth Bass genetics dominated the population as all Largemouth Bass sampled were pure Florida parental type or hybrids. Growth rates did not differ among the genetic groups for either sex. However, growth rate within this population was not fast as mean back-calculated lengths at age for the adult population were near the 50th percentile for ecoregion eight of the United States. Factors other than genetics are likely limiting the growth potential of Largemouth Bass in Grand Lake. If possible, managers may want to remove at least some pure northern parental type Largemouth Bass before stocking Florida parental type Bass to increase chances of successful incorporation of Florida Bass alleles into the population.

Keywords: stocking, genetic parental type, Largemouth Bass, growth, hybrid, back-calculate

Introduction

For decades, humans have been altering the genetics of both wild and domestic plant and animal populations to enhance or change the genetic composition of a particular population of interest (e.g., Dunham et al. 1992; Rai et al. 1999; Kameswara Rao et al. 2003). One reason for altering genetics is to restore genetic diversity of small isolated populations that have lost significant amounts of genetic diversity through genetic drift or have lowered fitness from inbreeding depression (e.g., Hedrick and Miller 1992). For example, female cougars from the Texas cougar subspecies (*Felis concolor stanleyana*) were introduced into the Florida panther (*Felis concolor coryi*) population after the Florida population was reduced to an estimated 30 individuals, became isolated and began suffering from inbreeding depression (e.g., physical deformities and decreased sperm viability; Roelke et al. 1993; Hedrick 1995; Hedrick and Fredrickson 2010).

A second reason for altering genetics is to enhance the genetic makeup of an existing genetically healthy population through the introduction of new genes to produce a desired characteristic not present in the current population. For example, the Florida subspecies of the Largemouth Bass (*Micropterus salmoides floridanus*), has been introduced into many waterbodies where the northern Largemouth Bass subspecies (*Micropterus salmoides salmoides*) is native (e.g., Pelzman 1980; Gilliland and Whitaker 1989; Dunham et al. 1992; Forshage and Fries 1995). The reason for stocking Florida parental type Largemouth Bass into northern parental type Largemouth Bass populations is that pure Florida parental type Largemouth Bass and their intraspecific hybrids have been shown to grow faster and attain larger sizes than pure northern parental type Largemouth Bass in some water bodies where the environment is similar to that of Florida (i.e., the native range of the Florida subspecies; Rieger and Summerfelt 1976; Inman et al. 1977; Bottroff and Lembeck 1978; Pelzman 1980; Maceina et al. 1988). Thus the introduction of Florida Largemouth Bass genetics into northern populations can result in faster growing, larger fish which will ultimately create higher quality angling experiences, and more satisfied anglers (Weithman and Anderson 1978; Maceina et al. 1988; Forshage and Fries 1995). Additionally, Florida parental type Largemouth Bass are less vulnerable to angling than their northern parental type counterparts, thus favoring longevity and the potential to grow to trophy sizes (Zolcynski and Davies 1976; Inman et al 1977; Kleinsasser et al. 1990).

For introductions meant to enhance the genetic composition of the native genetic parental type to be deemed successful, two criteria must be met. First, the introduced genetic material must be incorporated into the existing population and persist through time and second, the desired trait (e.g., increased growth rate) of the introduced genetic parental type must be expressed in the population. Both of these criteria have been met to varying degrees when evaluating the success of stocking Florida parental type Largemouth Bass into northern parental type Largemouth Bass populations. Many states have evaluated the introgression of stocked Florida parental type alleles into native northern parental type populations (e.g., Gilliland and Whitaker 1989; Dunham et al. 1992; Forshage and Fries 1995) and they have documented variable success. For example, Forshage and Fries (1995) found that out of 126 public reservoirs in Texas where Florida Largemouth Bass were stocked, six had 0% occurrence of Florida

Largemouth Bass alleles, 91 had a 20% or greater occurrence of Florida Largemouth Bass alleles in the population, and seven had almost complete replacement of the northern parental type with >80% Florida Largemouth Bass alleles in the population. Additionally, Maceina et al. (1988) found that pure Florida parental type Largemouth Bass reached a larger mean length at age-3 than native pure northern parental type Largemouth Bass in Aquilla Lake, Texas. Similarly, Forshage and Fries (1995) noted that the Texas state record Largemouth Bass increased from 6.12 kg to 8.25 kg after the introduction of Florida Largemouth Bass genetics to the state and that all state record Largemouth Bass caught after 1980 were either pure Florida parental type or F_1 hybrids. This suggests that growth of some individuals and young age-classes increased in some populations. However, very little research has been conducted on population level effects (e.g., growth of different genetic parental types) representing all age-classes present in the population following stocking of Florida parental type Largemouth Bass into wild northern Largemouth Bass populations (Phillip et al. 2002).

Most often, Florida parental type Largemouth Bass are stocked into existing northern parental type Largemouth Bass populations (e.g., Kulzer et al. 1987; Gilliland and Whitaker 1989; Dunham et al. 1992; Forshage and Fries 1995). However, the possibility exists in which one could renovate a water body and stock only pure Florida parental type Largemouth Bass in that impoundment. In certain instances when northern parental type Largemouth Bass are found in other water bodies within the watershed, northern parental type Largemouth Bass could get back into the system where only pure Florida parental type Bass were stocked and threaten the persistence of the Florida alleles in the population. Furthermore, reintroduction of northern parental type genetics into a pure Florida parental type population could lower the growth rates of the population as a whole. To the best of our knowledge, no research has been conducted on the persistence of the Florida Largemouth Bass genome when the possibility of northern parental type Largemouth Bass reinvading a system from other waterbodies within the watershed.

Additionally, research is lacking on differences in population level growth rates of the different genetic groups when Florida parental type Largemouth Bass are stocked into water bodies where northern parental type Largemouth Bass are native (Phillip et al. 2002). Similarly, Wright and Kraft (2012) recommended that future research should be directed towards assessing the genetic outcome (i.e., genetic makeup of populations and population level effects of the different genetic parental types on growth and fitness) of multiple generations of ponds stocked with both species and their crosses. This study could begin to provide information to fill these knowledge gaps. The objectives of our study were to 1) quantify the percent of pure northern parental type, pure Florida parental type, F_1 hybrids, and F_x hybrids in a private impoundment that was stocked only with pure Florida parental type Largemouth Bass following reclamation; and 2) assess population level differences in growth among the genetic groups from one population (i.e., Grand Lake, TX).

Methods

Study site

Grand Lake is a 45ha private impoundment located in eastern Texas which had all northern parental type Largemouth Bass removed by the Texas Parks and Wildlife Department (TPWD) using thiodan in 1972 as part of their program to evaluate the potential growth and survival of pure Florida parental type Largemouth Bass in Texas

(Richard Ott, Texas Parks and Wildlife Department, personal communication). Immediately following removal of northern parental type Largemouth Bass, Grand Lake was stocked with pure Florida parental type Largemouth Bass at rate of 247 fingerlings/ha, Fathead Minnows *(Pimephales promelas)* at a rate of 27.9 kg/ha, and Threadfin Shad at rate of 50.9 kg/ha (Richard Ott, Texas Parks and Wildlife Department, personal communication). The exact stocking history of Grand Lake following 1976 (the year monitoring was ceased by TPWD) is not known because ownership has changed several times; however, northern parental type Largemouth Bass do occur in the watershed above Grand Lake allowing for natural reintroduction of northern parental type genetics into the Florida parental type population in Grand Lake. Grand Lake is intensively managed for trophy Largemouth Bass, primarily through maintenance of the food web. Available prey fish include Bluegill, Redear Sunfish, Redbreast Sunfish (*Lepomis auritus*), Gizzard Shad (*Dorosoma cepedianum*), Threadfin Shad, Mozambique Tilapia (*Oreochromis mossambicus*), Black Crappie (*Pomoxis nigromaculatus*), White Crappie (*Pomoxis annularis*), Channel Catfish (*Ictalurus punctatus*), and Black Bullhead (*Ameiurus melas*). No exploitation of Largemouth Bass occurs on any of these impoundments except to reduce densities when density-dependent competition is evident.

Field sampling

To obtain tissue for genetic analysis, 80 Largemouth Bass were collected from Grand Lake in December 2011, using pulsed DC electrofishing. Upon collection, total length (mm) and weight (g) were measured and a pelvic fin clip was collected and stored in 95% ethanol for subsequent genetic analysis. The Largemouth Bass collected were representative of the entire size structure found in each lake. All size classes of

Largemouth Bass were collected to help ensure the genetic diversity was representative of the population as a whole, rather than an individual year class. Largemouth Bass collected from Grand Lake, TX ranged in size from 84 to 611 mm total length (TL; Figure 2.1). Additionally, sex was determined from all Largemouth Bass collected from Grand Lake by examination of the gonads, and sagittal otoliths were removed Grand Lake Bass for subsequent age and growth estimation.

Genetics

Total genomic DNA was extracted from fin tissue using a Promega Wizard Genomic DNA purification kit (Promega Corp., Madison, Wisconsin). DNA was then quantified using a Nanodrop ND-1000 spectrophotometer (Nanodrop Technologies, Wilmington, Delaware) and normalized to a concentration of 20 ng-μL^{-1}. Seven microsatellite loci previously published for Largemouth Bass (Table 2.1) were PCR amplified using multiplex reactions based on protocol suggested by Henegariu et al. (1997). An ABI Prism 377XL DNA sequencer (Applied Biosystems Inc., Foster City, California) was used to genotype individual fish. An internal size standard (GeneFlo 625; Chimerx Inc., Milwaukee, Wisconsin) was used to determine allele sizes, which was subsequently estimated using GeneScan software (Applied Biosystems Inc., Foster City, California). Allele calls were also verified manually to ensure proper scoring of multi-locus genotype data.

GENEPOP 4.2 (Rousset 2008) was used to test if Largemouth Bass samples departed from Hardy-Weinberg equilibrium (HWE). Fisher's exact test ($\alpha = 0.05$) was implemented in GENEPOP 4.2 with a Markov chain method using 1,000 batches of 1,000 iterations each to compute significance values (P; Guo and Thompson 1992;

Rousset 2008). A sequential Bonferroni method was used to adjust values of *P* for multiple comparisons (Rice 1989). Loci were tested at both the individual and population level. Any locus that did not conform to HWE expectations, was tested for heterozygote excess or deficiency using a *U* test in GENEPOP 4.2 (Rousset 2008). Cumulative effects of the rare, but non-zero genotypes can result in significant deviations from HWE using exact tests due to the small expected frequencies for rare genotypes associated with microsatellite data (Pamilo and Varvio-Aho 1984). To correct this, all exact tests with significant deviations from HWE expectations were retested using the modification of Hedrick (2000) where all genotypes with an expected frequency less than 1% were pooled and the locus retested using a chi-squared goodness-of-fit test in Minitab v.14.20 (Minitab Inc., State College, Pennsylvania). Estimates of genetic diversity for each individual fish at each microsatellite loci and across all loci were quantified using observed and expected heterozygosity, allelic richness (i.e., the number of alleles), and the number of rare alleles (i.e., the alleles found in <5% of the population).

To determine the most likely genetic origin (i.e., northern parental type n or Florida parental type) of Largemouth Bass from Grand Lake, we initially performed a Bayesian based assignment using the program STRUCTURE (Pritchard et al. 2000). To aid in assignment we obtained 34 known pure northern parental type Largemouth Bass collected from Big Sissabagama Lake, Sawyer County, Wisconsin and 16 pure Florida parental type Largemouth Bass from the US Fish and Wildlife Service, Warm Springs Fish Technology Center, Warm Springs, Georgia. STRUCTURE assigned 100% of the pure northern parental type Largemouth Bass to one population and 100% of the pure Florida parental type Largemouth Bass to another population with a ≥95% threshold

(Figure 2.2), verifying that we could differentiate these genetic parental types. Subsequently, we used STRUCUTRE to assign individual Largemouth Bass from each of the three impoundments to one of these two genetic parental types. If the results from our STRUCTURE analysis indicated that there were hybrids in Grand Lake, we used Bayesian model-based clustering and Markov Chain Monte Carlo as implemented in NewHybrids (Anderson and Thompson 2002) to calculate the posterior probability that each individual Largemouth Bass from was pure northern parental type, pure Florida parental type, an F_1 hybrid, or an F_x hybrid (post F_1 hybrid). Each individual fish was then assigned to one of these four groups based on an individual fish having at least a 70% probability of being one of the four genetic groups. If an individual fish did not have at least a 70% probability of being one of the four genetic groups, it was classified as uncertain.

Differences in growth among genetic groups

One sagittal otolith from each Largemouth Bass was embedded in an epoxy resin consisting of a mixture of five parts Buehler© Epoxicure® Epoxy Resin to one part Buehler© Epoxicure® Epoxy Hardener. A transverse cross section, approximately ½ mm thick, was cut through the focus of each otolith using a Buehler© IsoMet™ Low Speed Saw. Each thin section was then glued to a microscope slide using a cyanoacrylate adhesive and polished using 1000 grit wetted sandpaper. Ages for each Largemouth Bass were estimated from thin sectioned otoloiths by viewing the otolith through an Olympus© SZH10® dissecting microscope using transmitted light. A thin layer of immersion oil was placed on each otolith section to enhance clarity. Ages were estimated double-blind by a two experienced readers. Initially, each reader estimated ages from each sectioned otolith individually, and if each reader did not agree on their initial age estimate, both readers looked at the sectioned otolith simultaneously to reach a consensus age estimate for each fish. Because the Largemouth Bass were sampled in mid-December, the edge of each otolith was counted as an annuli.

Total sectioned otolith radius and the distance from the center of the focus to the edge of each annulus were measured on each otolith using an Olympus© DP72® camera mounted to the dissecting scope described above in combination with the Olympus© cellSens® Standard digital imaging software. All measurements were made along a transect parallel to the sulcus and measurements were made to the nearest thousandth of a millimeter. We plotted fish total length against structure radius to quantify if a linear relationship existed between structure radius and fish total length to assess if a linear back-calculation model could be used. We used the Fraser-Lee back-calculation model to back-calculate lengths at age for each Largemouth Bass following the methods described by Devries and Frie (1996). To assess differences in growth among the different genetic groups, mean back-calculated lengths at age were compared following the procedures presented by Isley and Grabowski (2007), but translated for Program R using, FishR (Ogle 2015). Largemouth Bass for which the genetic group was uncertain (i.e., did not have at least 70% probability of being a genetic group) were not included in this analysis. Only ages from which a mean back-calculated length at age could be computed (i.e., sample size of 2 or more back-calculated lengths at an age) were used for analyses. An alpha of 0.05 was chosen to denote significance when comparing models fit to mean back-calculated lengths at age. Additionally, a von Bertalanffy growth curve was fit to mean back-calculated lengths at age for each of the genetic groups of interest using the Solver tool in Microsoft® Excel.

Prior to comparing mean back-calculated lengths at age among genetic groups, mean back-calculated lengths at age were first compared between males and females, regardless of genetic parental type, to assess if growth differed among the sexes. All Largemouth Bass were included in this analysis. If the results of this analysis indicated growth differed by sex, mean back-calculated lengths at age for the different genetic groups were compared for each sex separately. To assess how growth rates in Grand Lake compare to other populations, mean back-calculated lengths at age for the Grand Lake population as a whole (i.e., all Largemouth Bass in the sample regardless of genetic group and including fish whose genetic group was unknown) were compared to the 50th and 95th percentiles of mean back-calculated lengths at age for Largemouth Bass in ecoregion 8, taken from Brouder et al. (2009).

Results

Genetics

All individual loci conformed to the Hardy-Weinberg expectations for the Grand Lake Largemouth Bass population. The number of alleles per locus varied from 2 – 21 for Largemouth Bass sampled from Grand Lake, Texas (Table 2.1). Observed heterozygosity for each locus ranged from 0.438 (Msa-31) to 0.925 (Msa-32) and expected heterozygosity for each locus ranged from 0.407 (Msa-31) to 0.888 (MSA-32). For the Largemouth Bass populations as a whole, expected heterozygosity was 0.708, observed heterozygosity was 0.736, and the mean number of alleles per locus was 11.29

(Table 2.2). Forty eight alleles were considered rare in the Grand Lake Largemouth Bass population.

Results of STRUCTURE analysis indicated that at least some Largemouth Bass from Grand Lake had genetic material from both the pure northern parental type population and pure Florida parental type population, and thus there were hybrids in the population (Figure 2.3). Therefore, NewHybrids was used to assign each Largemouth Bass to one of the four genetic groups described above (i.e., pure Florida parental type, pure northern parental type, an F_1 hybrid, or an F_x hybrid).

The Largemouth Bass population in Grand Lake was composed primarily of F_x hybrids (n = 33 or 41.25% of Largemouth Bass sampled) and pure Florida parental type (i.e., containing 100% Florida Largemouth Bass genetics) Largemouth Bass (n = 22 or 27.5% of Largemouth Bass sampled), with a few F_1 hybrids (6 or 7.5% of Largemouth Bass sampled). Nineteen or 23.75% of the Largemouth Bass sampled from Grand Lake were classified as uncertain (i.e., did not have at least a 70% probability of being one of the four genetic groups), and no pure northern parental type Largemouth Bass were sampled from this populations (Figure 2.4). Of the 19 Largemouth Bass whose genetic group was classified as uncertain, the genetic group with the highest percent probability of occurrence was pure Florida parental type or one of the hybrid groups (Figure 2.4). Additionally, the highest percent probability of any of these Largemouth Bass being pure northern parental type was 4.5% (Figure 2.4); therefore, every Largemouth Bass sampled had some pure Florida parental type Largemouth Bass alleles.

Differences in growth among genetic groups

Sagittal otoliths were sectioned from 75 of the 80 Largemouth Bass from Grand Lake for which genetic samples were collected. However, after removing the Largemouth Bass which had an unknown genetic group, a total of 58 Largemouth Bass were left to compare growth among genetic groups. Thirty seven of these 58 Largemouth Bass were females. Of the 37 females, six were F_1 hybrids. Mean back-calculated lengths at age were estimated up to age-5 for F_1 hybrid females as this was the oldest age for which multiple back-calculated lengths were estimated. Eleven of the 37 females were pure Florida parental type. Mean back-calculated lengths at age were estimated only up to age-4 as only one of the 11 pure Florida parental type females were older than age-4. Twenty 20 of the 37 females were F_x hybrids. Mean back-calculated lengths at age were estimated up to age-9 for F_x hybrid females. No pure northern parental type Largemouth Bass were captured in Grand Lake.

Twenty one of the 58 Largemouth Bass for which growth could be compared among genetic groups were males. None of the 21 male Largemouth Bass samples were F_1 hybrids; therefore, mean back-calculated lengths at age were not calculated for F_1 hybrid males. Ten of the 21 males were pure Florida parental type. Mean back-calculated lengths at age were estimated up to age-9 for pure Florida parental type. Eleven of the 21 males were F_x hybrids. Only one male of this genetic group was estimated to be older than age-8, resulting in mean back-calculated lengths at age up to age-8 for this genetic group.

There was a significant linear relationship between fish total length and structure radius (R^2 = 0.84, $F_{1,74}$ = 374.5, P<0.0001). Additionally, growth was significantly different between the sexes as there was a significant interaction between sex and the squared increment term (Incsq) and sex and the increment term (Inc) in the model (Figure 2.5; Table 2.3). Therefore, differences in growth among the genetic groups were compared for each sex separately. No significant differences were detected in mean back-calculated lengths at age among the different genetic groups for either sex as mean back-calculated lengths at age were nearly identical among the genetic groups for each sex (Figure 2.6). Additionally, none of the interaction terms between the squared increment term (Incsq) and genetic group (Group) or in increment term (Inc) and genetic group (Group) were significant for either sex, indicating no significant differences in growth among the genetic groups for either sex (Table 2.4). Growth of Largemouth Bass in Grand Lake was initially very fast as mean back-calculated lengths at ages 1 and 2 were similar to mean back-calculated lengths at age for the 95th percentile of ecoregion eight (Figure 2.7). However, growth rates of Largemouth Bass in Grand Lake did not keep pace with the 95th percentile as mean back-calculated lengths at age for age-5 and older Bass dropped to near or below the 50th percentile (Figure 2.7).

Discussion

The Largemouth Bass population in Grand Lake was dominated primarily by Florida alleles as all Largemouth Bass sampled were pure Florida parental type or a hybrid. This provides some evidence for the persistence of Florida Largemouth Bass alleles when faced with the potential reinvasion of northern parental type Largemouth Bass. However, as mentioned earlier, the exact stocking strategy after 1976 is unknown and therefore, more pure Florida parental type Largemouth Bass could have been stocked between 1976 and 2000 influencing the observed genetic makeup. Additionally, it is not known how many pure northern parental type Largemouth Bass eventually reinvaded

Grand Lake either through natural reinvasion from other waterbodies within the watershed where the northern parental type Largemouth Bass are native or through stockings of pure northern parental type Largemouth Bass for purposes such as supplementing the fishery.

It should be noted that there are currently at least some pure northern parental type Largemouth Bass in the Grand Lake population because F_1 hybrids were observed. Although we are not sure of the exact year after treatment with thiodan in which pure northern parental type Largemouth Bass were found in Grand Lake again, pure northern parental type Bass could have invaded in immediately after their removal because they are found in other water bodies within the same watershed as Grand Lake. Additionally, the effect of the removal was never fully evaluated so all pure northern parental type Largemouth Bass may not have been eradicated from the system prior to stocking pure Florida parental type Bass (Richard Ott, Texas Parks and Wildlife Department, personal communication). Pure northern parental type Largemouth Bass had to have reinvaded Grand Lake sometime prior to the year 2001 at the very latest because second generation or post-F_1 hybrid Bass (i.e., F_x Bass) that were estimated at nine years old were sampled from Grand Lake. Therefore, this lends evidence to the persistence and potential dominance of Florida parental type Largemouth Bass in impoundments where northern parental type Largemouth Bass are native as long as Florida parental type Largemouth Bass have the opportunity to generate a self-sustaining population.

The possibility exists that some of the factors that affect introgression of Florida alleles into native northern parental type Largemouth Bass populations may also affect the introgression of northern Largemouth Bass alleles into Florida Largemouth Bass populations, even when the Florida Bass populations exist in the native range of the northern parental type Bass. For example, in a study of 126 public reservoirs in Texas, Forshage and Fries (1995) found a significant negative correlation between the age of the reservoir when first stocked and percent Florida Largemouth Bass alleles, percent Florida Largemouth Bass genotypes, and percent of Bass with Florida alleles. Grand Lake was built in the 1950s and was 20 years old when it was renovated. Twenty years following initial construction was near the age at time of stocking of 20.7 years (range 5-71 years) reported by Forshage and Fries (1995). Additionally, Boxrucker (1986) also found that newly impounded reservoirs have the highest success when stocking Florida Largemouth Bass into northern parental type populations. As reservoirs age, productivity decreases followed by declines in recruitment and production of some fish species (Kimmel and Groeger 1988), thus potentially reducing stocking success and introgression rates. Additionally, older reservoirs are likely at or near their carrying capacity, which can increase competition between stocked and native Largemouth Bass potentially resulting in higher mortality rates of stocked Florida parental type Largemouth Bass and reduce rates of introgression (Forshage and Fries 1995). Despite the fact that Grand Lake was renovated, it was 20 years old at the time of renovation and therefore productivity could be decreasing and the pure Florida parental type Largemouth Bass population that was stocked had four years to reach carrying capacity and thus reduce the likelihood of reinvasion by pure northern parental type Bass.

The number of pure northern parental type Largemouth Bass that reinvaded Grand Lake could also explain the persistence of the Florida Largemouth Bass genome. Several researchers have found the number of stockings to be one of the most important factors driving the incorporation of Florida Largemouth Bass genes into northern Largemouth Bass populations (Kulzer et al. 1987; Dunham et al. 1992, Forshage and Fries 1995). Kulzer et al. (1987) hypothesized that repeated stockings in different years increased chances of successful introgression due to annual variation in survival of stocked individuals. New Lake only had two stockings of pure Florida parental type Largemouth Bass and one stocking of F_1 hybrid Bass, whereas, reservoirs in the study conducted by Dunham et al. (1992) all had at least three stockings of pure Florida parental type Bass and as many as 11 in 18 years. Therefore, the number of Largemouth Bass trying to reinvade Grand Lake could also affect introgression of the northern parental type into the Florida population. Although pure northern parental type Largemouth Bass do occur in other water bodies within the watershed, it is unlikely that large numbers of pure northern parental type Bass similar to those that are stocked by a management agency tried to invade over many years.

The biology of the two subspecies could also explain the persistence of the Florida genome. In a study of a newly impounded Texas reservoir in which pure Florida parental type Largemouth Bass were stocked into a native northern parental type population, Maceina et al. (1988) found that female Florida parental type Largemouth Bass were significantly larger by age-3 than their northern counterparts and had significantly higher fecundity as a result. In that same study, Maceina et al. (1988) also found that pure Florida parental type and hybrid Largemouth Bass had significantly higher survival during the first few years of life compared to pure northern parental type Largemouth bass. Higher size specific fecundity and survival were two reasons pure Florida parental type and hybrid Largemouth Bass were the dominant genetic groups within five years after stocking in a newly created reservoir in Texas (Maceina et al. 1988) and could explain the dominance of Florida genetics in Grand Lake.

No differences in growth were observed among genetic groups sampled for either sex of Largemouth Bass sampled from Grand Lake. The initial reason for stocking Florida parental type Largemouth Bass into Grand Lake was because at the time of stocking, it was thought that pure Florida parental type Largemouth Bass and their hybrids could grow faster and attain larger sizes than the native pure northern parental type Largemouth Bass in some environments. Research has since provided evidence that Largemouth Bass with Florida genetics do grow faster than their northern counterparts in some systems (e.g., Rieger and Summerfelt 1976; Inman et al. 1977; Bottroff and Lembeck 1978; Pelzman 1980; Maceina et al. 1988). However, we did not collect any pure northern parental type Largemouth Bass in our sample; therefore, we could not directly compare growth rates of the native parental type (i.e., northern parental type) of Largemouth Bass to those with introduced genetics (i.e., Florida parental type) to assess whether Largemouth Bass with Florida genetics grew faster than their northern counterparts in the same system. Additionally, it should be noted that in some water bodies in the south, pure Florida parental type Largemouth Bass may grow at similar rates to their northern counter parts or may not grow as well as pure northern parental type Bass at some ages (e.g., Zolczynski and Davies 1976; Kleinsasser et al. 1990). Therefore, the ability to successfully increase growth rates of Largemouth Bass by stocking Florida parental type Bass into water bodies where the northern parental type is native may be system specific.

Growth rates of juvenile (i.e., ages 1 and 2) Largemouth Bass in Grand Lake were fast as mean back-calculated lengths at these ages for the population were at or near the 95th percentile for ecoregion eight. The habitat complexity and food web of Grand Lake could explain the fast growth rates for these ages. Bettoli et al. (1992) found that age-0 Largemouth Bass in Lake Conroe, Texas switched to piscivory at smaller sizes and had significantly faster first year growth following the removal of all submersed aquatic vegetation by Grass Carp (*Ctenopharyngodon idella*). Other research has also shown that age-0 and juvenile Largemouth Bass forage efficiency is highest in areas with no vegetation or low densities of vegetation or areas where vegetation is removed (e.g., Hayse and Wissing 1996; Olson et al. 1998) Grand Lake also has a population of Grass Carp which have removed all of the submersed aquatic vegetation, thus potentially providing the opportunity for age-0 Largemouth Bass within Grand Lake to switch to piscivory at small sizes. Additionally, Grand Lake has an extensive prey fish community providing ample prey fish for age-0 Largemouth Bass.

Despite fast growth rates at young ages, growth rates of older individuals (i.e., ages 3 and older) slowed as mean back-calculated lengths at age for the population decreased to the 50th percentile for ecoregion 8. All of the Largemouth Bass sampled were hybrids or pure Florida parental type fish so a factor other than just genetic group is likely limiting the growth potential of Largemouth Bass in Grand Lake. One possible explanation for decreased growth among older individuals is habitat limitations. As mentioned earlier, Grand Lake has no submersed aquatic vegetation as a result of Grass Carp, thus reducing the opportunity for Largemouth Bass to forage as efficiently as possible. Additionally, as reservoirs age, flooded timber decomposes and habitat provided by coarse woody debris is lost (Kimmel and Groeger 1986). Grand Lake was constructed in the 1950s, allowing for nearly 60 years of decomposition of woody debris to take place. Therefore, without submersed aquatic vegetation or significant amounts of coarse woody debris, habitat may be limiting growth of adult Largemouth Bass in Grand Lake. Sass et al. (2006), found a significant decrease in consumption and growth of Largemouth Bass in a segment of Little Rock Lake, Wisconsin in which 75% of the coarse woody debris was removed compared to an unaltered reference segment of the lake. Although habitat in Grand Lake may be ideal for growth of juvenile Largemouth Bass, it may be limiting growth of adult Largemouth Bass thus highlighting the need to manage for all life stages of the species of interest.

Through this study, we were able to evaluate the effects of different stocking strategies on the composition of Florida Largemouth Bass alleles in private impoundments. The different stocking strategies evaluated resulted in different levels of success as far as composition of Florida Largemouth Bass genetics within each population. Populations in which northern parental type Largemouth Bass were removed prior to stocking Florida parental type Bass alone or in combination with northern parental type Bass and F_1 hybrids had higher contribution of Florida genetics than the impoundment where Florida parental type Largemouth Bass were stocked into an existing native northern parental type population. If the management objective of a particular water body is to maximize the contribution of Florida alleles where the northern subspecies is native, managers may want to consider removing northern parental type Largemouth Bass from the impoundment, or at least some portion of it (e.g., a cove or bay) prior to stocking Florida parental type Largemouth Bass to maximize success of the stocking. We could not assess whether Largemouth Bass with Florida genetics grew faster than the native northern parental type Largemouth Bass in Grand Lake. However, growth of the population as a whole was not fast as mean back-calculated lengths at age were near the 50th percentile for adult Largemouth Bass, which lends evidence to the desired trait of faster growth rates not being expressed in the Grand Lake population as a whole. However, this does not mean that individuals cannot reach trophy potential. Since the introduction of Florida genetics to the state of Texas, the Texas state record Largemouth Bass has increased by over two kilograms with all new state records having Florida genetics (Texas Parks and Wildlife 2014) indicating the success of introducing Florida genetics to other Largemouth Bass populations in Texas. It is likely a factor other than genetics that is limiting the growth potential of Largemouth Bass in Grand Lake.

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TABLE 2.1. Seven microsatellite loci used, number of alleles observed (A), observed allele size range (Range; in base pairs), and the references for each microsatellite locus used to assign genetic groups to Largemouth Bass sampled from Grand Lake, TX in December, 2011.

Locus	A	Range	Reference
Msa-01	21	109-219	Seyoum et al. 2013
Msa-05	8	121-167	Seyoum et al. 2013
Msa-14	17	171-253	Seyoum et al. 2013
Msa-31	2	237-239	Seyoum et al. 2013
Msa-32	16	257-313	Seyoum et al. 2013
Lma10	9	109-133	Lutz-Carrillo et al. 2006
Mdo3	6	105-121	Lutz-Carrillo et al. 2006

TABLE 2.2. Total number of Largemouth Bass sampled (N), number of Loci used (Loci Typed), unbiased heterozygosity (Unbiased Hz), observed heterozygosity (Observed Hz), and the mean number of alleles per loci (Number Alleles; value in parentheses is SD) for the Largemouth Bass populations as a whole sampled from Grand Lake, TX in December, 2011.

Population	N	Loci Typed	Unbiased Hz	Observed Hz	Number Alleles
Grand Lake	80	7	0.708 (0.06)	0.736 (0.02)	11.29 (6.82)

TABLE 2.3. Results of an ANOVA comparing models fit to mean back-calculated lengths at age for male and female Largemouth Bass sampled from Grand Lake, TX in December 2011.

Source	**df**	**Type III SS**	**F-value**	**Pr(>F)**
Intercept	1	400912	317.37	<0.0001
Sex	1	575	0.46	0.500
Inc	1	470711	372.63	<0.0001
Incsq	1	127419	100.87	<0.0001
Sex*Inc	1	16934	13.41	0.0003
Sex*Incsq	1	9525	7.54	0.0064
Residuals	373911	296		

TABLE 2.4. Results of an ANOVA comparing models fit to mean back-calculated lengths at age for different genetic groups of male and female Largemouth Bass samples from Grand Lake, TX in December 2011.

	Males				Females			
Source	**df**	**Type III SS**	**F-value**	**Pr(>F)**	**df**	**Type III SS**	**F-value**	**Pr(>F)**
Intercept	1	89803	160.38	<0.001	1	63129	39.71	<0.001
Group	1	291	0.52	0.47	2	4416	1.39	0.252
Inc	1	51627	92.2	<0.001	1	55698	35.04	<0.001
Incsq	1	10024	17.90	<0.001	1	8796	5.53	0.020
Group*Inc	1	68	0.12	0.72	2	3721	1.17	0.313
Group*Incsq	1	2	0.004	0.95	2	2491	0.78	0.458
Residuals	76	42556			146	232103		

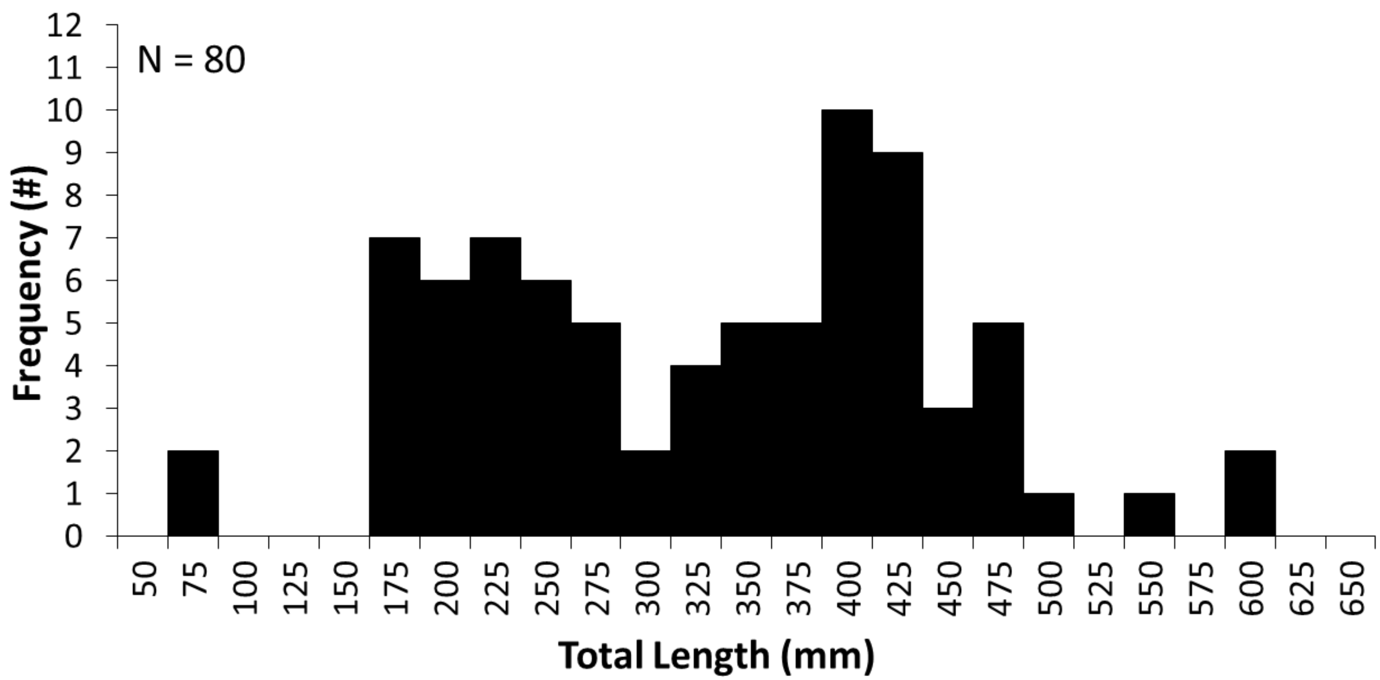

FIGURE 2.1. Length-frequency histogram for Largemouth Bass sampled from Grand Lake, TX in December, 2011.

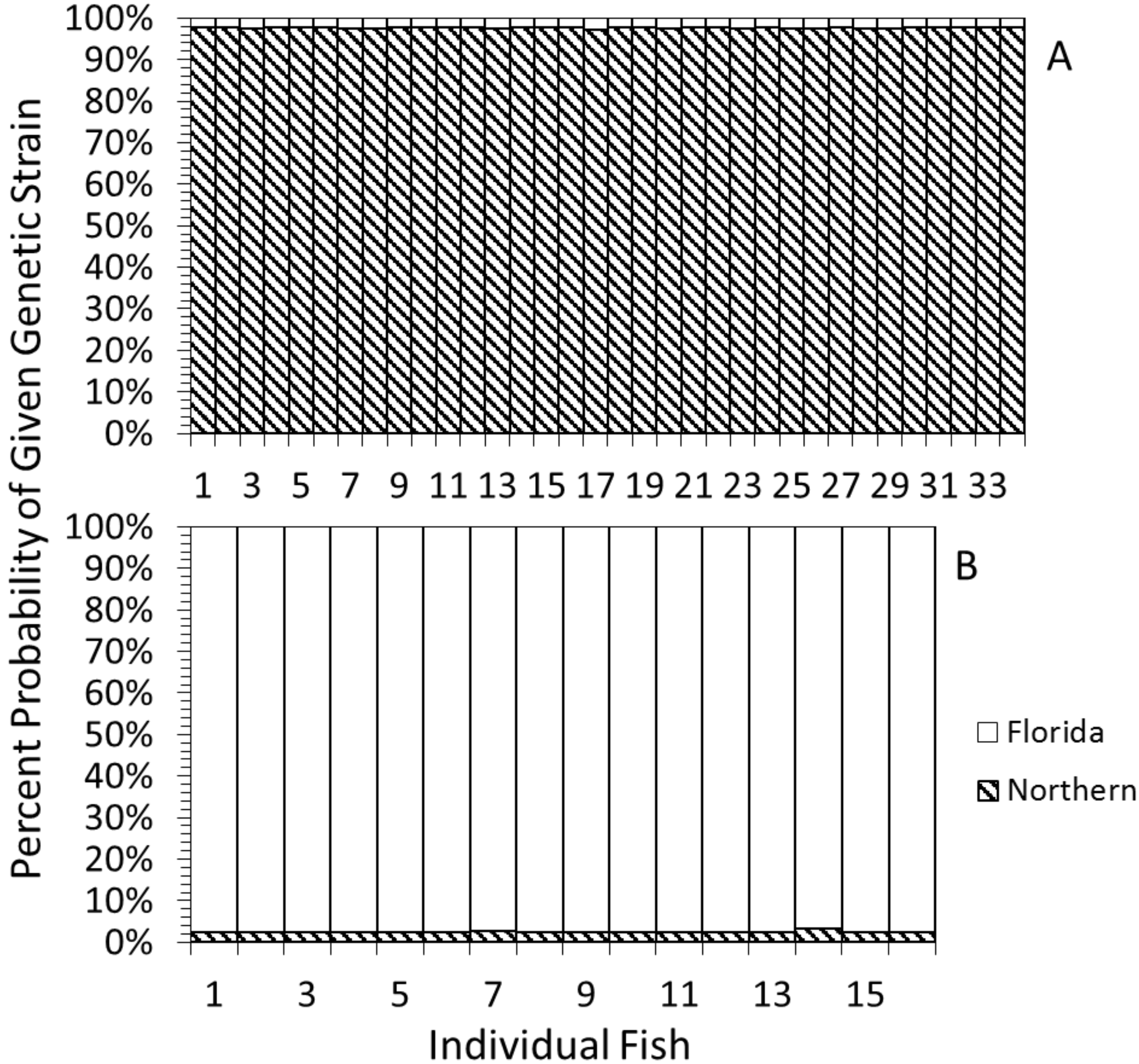

FIGURE 2.2. Percent probability of an individual Largemouth Bass sampled from Big Sissabagama Lake, Sawyer County, Wisconsin (A) and the US Fish and Wildlife Service, Warm Springs Fish Technology Center, Warm Springs, Georgia (B) being pure northern parental type (Northern) or pure Florida parental type (Florida) as assigned by the program STRUCTURE.

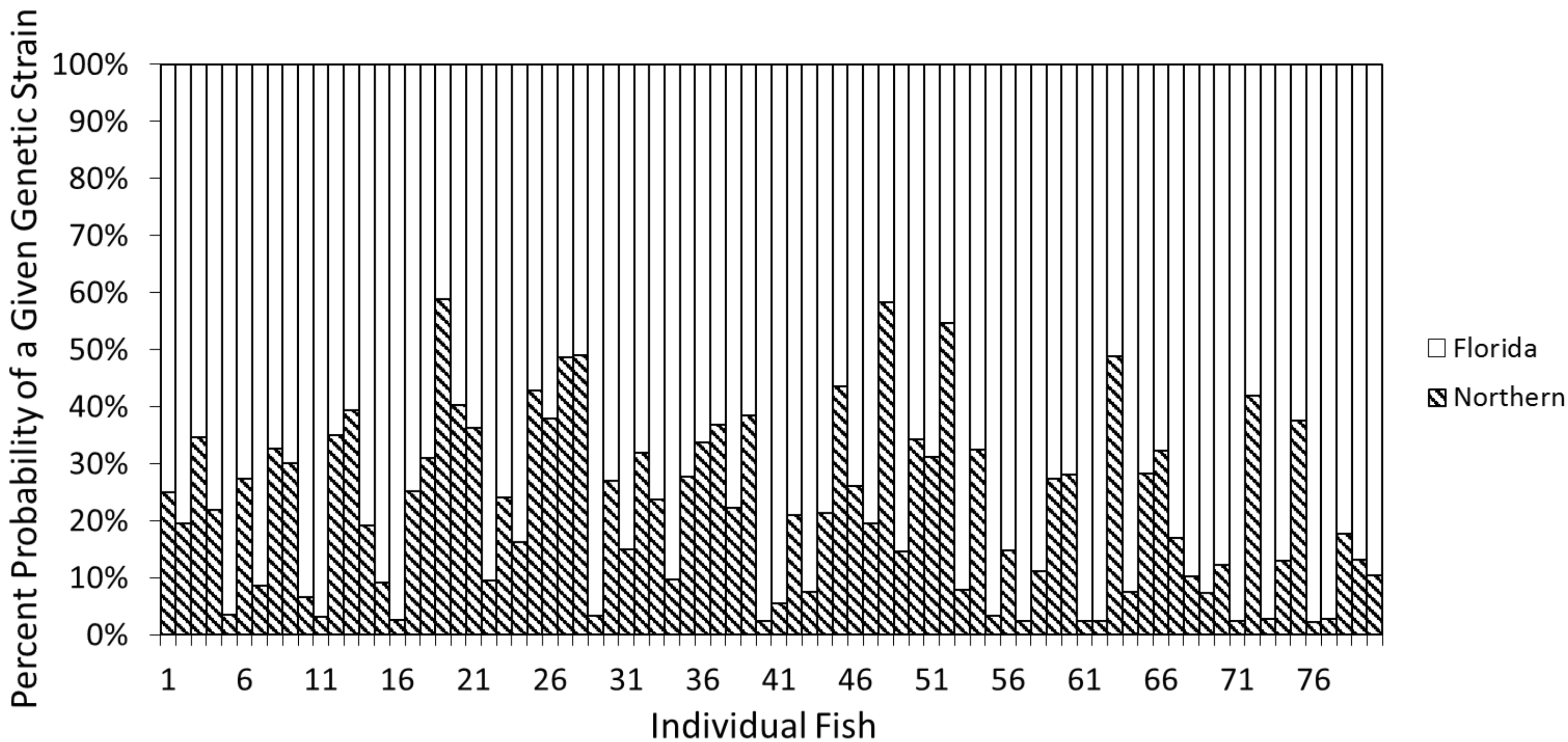

FIGURE 2.3. Percent probability of an individual Largemouth Bass sampled from Grand Lake, TX in December, 2011 being pure northern parental type (Northern) or pure Florida parental type (Florida) as assigned by the program STRUCTURE.

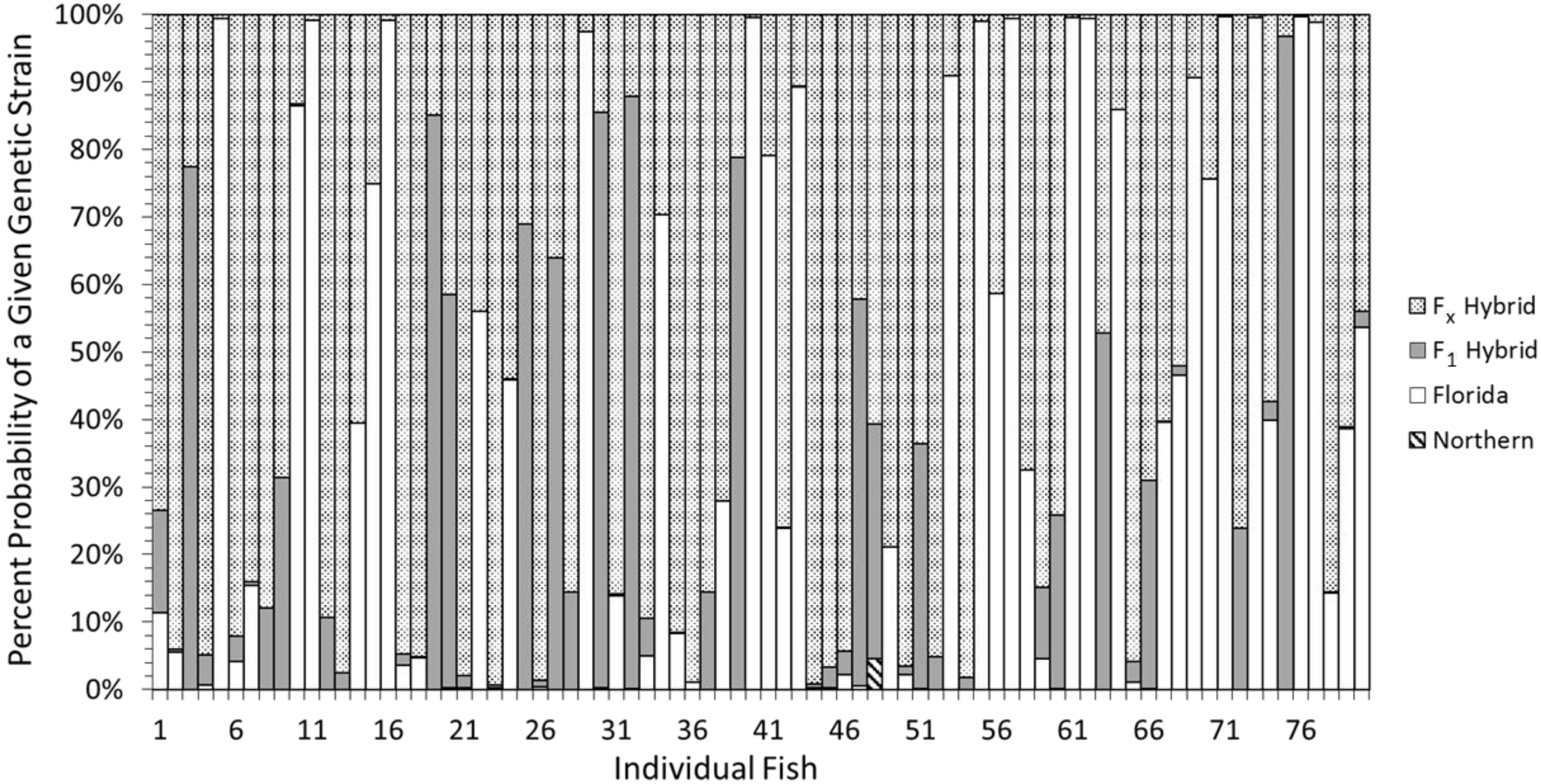

FIGURE 2.4. Percent probability of an individual Largemouth Bass sampled from Grand Lake, TX in December, 2011 being pure northern parental type (Northern), pure Florida parental type (Florida), an F_1 hybrid (F_1 Hybrid), or an F_x hybrid (F_x Hybrid) as assigned by the program NewHybrids.

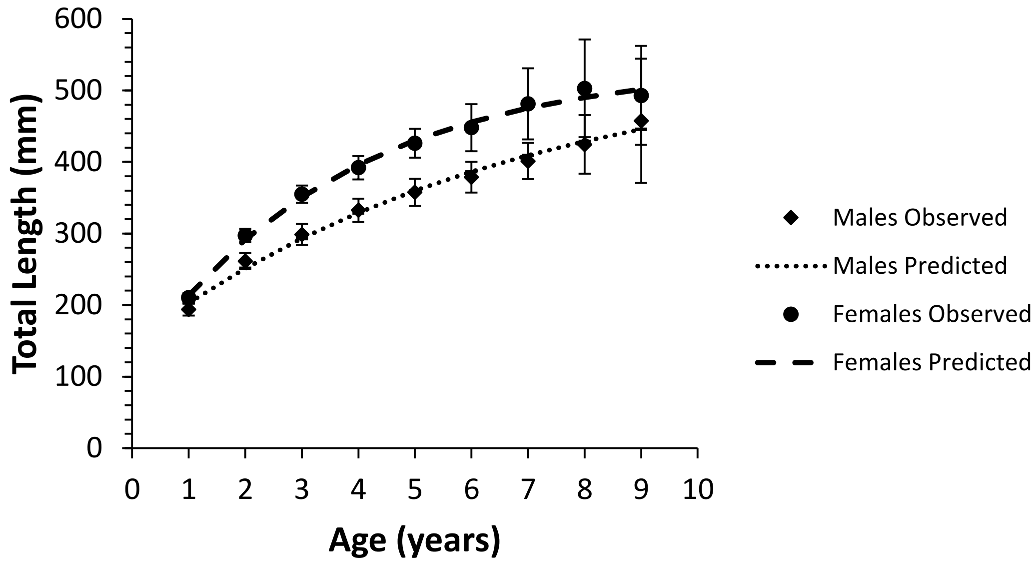

FIGURE 2.5. Mean back-calculated lengths at age for male (Males Observed) and female (Females Observed) Largemouth Bass sampled from Grand Lake, Texas in December, 2011. The two dashed lines represented predicted lengths at age from a von Bertalanffy growth model for each of the sexes. Error bars represent 95% confidence intervals.

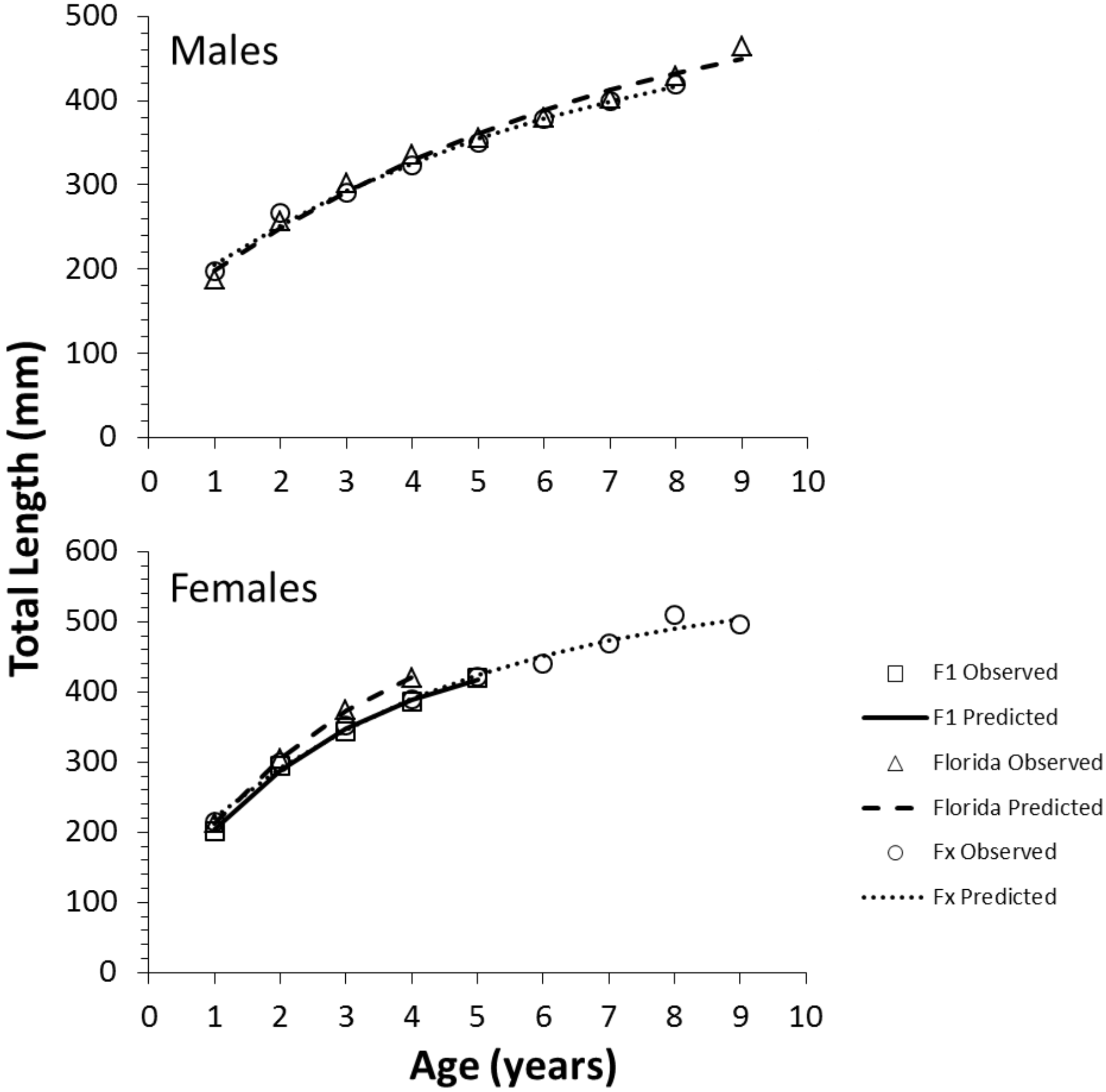

FIGURE 2.6. Mean back-calculated lengths at age for F1 hybrid (F1 Observed), pure Florida parental type (Florida Observed), and Fx hybrid (Fx Observed) Largemouth Bass sampled from Grand Lake, Texas in December, 2011. Mean back-calculated lengths at age were separated by sex. Dashed lines represented predicted lengths at age from a von Bertalanffy growth model for each of the genetics groups for both males and females.

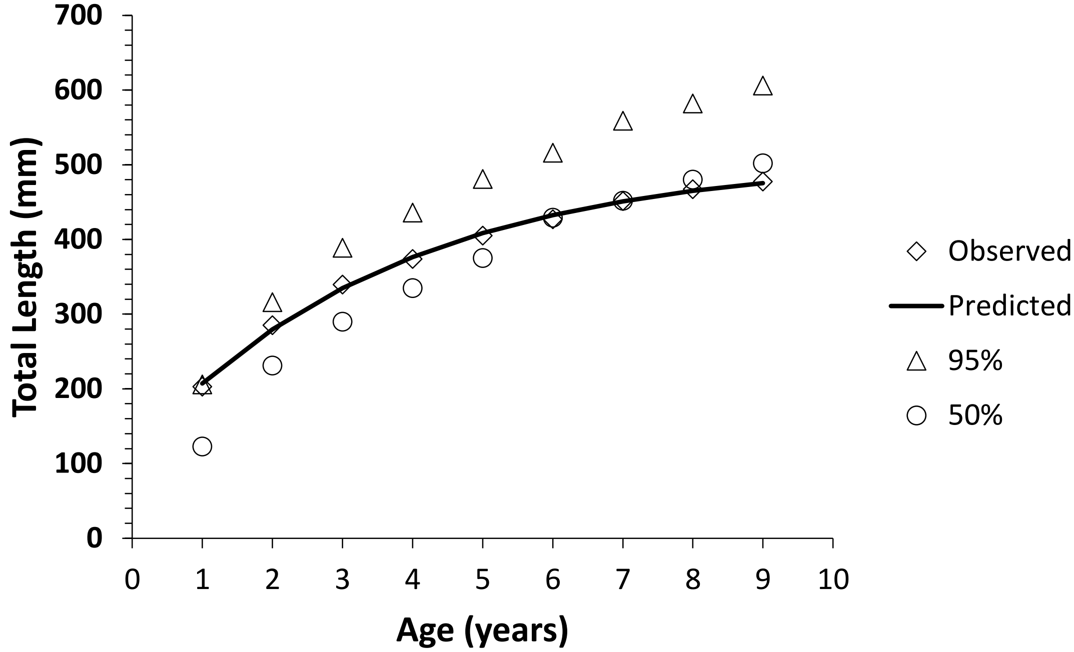

FIGURE 2.7. Mean back-calculated lengths at age for all Largemouth Bass sampled from Grand Lake, Texas in December, 2011 (Observed). The solid line represents a von Bertalanffy growth curve fit to mean back-calculated lengths at age (Predicted). The triangles and circles represent mean back-calculated lengths at age for the 95th and 50th percentiles for Largemouth Bass from ecoregion eight.

CHAPTER 3: ESTIMATES OF SURVIVAL, GROWTH, AND CONDITION FOR THREE DIFFERENT STOCKED GENETIC PARENTAL TYPES AND NATIVE LARGEMOUTH BASS IN A PRIVATE TEXAS IMPOUNDMENT

Abstract

Different genetic parental types of Largemouth Bass are often stocked into impoundments to enhance the growth potential, condition, and survival of Bass in a particular fishery. However, the success of these stockings is not always evaluated. Growth, condition, and survival of three different genetics groups of Largemouth Bass stocked into a private impoundment were evaluated and compared to the performance (i.e., growth, condition, and survival) of native Largemouth Bass. Annual survival of Grand Lake native Largemouth Bass was high at approximately 70-75%, but growth was slow and relative weights tended to be lower than desired to create a trophy fishery with most fish having relative weights in the upper 80s. Stocked pure Florida parental type Largemouth Bass had the lowest annual survival rates (i.e., approximately 45%) and had growth and condition estimates similar to native Grand Lake Largemouth Bass. Feed trained hybrid Tiger Largemouth Bass had the highest annual survival rates at approximately 85% and this genetic group showed the fastest growth rates and maintained the highest condition with most fish maintaining relative weights over 100. Survival rates were not estimated for stocked pure northern parental type Largemouth Bass due to low sample sizes, but growth and condition estimates for this group were similar to native Grand Lake Largemouth Bass. Survival estimates for native Grand Lake Largemouth Bass are high enough to maintain a trophy Largemouth Bass fishery yet growth and condition is low, indicating a factor other than survival is limiting the creation of a trophy fishery in this impoundment. Stocking feed trained hybrid Tiger Largemouth Bass may increase the potential for creating a trophy fishery. Care should be

taken when choosing a genetic group to stock to prevent the effects of outbreeding depression.

Keywords: Survival, growth, condition, Largemouth Bass, Stocking

Introduction

Fish stocking is a tool used by fisheries managers to create, maintain, restore, and augment fish populations (Trushenski et al. 2010). In the United States, the practice of stocking fish by government agencies or organizations such as the Sierra Club began in the 1800s (e.g., Tunison et al. 1949; Pister 2001). By the 1930s, there were 87 Federal fish hatchery units and approximately 400 state fish hatcheries operating throughout the United States (Earle 1937; Tunison et al. 1949). Today, fish stocking continues to be an integral part of fisheries management throughout the United States. For example, in 2004, an estimated 1.7 billion fish from 104 fish species were stocked by state agencies and the U.S. Fish and Wildlife Service throughout the United States (Halverson 2008). Fish species stocked by these agencies include popular cold, cool, and warmwater sport fish species, rare and declining species, as well as forage fish species (Halverson 2008). Additionally, stocked fish can contribute significantly to sport fish angling as 40% of sport fishing in Michigan relies on stocked fish and 70% of trout and salmon caught in the Great Lakes are from stocked origins (Trushenski et al. 2010).

Many reasons exist as to why fisheries managers stock fish. One reason is to establish recreational fisheries in newly created water bodies (e.g., small impoundments), in water bodies that have been depauperate of sport fish, or in water bodies that have been reclamated to remove undesirable fish species. For example, in the mid-late 1800s, trout were stocked in western mountain lakes that had few to no fish to establish new fisheries (Pister 2001). Additionally, an estimated 2.6 million small impoundments have been constructed in the U.S. (Smith et al. 2002), and many recommendations have been presented for initially creating fish communities in these impoundments or continuously managing these fisheries through stocking (e.g., Willis et al. 2010; Wright and Kraft 2012). A second reason for stocking fish is to supplement wild populations where natural reproduction is occurring but habitat modifications or limitations, erratic recruitment, intense harvest, or biological or anthropogenic interactions limit natural production (i.e., supplemental stocking). Supplementally stocked walleyes can increase year class strength in some lakes (e.g., Lajeone et al. 1992; Parsons et al. 1994; Li et al. 1996) and can contribute significantly to walleye harvest from some year classes (Parsons et al. 1994).

A third reason for stocking fish is to control undesired organisms. Grass Carp (Ctenopharyngodon idella) have been successfully used to control nuisance aquatic vegetation in many water bodies (Mitzner 1978; Shireman and Maceina 1981; Martyn et al. 1986; Chilton II and Muoneke 1992). Additionally, walleye and northern pike stocking was used to reduce planktivorous fish (e.g., yellow perch and cisco) biomass and increase water clarity in Lake Mendota, WI due to an increase in *Daphnia* grazing on phytoplankton (Lathrop et al. 2002). Stocking has also been used to aid in the recovery of populations of rare and endangered fishes (e.g., Simons et al. 1989; Ryden 2000a; Ryden 2000b), alter the genetics of a population for a preferred characteristic (e.g., growth; Forshage and Fries 1995; Buckmeier et al. 2003), creation of a trophy fishery (e.g., muskellunge in Minnesota; Wingate and Younk 2007), and forage fish stocking to supplement available prey (e.g., Modde 1980; Dauwalter and Jackson 2005).

Regardless of the goal of the stocking program, all stocking programs should be evaluated to assess whether goals have been achieved, to assess whether unintended consequences have occurred within the stocked fish or native community, and to develop methods to improve the stocking program in the future (Murphy and Kelso 1986; Wahl et al. 1995; Trushenski et al. 2010). The possibility of several unintended consequences exists when stocking fish. One unintended consequence of hatchery reared fish in inbreeding if closely related individuals are used as brood stock. Fitness of inbred individuals can be lower due to physical abnormalities or developmental abnormalities and reduced reproductive viability as well as loss of genetic diversity and resulting ability to adapt to changing environments (Tave 1993; Trushenski et al. 2010). A second concern with fish stocking is loss 0f fitness due to outbreeding depression, or the loss of fitness in offspring due to hybridization (Templeton 1986). For example, many populations have coadapted gene complexes that have evolved to allow for greatest survival and fitness within the local environment. These gene complexes could be lost if members of the same species with genes adapted for different environmental conditions are introduced (Templeton 1986; Phillipp and Claussen 1995; Phillipp et al. 2002). A last unintended consequence could be a reduction in growth, condition, and survival of stocked and/or resident individuals after stocking due to mechanisms such as predation or competition (Li et al. 1996; Buynack and Mitchell 1999).

Florida parental type Largemouth Bass have been extensively stocked throughout the southern United States where northern parental type Largemouth Bass are native

(Gilliland and Whitaker 1989; Dunham et al. 1992; Forshage and Fries 1995). Florida parental type Largemouth Bass have been introduced into northern parental type populations because pure Florida parental type Bass and their intraspecific hybrids grow faster and attain larger sizes in some water bodies that closely resemble their native range in Florida (Rieger and Summerfelt 1976; Inman et al. 1977; Maceina et al. 1988). Furthermore, Florida parental type Largemouth Bass are less vulnerable to angling than their northern counterparts (Zolcynski and Davies 1976; Inman et al 1977; Kleinsasser et al. 1990). Many researchers have evaluated introgression of Florida Largemouth Bass alleles into northern Largemouth Bass populations and results have shown variable success from complete absence of Florida alleles in some populations to highly introgressed populations (Gilliland and Whitaker 1989; Dunham et al. 1992; Forshage and Fries 1995). Although some studies have shown that pure Florida parental type individuals do grow faster their northern counterparts to young ages in wild northern parental type populations where Florida parental type Bass were stocked (e.g., Maceina et al. 1988), few studies have examined population level changes in growth following stocking of Florida Largemouth Bass (Phillipp et al. 2002). Additionally, Forshage and Fries (1995) noted that the Texas state record Largemouth Bass increased from 6.12 kg to 8.25 kg after the introduction of Florida Largemouth Bass genetics to the state and that all new state record Largemouth Bass caught after 1980 were either pure Florida parental type or hybrids.

Grand Lake, Texas is a private 45 hectare impoundment with a management goal of growing 6.8 kg Largemouth Bass. To achieve this goal, over 600 adult (250-550 mm total length [TL]) suspected pure Florida parental type Largemouth Bass (see description in methods) from two different origins and feed trained F_1 Largemouth Bass were stocked into Grand Lake during winter 2011-2012. Adult Largemouth Bass were stocked because of higher probability of survival and to achieve two primary goals: 1) To immediately introduce or increase Florida alleles in the population (the genetic makeup of the Largemouth Bass population in Grand Lake in 2011 was unknown; see Chapter 2) and 2) Create a lake with trophy potential within a year or two by stocking adults with genetics that select for fastest growth potential. This provided the unique opportunity to study changes in survival, growth, and condition of stocked adult Largemouth Bass following stocking as well as monitor changes in growth, condition, and mortality of the native Largemouth Bass population following the stocking event. The objectives of our study were to: 1) quantify survival of stocked Largemouth Bass of different origins and native Largemouth Bass in private impoundment; and 2) quantify changes in growth and condition of the different origins of stocked Largemouth Bass and native Largemouth Bass in a impoundment following a major stocking event of adult Largemouth Bass.

Methods

Live Recaptures Survival

Largemouth Bass from three different origins were stocked into Grand Lake, Texas during the winter of 2011-2012. The specific characteristics (i.e., number and sizes) of each genetic origin are described below. Genetics of the three different origins of Largemouth Bass were assessed using the methods described in Breeggemann et al. (2015) to verify the Largemouth Bass were of the expected genetic origin. Additionally, at the time of stocking, total length (mm) and weight (g) were recorded for each Largemouth Bass and each Bass had a Biomark® GPT12 12mm Passive Integrated

Transponder (PIT) tag implanted into the back musculature using a Biomark® MK-10 implanter timmped with a N125 syringe style implanting needle. Numbers of PIT tags were also recorded at the time of stocking. The PIT tag was implanted of the left side of each Largemouth Bass, approximately 0.5cm under the skin and just below the dorsal fin. All tags were sterilized with 95% ethanol prior to implantation and the implanting needle was sterilized with 95% ethanol in between each injection (Wagner et al. 2007).

One hundred five hatchery raised Largemouth Bass from Alabama, whose genetic parental type was expected to be F_1 hybrid Tiger Bass (i.e., female pure Florida parental type Largemouth Bass and male pure northern parental type Largemouth Bass), were stocked into Grand Lake on December 17, 2011. These Largemouth Bass ranged in size from 254 mm TL to 438 mm TL (Figure 3.1). Fin clips were taken from 51 of these Largemouth Bass to verify they were F_1 hybrids. On that same stocking date, 25 hatchery raised Largemouth Bass from Arkansas, whose genetic parental type was thought to be pure Florida parental type, were also stocked into Grand lake. These Largemouth Bass ranged in size from 240 mm TL to 370 mm TL (Figure 3.1). Fin clips were taken from all 25 of these Largemouth Bass to verify that they were pure Florida parental type. Additionally, 516 hatchery raised Largemouth Bass from Florida, whose genetic parental type was expected to be pure Florida parental type, were stocked into Grand Lake in February and March of 2012. These Largemouth Bass ranged in size from 330 mm TL to 558 mm TL (Figure 3.1). Fin clips were taken from 43 of these Largemouth Bass to verify they were pure Florida parental type.

To collect mark-recapture data of Largemouth Bass in Grand Lake, pulsed DC electrofishing was used to sample Largemouth Bass multiple times each year beginning in spring 2012 and ending in fall 2014. Three sampling events occurred throughout 2012: mid-May, mid-August, and mid-November. Five sampling events occurred in 2013: mid/late-May, mid-June, late-July, mid-September, and late-October. Five sampling events also occurred in 2014: early-February, mid-May, early-July, mid-September, and late-October. During each sampling event, every Largemouth Bass sampled that was larger than 250 mm TL was scanned for a PIT tag using a Biomark® hand held PIT tag reader. If an individual Largemouth Bass already had a PIT tag implanted, the tag number was recorded, total length and weight were measured and recorded, and the fish was released back into the lake. If a Largemouth Bass greater than 250 mm TL (we chose to use 250 mm TL as our minimum size for PIT tagging to reduce tagging induced mortality) did not have a PIT tag implanted at the time of capture, one was implanted using the methods described above, and again length and weight were measured and recorded and the fish was released into the lake. All Largemouth Bass sampled in Grand Lake that were not PIT tagged and stocked into Grand Lake in one of the three stocking events described above were considered a native Largemouth Bass to Grand Lake (subsequently referred to as Grand Lake native). Throughout all 13 sampling events, a total of 695 native Largemouth Bass were PIT tagged ranging in size from 251 mm TL to 605 mm TL (Figure 3.2).

The Cormack-Jolly-Seber (CJS) Live Recaptures model in Program MARK was used to estimate and compare survival of two different origins of Largemouth Bass stocked into Grand Lake as well as native Largemouth Bass within the system. Due to a low initial sample size at time of stocking and few recaptures, the stocked Florida parental type Largemouth Bass from Arkansas were not included in the mortality analysis but were included in the growth and condition analysis described below. Additionally, because continuous marking and recaptures were used for the Grand Lake native Largemouth Bass whereas recaptures only were used for the stocked F_1 hybrids and stocked Florida parental type Bass from Florida, two separate analyses were run in program MARK; one for the stocked F_1 hybrids and stocked Florida parental type Bass from Florida (each as a separate group in MARK) and one for the Grand Lake native Bass. The Program RELEASE good of fit test in Program MARK was run on the most general model for the analysis of Grand Lake native Largemouth Bass as well as the analysis of the F_1 hybrids and stocked Florida parental type Bass from Florida and c-hats were adjusted according to the results of these analyses. Lastly, because there were different time intervals between sampling events, the "Set Time Intervals" option in MARK was used to account for this. Initially, the number of weeks between sampling intervals was calculated and that number was divided by 26 (i.e., the number of weeks in six months) to have MARK estimate survival over 6 month seasons.

Initially, seven models were run using the CJS Live Recaptures model in Program MARK to estimate survival of Grand Lake native Largemouth Bass between mid-May, 2012 and late-October, 2014. The first and simplest model (i.e., had the fewest parameters) was a constant model (hereafter referred to as Constant) in which both survival and detection probabilities were constant across all 12 time intervals between the 13 sampling events. The second model was a season by year survival and detection model (hereafter referred to as Season*Year) where survival and detection were held constant for all time intervals within a growing or non-growing season for a year but they differed among years. For example, survival and detection were held constant for the two time intervals between the mid-May and mid-November, 2012 (i.e., the 2012 growing season), survival and detection were held constant for the single time interval between mid-November, 2012 and mid-May, 2013 (i.e., the 2012-2013 non-growing season), and survival and detection were held constant for the four time intervals between mid-May and late-October, 2013 (the 2013 growing season), etc. The third model was an annual survival and detection model (hereafter referred to as Year) in which survival and detection were held constant for all time intervals within a given year but survival and detection for time intervals among years could be different. For this analysis, we chose to start the year after our late-October to mid-November sampling period resulting in a partial year for the time period starting in May, 2012 and ending in mid-November. Therefore, all survival and detection were held constant for all time intervals between mid-November, 2012 and early November, 2013, etc.

The fourth model was a seasonal survival and detection model (hereafter referred to as Season) where survival and detection were held constant for all sampling intervals within the growing season (i.e., between the May sample and the late-October to mid-November sample each year) of all years and survival and detection were held constant for all non-growing season intervals (i.e., between the late-October to mid-November sample and May sample the following spring) of all years. For example, survival and detection were held constant for the two time intervals between the mid-May and mid-November, 2012 and the four time intervals between mid-May and late-October, 2013, etc. Additionally, three more models were run keeping survival the same as in the latter four models described above (i.e., Year, Season, and Season*Year) but detection was held constant across all time intervals for the entirety of the summer. These models are all referred to as survival times the time interval of interest plus (e.g., time or year) plus detection times constant. For example, the model in which survival varied by year and detection was help constant across all time intervals was referred to as Survival*Year + Detection*Constant.

Upon evaluation of our parameter estimates from our initial seven models, we observed that detection probabilities during our May, 2013 sample (the second season in our Season*Year models) was extremely low. This was due to the fact that our electrofishing boat malfunctioned during the May, 2013 sampling limiting our effort during this sampling event. Therefore, five models were built to address this. In all of these five models, survival was held constant across the two non-growing seasons to better estimate survival over the 2012/2013 non-growing season under the assumption survival was similar among winters. The first model allowed survival to be constant across time periods and detection was constant across time periods except for May, 2013 (Survival*Constant + Detection*Constant Except Gear Failure). The second model allowed survival to vary by season but seasonal survival was constant among years and detection was held constant except for May, 2013 (Survival*Season + Detection*Constant Except Gear Failure). The third model was similar in the survival was held constant across the two non-growing seasons, survival was allowed to vary among the three growing seasons but was constant within a growing season, and detection was held constant except for May, 2013 (Season*Non-growing*Constant*Growing*Year + Detection*Constant Except Gear Failure). The fourth model allowed survival to vary by season but was held constant across years and detection was allowed to vary by season and year (Survival*Season +

Detection*Season*Year). The last model held survival constant across non-growing seasons, allowed survival to vary among the three growing seasons, and allowed detection to vary by time (Survial*Non-growing*Constant*Growing*Year + Detection*Season*Year).

Thirty four models were run using the CJS Live Recaptures model in Program MARK to estimate survival of the stocked F_1 hybrids and Florida parental type Largemouth Bass from Florida. Both of these stocking origins had one extra season (i.e., 2011/2012 non-growing season) for which to estimate survival because they were stocked during that season. Recaptures did not begin until May, 2012 so the two of the three stocking events in which an individual was not stocked received periods in the capture history to denote that recapture was not possible. Each of the two origins of stocked Largemouth Bass were considered their own attribute group for this analysis, thus allowing us to quantify if the best predictive model(s) for survival resulted from the two stocked groups having different estimates of survival and/or detection probabilities.

The first seven models used to estimate survival of the stocked F_1 hybrid and Florida parental type Largemouth Bass from Florida were the same as the first seven models described for the analysis of survival of Grand Lake native Largemouth Bass (i.e., Constant, Season* Year, Year, Season, Survival*Season*Year+Detection*Constant, Survival*Year+Detection*Constant, and Survival*Season+Detection*Constant). For these seven models, we were not trying to detect differences in survival or detection between the two groups. Furthermore, we ran four additional models in which the four different survival scenarios (i.e., Constant, Season, Year, and Season*Year) were separated by groups (i.e., the two groups could have different estimates of survival for a given time period) but detection was held constant across all time periods and was the same for each of the two groups (i.e., there was only one estimate of detection for the entire analysis that was the same across all time intervals and for each group). These four models were coded by adding a *Group behind only the survival part of the model name (e.g., Survival*Time*Group) with the detection portion of the model name stating Detection*Constant.

Four more models were run in which survival was the same for the two groups over the four different survival time scenarios (i.e., Constant, Season, Year, and Season*Year) and the estimate of detection was constant across all time intervals but each group could have a different estimate of detection. These four models were named by having survival time the time interval of interest (e.g., Survival *Year) and by adding a *Group behind all of the Detection*Constant parts of the model name (i.e., Detection*Constant*Group). Seven additional models were run with group affects for estimating both survival and detection. Four of these models were run in which survival was modeled over the four time intervals and differed by group with detection being held constant across all time intervals but allowed to differ by group. Naming of these models included a *Group behind the survival portion of the name and a Constant*Group behind the detection portion of the name. Three of these models allowed both survival and detection to be modeled over a given time interval of interest (i.e., Season, Year, or Season*Year) with both survival and detection differing among the two groups. Model names included the time interval and group interaction (e.g., Season*Group) behind both the survival and detection portions of the model names.

Similar to the Grand Lake native Largemouth Bass models, 12 additional models were built for the Florida parental type and F_1 hybrid survival model set to account for the broken electrofishing boat and reduced effort and potentially lowered detection probability during the May, 2013 sampling event. These twelve models allowed survival to vary over different time scenarios (i.e., season, constant, etc.) except non-growing seasons were always held constant as with the Grand Lake native Largemouth Bass simulations. Furthermore, detection was held constant but in some models allowed for a group effect and detection during the May, 2013 sample was always different than the other detection probabilities.

For this study, we assumed the effects of tag loss and tagging mortality to be negligible given the techniques used for PIT tag implantation. Although we did not directly evaluate tag loss or tagging mortality for this study, other studies have shown PIT tag retention to be 100% out to two years for Largemouth Bass implanted with PIT tags in their peritoneal cavity (Harvey and Campbell 1989) and near 100% retention (98.9-100%) in Muskellunge (*Esox masquinongy*) that had PIT tags implanted in the dorsal musculature out to 153 or 210 days (Wagner et al. 2007). Furthermore, many studies have shown tagging mortality associated with PIT tag implantation to also be low (e.g., Dare 2003; Wagner et al. 2007). Therefore, survival rates estimated from live recaptures of PIT tagged Largemouth Bass were not adjusted for either tag loss or tagging mortality.

Known Fate Survival

Forty two Largemouth Bass had F1235 radio tags (Advanced Telemetry Systems© [ATS]) surgically implanted into their abdominal cavity beginning in May,

2013. For a complete description of the procedures used to surgically implant the radio tags and the dates tags were implanted, see Breeggemann et al. (2016). Largemouth Bass ranged in size from 446-601mm Total Length (TL) and weighed between 1345 and 4010g (see Breeggemann et al 2016). Largemouth Bass were tracked and located on a weekly basis using an R4500 Challenger Receiver (ATS) and a 3-way yagi antenna (ATS) in combination with the zero-point tracking method described by Nelson (1990) and Cooke et al. (2012). Tracking of Largemouth Bass began in June, 2013 and ended in October, 2014. Largemouth Bass were considered dead when movement ceased for at least 3 weeks or the Bass washed up on shore. Largemouth Bass that were presumed dead were continually located even after a mortality was suspected in case movement resumed.

The known fates model in Program MARK was used to estimate survival of radio tagged Largemouth Bass. The year was divided up into four different three month seasons: spring (March – May); summer (June – August); fall (September – November); and winter (December – February). Because we were not interested in weekly survival, all weekly telemetry locations within a given season were held constant and were used to estimate survival for the entire 3 month season via the derived estimates in MARK. We were able to estimate survival over six total seasons beginning in summer 2013 and ending in fall 2014. Five models were run in MARK to estimate survival of radio-tagged Bass. The first and simplest model was again the constant model (referred to as Constant in the results) where survival was constant across all six seasons. The second and most general model was the time model (referred to as Time in the results) where survival was different across all six seasons. The third model was a season model (referred to as Season) where survival differed among each of the four seasons but year did not matter.

Therefore, survival was the same in summer 2013 and summer 2014 for this model. The fourth model was used to compare survival during the growing season and non-growing season (referred to as Growing Season in the results). For this model, survival was the same across the spring, summer, and fall seasonal periods but different during the winter season. Additionally, survival was the same among years for the “Growing Season” model. The last model was similar to the fifth model (i.e., comparing survival during the growing season to the non-growing season) except survival was different among years (referred to as Growing Season*Year). Therefore, survival during the 2013 growing season (i.e., summer and fall 2013) was compare to the non-growing season and the 2014 growing season. Similar to the CJS models, model averaging was used to get the best overall estimates of seasonal survival from our candidate set of models.

Growth and Condition

Lengths and weights of recaptured PIT tagged Largemouth Bass sampled during one of the 13 sampling events were used to assess temporal trends in growth and condition of the four different origins of Largemouth Bass. Growth of the different origins was assed using changes in total length. A Largemouth Bass must have been at large for at least the majority of the growing season (i.e., four months of the months of May through October) to be included in the growth analysis. The majority of at least one growing season from the time of tagging to the time of recapture was used so as not to bias our conclusion about growth by including Largemouth Bass that were at large for periods of time but likely not growing such as winter months. For example, if a Largemouth Bass was PIT tagged in November, 2012 and recaptured in May, 2013, it was not included in the growth analysis because it was not at large for at least the majority of one growing season between the time of tagging and recapture.

Condition of the different genetic parental types was assessed using relative weights (W_r) as described by Anderson and Neumann (1996). All Largemouth Bass were included in the analysis of relative weight regardless of time at large between tagging and capture events because relative weights can change quickly over short periods throughout the entire year. Total length and condition at the time of stocking were the starting length and condition used for recaptured Largemouth Bass from one of the three stocked origins. Total length and condition of native Largemouth Bass at the first encounter event were the starting length and condition for native Bass. In the event that a stocked or native Largemouth Bass was recaptured multiple times throughout sampling, the length and condition of that fish during the latest sampling event in which it was recaptured was used and the final length and condition to assess temporal trends in growth and condition. Therefore, every single Largemouth Bass included in the analysis had only a starting and final length and condition regardless of the number of times it was recaptured.

Results

Live Recaptures Survival

Genetic analyses revealed that some of the stocked Largemouth Bass were not the genetic parental type we expected. The stocked Largemouth Bass from Alabama that we expected to be all F_1 hybrids were predominantly F_1 hybrids (35 of 51 sampled Largemouth Bass or 69%), but there were some second generation or later hybrids within these stocked Bass (i.e., F_x hybrids; 10 of 51 sampled Largemouth Bass or 20%; Figure 3.2). Six of the Largemouth Bass that we expected to be F_1 hybrids (i.e., 11%) had an uncertain genetic parental type (i.e., did not have at least 70% certainty of being a certain genetic parental type based on Breeggemann et al. [2015]; Figure 3.2). However, all six of these Largemouth Bass had a combined 99% probability of being a hybrid (i.e, F_1 or F_x hybrid; Figure 3.2), making them one of the hybrid parental types. This origin will subsequently be referred to as stocked hybrids. Unexpectedly, none of the 25 hatchery raised Largemouth Bass from Arkansas that we expected to be pure Florida parental type were pure Florida parental type. Twenty four of the 25 (96%) Largemouth Bass from this stocking had a 99% probability of being pure northern parental type and one (4%) had a 94% probability of being an F_1 hybrid (Figure 3.2). This origin will be subsequently referred to as stocked northern parental type. The only stocking event in which all of the stocked Largemouth Bass were from the genetic origin we expected was the hatchery raised adult Largemouth Bass from the state of Florida. All 43 Largemouth Bass from this stocking had an 89% or greater probability of being pure Florida parental type, with 42 of the 43 having a 96% or greater probability of being pure Florida parental type, indicating they were all pure Florida parental type (Figure 3.2). This origin will be subsequently referred to as stocked Florida parental type.

No overdispersion was found in the data from the program RELEASE goodness of fit test (Chi-square = 24.8404, df = 30) for the Grand Lake native Largemouth Bass survival models. Therefore, no adjustments were made to c-hat. The models in which capture probabilities accounted for the sampling event in which our electrofishing boat failed (i.e., gear failure) and sampling was limited were the best fitting models (Table 3.1). The best model estimated survival to be constant across all seasons (both growing seasons and non-growing seasons) and years at 82% (95% confidence interval from 65-

92%) for each 6 month season and detection was constant across seasons at 0.03 except for the sampling event with the gear failure where capture probability was $0.1x10^{-8}$. The other competing model, which held approximately W_i =32% of the AIC weight, estimated survival to be constant within seasons across years (i.e., the same in all growing seasons and the same in all non-growing seasons; Table 3.1). However, deviances were very similar between the top two models and the second model only added one parameter, thus making the second model a competing model without a much better fit. Due to the fact that the second model incorporated only one extra parameter but didn't fit better, we consider only the top (i.e., constant) model as a competing model (Burnham and Anderson 2002). Furthermore, due to low sample sizes as a result of the gear failure in our spring, 2013 sampling event, non-growing season survival was poorly estimated (i.e., had large confidence intervals) in the second competing Survival*Season model, adding more evidence for not considering this model. Estimated annual survival from the top (Constant) model were approximately 67%.

No overdispersion was found in the data from the program RELEASE goodness of fit test (Chi-square = 8.425, df = 15) for the stocked pure Florida parental type and stocked hybrid Largemouth Bass survival models. Similar to the Grand Lake native Largemouth Bass results, the models in which the detection probabilities as a result of the gear failure during the May, 2013 sampling event were the best fitting models (Table 3.2). The model with the highest weight (i.e., 0.25) estimated survival to be constant across all seasons but different for the two groups and detection to be constant across all seasons and different for each group with different detection probabilities during the May, 2013 sampling event (Table 3.2). Seasonal survival estimates from this model were higher for the stocked hybrid Largemouth Bass at approximately 92% (95% confidence interval of 30-99%) per six month season compared to the stocked Florida parental type Largemouth Bass at approximately 67% (95% confidence interval of 60-73%) per six month season. Similar to the Grand Lake native Largemouth Bass survival models, the next two competing models were both season models (i.e., survival was different among the growing season and non-growing seasons but constant with a season across years) with one of the two season incorporating a group effect (Table 3.2). Again similar to the Grand Lake native Largemouth Bass models, these models did not explain much more deviance and non-growing season survival estimates were poorly estimated due to low sample sizes from the gear failure and therefore these models were not considered (Burnham and Anderson 2002). Total annual survival rates for the pure Florida parental type Largemouth Bass were estimated to be approximately 45% whereas total annual survival rates for the stocked hybrids were estimated to be 85%.

Known Fate Survival

Four models carried the majority of the AICc weight from the known-fate simulations (Table 3.3). The model with the highest weight (i.e., 0.45) was the growing season model (Table 3.3) in which survival was the same across all three seasons that encompass the growing season (i.e., spring, summer, and fall) among both years of sampling at 91% for the season and survival was higher for the winter season at 100% (Figure 3.3). The second best model (model weight = 0.21) was a constant model in which survival was constant across all seasons and years at just under 93% per season (Table 3.3; Figure 3.3). The model with the third highest weight (i.e., 0.17) was similar to the first model in which survival was constant across all three seasons in the growing season except this model allowed for different survival rates during the 2013 and 2014 growing seasons (Table 3.3). Survival estimates from this Growing Season*Year model were 91.3% during the two seasons in the 2013 growing season, 100% during the 2013/2014 winter, and 90.7% during the three seasons in the 2014 growing season (Figure 3.3). The last model that carried any significant model weight (i.e., 0.15) was the season model in which survival was the same within seasons across years (Table 3.3). Estimates of survival from the season model were 95% for the summer, 86% for the fall, 100% for the winter, and 89% for the spring (Figure 3.3). Model averaged estimates of survival were similar during all growing season months across the study at 92.1% during summer 2013, 90.6% during fall 2013, 90.9% during spring 2014, 92% during summer 2014, and 90.4% during fall 2014 and were higher during winter 2013/2014 at 98.5% (Table 3.3). Annual survival rates from the model averaged results are estimated to be between 70-75%.

Growth and Condition

Overall, growth was slow for all four origins of Largemouth Bass with the stocked F_1 and F_x hybrids (i.e., stocked hybrids) from the hatchery in Alabama growing the fastest. All of the stocked hybrid Largemouth Bass that were at large for at least the majority of one growing season after they were stocked grew at least 34mm TL with the largest gain in length being 147mm for a hybrid Bass that was at large for just about 3 years from the time of tagging until the time of its latest recapture (Figure 3.4). The stocked northern parental type Largemouth Bass from the hatchery in Arkansas did not grow as fast as the stocked hybrids. Only three of the stocked northern parental type Largemouth Bass were recaptured at least the majority one growing season after stocking and the greatest gain in length was 53mm for a Bass that had two full growing seasons to grow (Figure 3.5). One of the stocked northern parental type Largemouth Bass had three full growing seasons to grow, yet it grew only 35mm (Figure 3.5). Sixty five of the stocked Florida parental type Largemouth Bass from Florida were at large for at least the majority of one growing season between stocking and the time of final recapture and 51% of these grew 10mm or less, despite having three growing seasons to grow in some instances (Figure 3.6). Only one of the stocked Florida parental type Largemouth Bass grew more than 100mm from the time it was stocked until the latest time it was recaptured and that individual grew 148mm over three growing seasons (Figure 3.6).

Fifty four native Grand Lake Largemouth Bass were at large for at least four months of one growing season (i.e., the majority of one growing season) in between the time of initial tagging and final recapture. Twenty nine (54%) of these native Grand Lake Largemouth Bass grew 10mm or less despite having at least the majority of one growing season to grow (Figure 3.7). None of the native Grand Lake Largemouth Bass grew 100mm between the times of initial tagging and recapture with the largest length gain being 81mm for a Bass that had two growing seasons to grow (Figure 3.7). Additionally, only 18 Grand Lake native Largemouth Bass grew more than 25mm and 16 of these 18 largest gains in total length were from Bass whose initial total length at the time of tagging was between 260 and 381mm (Figure 3.7). Similarly, some of the Grand Lake native Largemouth Bass were at large for three growing seasons from the time of initial tagging until their final recapture, yet they grew very little (Figure 3.7). For example, a Grand Lake native Largemouth Bass was PIT tagged on 5/19/2012 when it was 386mm TL and it was recaptured on 10/30/2014 when it was 394mm TL. This Largemouth Bass grew only 8mm TL in three growing seasons, despite being a length that should be growing at some of the fastest rates of its life.

The stocked hybrid Largemouth Bass from the hatchery in Alabama were all in good condition at the time of stocking with all 14 Bass having relative weights ≥100 at the time of stocking (Figure 3.8). Despite the fact that nine of the 14 Largemouth Bass' relative weights decreased between the time of stocking and their final recapture, the stocked hybrid Largemouth Bass performed the best of any of the fours parental types with 10 of the 14 Bass still having relative weights above 100 at the time they were recaptured (Figure 3.8). Additionally, only two of these stocked hybrids had relative weights below 90 when they were recaptured (Figure 3.8). The condition of the stocked northern parental type Largemouth Bass from the hatchery in Arkansas at the time of stocking was not as good as the stocked hybrids with the stocked northern parental type Bass having relative weights between 85 and 96 (Figure 3.9). The three stocked northern parental type Largemouth Bass whose final recapture came within a year after stocking (i.e., 2012 sampling) all showed decreases in relative weights into the 70s or 80s (Figure 3.9). However, the two stocked northern parental type Bass that whose final capture came in 2013 or 2014 showed increases in condition and had relative weights in the 90s (Figure 3.9).

The stocked Florida parental type Largemouth Bass from a hatchery in Florida were also in very good condition at the time of stocking with 94% having relative weights above 90 and 67% having relative weights above 100 (Figure 3.10). No stocked Florida parental type Largemouth Bass from Florida had a relative weight below 84 at the time of stocking (Figure 3.10). However, the stocked Florida parental type Largemouth

Bass showed a dramatic decline in relative weights during the year after stocking (Figure 3.10). All but three of the 60 stocked Florida parental type Largemouth Bass whose final recapture date occurred within a year after stocking (i.e., 2012) dropped in relative weights with some showing decreases in relative weights by as much as 45 and some relative weights dropping into the 60s (Figure 3.10). Additionally, only 6 of the 60 stocked Florida parental type Largemouth Bass whose final recapture date occurred in 2012 had relative weights above 100 at the time of recapture (Figure 3.10). Stocked Florida parental type Largemouth Bass from Florida whose final recapture came in 2013 or 2014 had more variable relative weights but showed a progressive recovery (Figure 3.10). Only eight of the 51 (16%) stocked Florida parental type Largemouth Bass whose finale recapture came in 2013 or 2014 had relative weights between 70 and 80 (none had relative weights below 70) while 12 of the 51 (24%) had relative weights above 100 (Figure 3.10).

Relative weights of native Grand Lake Largemouth Bass were variable throughout the entirety of the study and variable within individual sampling events with some Bass having relative weights above 100 with others having relative weights in the 70s for the same sampling event (Figure 3.11). Additionally, some native Grand Lake Largemouth Bass showed dramatic increases in relative weights from their tagging condition to their final recapture condition with one Bass having an initial tagging condition of 80 and a final recapture condition of 118 (Figure 3.11). Other native Grand Lake Largemouth Bass showed dramatic declines in condition with one Bass having a starting condition of 87 and a final recapture condition of 60 (Figure 3.11). Overall, native Grand Lake Largemouth Bass condition was below average throughout the entirety of the study with the population having a mean relative weight of 87 at the time of initial tagging and the population having a mean relative weight of 86 at the time all Largemouth Bass were recaptured (Figure 3.11).

Discussion

Predicted survival rates varied among the genetic origins with the stocked Florida parental type Largemouth Bass having the lowest predicted survival rates, followed by the Grand Lake native and radio tagged Bass, and the stocked hybrids having the highest predicted survival. Annual survival rates for native Largemouth Bass (i.e., both native PIT tagged and radio tagged Bass from the survival analyses) were higher than many other Largemouth Bass fisheries. For example, Allen et al. (1998) complied annual mortality rates for 34 Largemouth Bass populations throughout the United States and found that most populations had annual mortality rates >50% and some as high as 80%. However, it should be noted that all of the populations present in Allen et al. (1998) had exploitation and Grand Lake does not. Many of the Largemouth Bass populations presented by Allen et al. (1998) had natural mortality rates of approximately 30% which is what was observed in this study. Allen et al. (2002) compiled annual mortality rates for 45 Largemouth Bass populations in Florida and found that the average annual mortality rate for these populations was 51% and that 70% of these populations had mortality rates between 40-60%. Survival rates from Grand Lake were again higher than for most of the populations in Florida (Allen et al. 2002). Furthermore, Crawford et al. (2002) predicted annual mortality rates to be from 27-41% in order to have a trophy Largemouth Bass fishery in Florida. Survival rates of Grand Lake Largemouth Bass fall right within the range presented by Crawford et al. (2002) indicating Largemouth Bass should live long enough to reach trophy size in Grand Lake.

Unfortunately, we were not able to assess seasonal trends in survival using our PIT tagged data, but known fate models did suggest seasonal trends in survival of Largemouth Bass in Grand Lake with Largemouth Bass having higher survival during winter than the rest of the year. Our most plausible explanation for this is high water temperatures during the summer and associated metabolic stress associated with these. Optimal water temperatures for Largemouth Bass are 26-28°C (Coutant & Cox 1976) and summer water temperatures in Texas may exceed these optimal temperatures, especially during late afternoons at the hottest point of the day. Temperatures above a Largemouth Bass' thermal optima may increase metabolic demands of the fish and the stress associated with that fish and may even force that individual to seek out more optimal water temperatures. Although movement of Largemouth Bass in response to sub-optimal water temperatures has not yet been evaluated in Largemouth Bass, it has been observed in Smallmouth Bass (*Micropterus dolomieu*), a very closely related speices (Schreer and Cooke 2002).

Overall, the stocked, feed-trained hybrid Tiger Bass had higher estimated survival, grew more, and maintained higher relative weights that any other genetic group within the population. One potential reason for the higher survival, faster growth, and higher condition of these hybrids is readily available food throughout the entire growing season. Grand Lake has 11 commercial fish feeders stationed on shore around the lake as well as two floating feeders which are all programmed to dispense commercial feed three times a day throughout the growing season, thus providing a continuous feed source for these fish. Furthermore, diet analyses revealed that pellets were observed in Largemouth Bass diets in Grand Lake as late as the 2014 growing season indicating continued use of pelleted food by these feed-trained stocked hybrid Largemouth Bass years after stocking (Chapter 4). Other researchers have shown that Largemouth Bass respond behaviorally to the availability of food which can thus translate to growth. For example, Savitz et al. (1983) found that Largemouth Bass released at control feeders that released 10 Fathead Minnows (*Pimephales promelas*) per hour had significantly smaller home ranges than Largemouth Bass released at control feeders. Having a readily available high energy food source combined with reduced energy expenditures to acquire food (Savitz et al. 1983) could maximize growth and survival of Largemouth Bass.

A second possible explanation for the faster growth of the stocked feed-trained hybrid Largemouth Bass is hybrid vigor or heterosis in which first generation hybrids may be more aggressive than their pure parental type counterparts at feeding or other behaviors, have faster growth, be more resistance to disease, have higher survival, or express another enhanced trait that increases growth and survival (Shull 1948). Although our genetic analyses revealed that not all of the individuals from this stocking were F1 hybrids, >70% were so the vast majority could express hybrid vigor. Hybrid vigor has been shown to occur in many fish species throughout the world including sunfishes (Krumholz 1950; Hubbs 1955), trout and salmonids (Ayles and Baker 1983; Einum and Fleming 1997), hybrid striped bass (Kirby et al. 1987), and catfish (Rahman et al. 1995). The feed trained hybrid Largemouth Bass were all bred with the female having pure Florida parental type genetics and the male having pure northern parental type genetics (i.e., a Tiger Bass) to maximize growth and the expression of hybrid vigor as pure Florida parental type Largemouth Bass have been shown to grow faster and attain larger size than the pure northern parental type counter parts (Rieger and Summerfelt 1976; Inman et al. 1977; Maceina et al. 1988). Perhaps the combination of hybrid vigor as well as being feed trained and having feed pellets readily available led to the faster growth and higher relative weights observed in the feed trained hybrid Largemouth Bass in Grand Lake. Future research using feed trained hybrid Largemouth Bass and Largemouth Bass that only eat natural prey in a common garden design could disentangle the mechanism of faster growth observed in this study.

Aside from the feed trained hybrid Largemouth Bass stocked into Grand Lake, the other three genetic origins (i.e., stocked northern parental type, stocked Florida parental type, and Grand Lake native Largemouth Bass) had slow growth except for some of the small Largemouth Bass <300mm TL. Growth rates for these three genetic origins were similar to Largemouth Bass growth rates in Grand Lake prior to the major stocking event (Chapter 2). As mentioned earlier, several researchers have shown that Florida parental type and hybrid Largemouth Bass can grow faster and maintain better condition than northern parental type Largemouth Bass (Rieger and Summerfelt 1976; Inman et al. 1977; Maceina et al. 1988). Furthermore, the Grand Lake native Largemouth Bass population was comprised primarily of a mix of pure Florida parental type Largemouth Bass and hybrids (Chapter 2). Therefore on a genetic basis alone, we would have predicted faster growth among the stocked pure Florida parental type Largemouth Bass as well as the Grand Lake native Largemouth Bass. This provides evidence that simply stocking Florida genetics into a water body does not guarantee fast growth rates if some other factor is limiting growth.

One factor that could be potentially limiting growth of Largemouth Bass in Grand Lake is food resources. Largemouth Bass are considered piscivorous and several studies have shown that age-0 Largemouth Bass grow significantly faster on diets comprised primarily of fish prey compared to other types of prey (Shelton et al. 1979; Timmons et al. 1980; Gutreuter and Anderson 1985; Adams and DeAngelis 1987; Bettoli et al. 1992). Furthermore, other piscivorous fish species such as the Walleye (*Sander viterus*) grow faster on diets composed primarily of fish compared to those in invertebrates (Ward et al. 2007; Graeb et al. 2008). Diets collected from Grand Lake Largemouth Bass over three years showed that early in the spring (i.e., May) Largemouth Bass often consumed a considerable amount of crayfish (family Cambaridae) and that other invertebrates are found at least in small quantities in Largemouth Bass diets throughout the year (Chapter 4). Additionally, Largemouth Bass did shift over to feeding on primarily fish by mid-summer and maintained that feeding strategy for the rest of the growing season (Chapter 4). However, bioenergetics simulations assessing growth potential of Largemouth Bass in Grand Lake on a diet consisting of 100% shad (i.e., *Dorosoma spp*.) throughout the entire growing season revealed that there is room for improvement in Largemouth Bass growth if they consumed even more fish. Stocking a more cool water tolerant species such as Rainbow Trout (*Oncorhynchus mykiss*) could give Largemouth Bass a high energy prey source early in the spring until the age-0 shad and sunfish become desirable prey sizes.

A second factor that could be limiting the growth potential of Largemouth Bass in Grand Lake is habitat as Largemouth Bass are considered a species that closely associates with structure and cover. For example, Wiley et al. (1984) found that intermediate densities of vegetation maximized Largemouth Bass production in small Illinois ponds.

In another study, Sass et al. (2006) found that Largemouth Bass in a lake in northern WI in which 75% of the coarse woody debris had been removed consumed less fish and grew more slowly than fish in a reference basin. Additionally, Ahrenstorff et al. (2009) found that Largemouth Bass in northern WI lakes with lower densities of coarse woody debris had larger home ranges and consumed less prey than Bass in lakes with more woody debris. Ahrensorff et al. (2009) hypothesized that when habitat (i.e., woody debris) was reduced, Largemouth Bass spent extra time and expended additional energy searching for prey and thus growth slowed as a result. Grand Lake was built in the 1950s and is considered an aging reservoir in which habitat quality and quantity has declined. Furthermore, Grass Carp have been stocked into Grand Lake removing all submersed aquatic vegetation. Radio telemetry of Largemouth Bass in Grand Lake has shown that some Largemouth Bass have large seasonal use areas as well as travel over 1,000 meters in a 24hours period (Chapter 5). Thus a lack of habitat could be forcing Largemouth Bass to move extensive distances to capture food, etc., similar to the results of Ahrenstorff et al. (2009).

At the time of stocking, the pure Florida parental type Largemouth Bass were all in very good condition (i.e., relative weights >90) and we expected this genetic origin to perform much better than the native Largemouth Bass in Grand Lake. However, within months after stocking, their relative weights declined dramatically down to the 70s and 80s and subsequent recaptures throughout the following years showed that some relative weights for this origin remained poor while a few recovered. Furthermore, estimated survival rates for the stocked pure Florida parental type Largemouth Bass were lower than for any other genetic origin and growth rates for most of the individuals recaptured were poor. All of these factors provide evidence for the potential for outbreeding depression or the loss of fitness due to the breakup of coadapted gene complexes (i.e., favorable allele combinations) following the stocking of this genetic origin (Hallerman 2003). Outbreeding depression has been shown in other Largemouth Bass populations following the introduction of new genetics. For example, pure Florida parental type Largemouth Bass and hybrids between northern parental type and Florida parental type Bass were shown to have lower growth and survival than pure northern parental type Largemouth Bass in Illinois (Phillipp 1991; Phillipp and Whitt 1991). Furthermore, Phillipp and Clausen (1995) showed that outbreeding depression can occur by moving the same parental type of Largemouth Bass from different water bodies within the same state. Although there is some evidence for the potential for outbreeding depression, growth rates and condition of pure Florida parental type Largemouth Bass in the years 2013 and 2014 were similar to Grand Lake native Largemouth Bass and therefore they may not reduce growth or condition of the population going forward. However, we did not observe the enhanced growth that we expected from the stocked pure Florida parental type Bass and the true effect of stocking may not be seen until these stoked fish have had a couple of years to spawn and introduce their genetics into the population.

Management Implications

Survival rates of the native Largemouth Bass population in Grand Lake are high enough to allow Largemouth Bass to reach ages in which they can reach their full growth potential and create a trophy fishery. During a population assessment in December, 2011, otoltihs were collected from 75 Largemouth Bass from Grand Lake and nearly 10% (i.e., seven Largemouth Bass) of the Bass sampled were estimated to be age-9 or age-10 from sectioned otoliths (Chapter 2). Thus, management does not need to be tailored to enhance survival. The genetic origin that performed the best (i.e., highest survival rates, fastest growth, and highest relative weights) were the feed trained hybrid Largemouth Bass stocked into Grand Lake. However, to maintain feed trained hybrids in the population, they may have to be repeatedly stocked every couple of years. Subsequent generations will not be feed trained and therefore offspring from the hybrids may not grow as quickly. Furthermore, offspring from the hybrids will be second generation hybrids and second generation and later hybrids may not show the same hybrid vigor as first generation hybrids (Emlen 1991; Hallerman 2003; McGinnity et al. 2003). The stocked pure Florida parental type Largemouth Bass from Florida did not perform as well as we had expected. It is unknown if stocking these fish will result in outbreeding depression as growth for the native population was slow as well. Stocking a few individuals into a smaller pond with similar conditions to the Lake in which you want to do a major stocking and subsequently monitoring their performance in this small pond may provide insight into whether a major stocking event into a larger system using those genetics is appropriate. Simply managing for genetics does not guarantee that you can create a trophy Largemouth Bass fishery. All other factors that affect growth such as diet and habitat must be optimal in order for Largemouth Bass to reach their full growth potential.

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TABLE 3.1. AIC rankings among competing Cormack Jolly Seber models to estimate seasonal survival of Grand Lake native Largemouth Bass sampled between May, 2012 and October, 2014.

Model	AICc	Delta AICc	AICc Weight	Model Likelihood	Parameters	Deviance
Survival*Constant + Detection*Constant Except Gear Failure	943.55	0.00	0.538	1.00	3	162.93
Survival*Season + Detection*Constant Except Gear Failure	944.61	1.06	0.317	0.59	4	161.97
Survival*Non-growing*Constant*Growing*Year + Detection*Constant Except Gear Failure	948.27	4.72	0.051	0.09	6	161.57
Survival*Season + Detection*Season*Year	948.71	5.16	0.041	0.08	7	159.97
Survival*Non-growing*Constant*Growing*Year + Detection*Season*Year	950.44	6.89	0.017	0.03	9	157.61
Constant	950.94	7.38	0.013	0.02	2	172.33
Season*Year	952.02	8.46	0.008	0.01	10	157.14
Survival*Year + Detection*Constant	952.63	9.08	0.006	0.01	4	169.99
Survival*Season + Detection*Constant	952.77	9.22	0.005	0.01	3	172.15
Season	954.68	11.12	0.002	0.00	4	172.03
Year	956.32	12.77	0.001	0.00	6	169.62
Survival*Season*Year + Detection*Constant	956.63	13.08	0.001	0.00	6	169.93

TABLE 3.2. AIC rankings for different Cormack Jolly Seber models to estimate seasonal survival of stocked Pure Florida parental type and hybrid Largemouth Bass sampled from Grand Lake, TX between May, 2012 and October, 2014.

Model	AICc	Delta AICc	AICc Weight	Model Likelihood	Parameters	Deviance
Survival*Constant*Group+Detection*Constant*Group Except Gear Failure	1388.32	0.00	0.25	1.00	6	154.02
Survival*Season*Group+Detection*Constant*Group Except Gear Failure	1388.76	0.44	0.20	0.80	8	150.38
Survival*Season+Detection*Constant*Group Except Gear Failure	1389.07	0.75	0.17	0.69	6	154.77
Survival*Season+Detection*Constant Except Gear Failure	1390.44	2.12	0.09	0.35	4	160.19
Survival*Constant+Detection*Constant Except Gear Failure	1390.88	2.55	0.07	0.28	3	162.65
Survival*Constant+Detection*Constant*Group Except Gear Failure	1391.32	3.00	0.06	0.22	5	159.05
Survival*Non-growing*Constant*Growing*Year+ Detection*Constant*Group Except Gear Failure	1391.37	3.05	0.06	0.22	8	152.99
Survival*Non-growing*Constant*Growing*Year+ Detection*Constant Except Gear Failure	1392.64	4.31	0.03	0.12	6	158.33
Survival*Constant*Group+Detection*Constant Except Gear Failure	1392.76	4.44	0.03	0.11	4	162.52
Survival*Season*Group+Detection*Constant Except Gear Failure	1393.22	4.90	0.02	0.09	6	158.92
Survival*Non-growing*Constant*Growing*Year*Group+ Detection*Constant*Group Except Gear Failure	1394.52	6.20	0.01	0.05	12	147.92
Survival*Non-growing*Constant*Growing*Year*Group+ Detection*Constant Except Gear Failure	1397.32	9.00	0.00	0.01	10	154.84
Season*Year	1398.80	10.48	0.00	0.01	12	152.20
Survival*Constant*Group+Detection*Constant*Group	1400.40	12.07	0.00	0.00	4	170.15
Survival*Year*Group+Detection*Constant	1402.27	13.95	0.00	0.00	7	165.93

TABLE 3.2 CONTINUED. AIC rankings for different Cormack Jolly Seber models to estimate seasonal survival of stocked Pure Florida parental type and hybrid Largemouth Bass sampled from Grand Lake, TX between May, 2012 and October, 2014.

Model	**AICc**	**Delta AICc**	**AICc Weight**	**Model Likelihood**	**Parameters**	**Deviance**
Year	1402.84	14.52	0.00	0.00	6	168.54
Survival*Year*Group+Detection*Constant*Group	1403.04	14.72	0.00	0.00	8	164.66
Survival*Year+Detection*Constant	1403.04	14.72	0.00	0.00	4	172.80
Survival*Season*Year+Detection*Constant*Group	1403.15	14.83	0.00	0.00	8	164.77
Constant	1403.33	15.01	0.00	0.00	2	177.12
Survival*Season*Group+Detection*Constant*Group	1403.54	15.22	0.00	0.00	6	169.24
Survival*Year+Detection*Constant*Group	1403.60	15.28	0.00	0.00	5	171.33
Survival*Constant+Detection*Constant*Group	1403.61	15.28	0.00	0.00	3	175.38
Survival*Season+Detection*Constant*Group	1404.37	16.05	0.00	0.00	4	174.13
Survival*Season+Detection*Constant	1404.86	16.54	0.00	0.00	3	176.64
Survival*Season*Year+Detection*Constant	1405.03	16.71	0.00	0.00	7	168.69
Survival*Constant*Group+Detection*Constant	1405.20	16.88	0.00	0.00	3	176.98
Survival*Year*Group+Detection*Year*Group	1405.47	17.15	0.00	0.00	12	158.86
Season	1406.64	18.31	0.00	0.00	4	176.39
Survival*Season*Group+Detection*Season*Group	1406.91	18.59	0.00	0.00	8	168.53
Survival*Season*Year*Group+Detection*Constant	1407.42	19.10	0.00	0.00	13	158.75
Survival*Season*Group+Detection*Constant	1407.82	19.50	0.00	0.00	5	175.55
Survival*Season*Year*Group+Detection*Constant*Group	1408.67	20.35	0.00	0.00	14	157.92
Survival*Season*Year*Group+Detection*Seasoon*Year*Group	1410.23	21.91	0.00	0.00	24	138.41

TABLE 3.3. AIC rankings for different known fate models to estimate seasonal survival of radio tagged Largemouth Bass in Grand Lake, TX from summer, 2013 through fall, 2014.

Model	AICc	Delta AICc	AICc Weight	Model Likelihood	Parameters	Deviance
Growing Season	98.71	0.00	0.45	1.00	2	31.65
Constant	100.27	1.56	0.21	0.46	1	35.21
Growing Season*Year	100.71	2.00	0.17	0.37	3	31.64
Season	100.95	2.24	0.15	0.33	4	29.86
Time	104.64	5.92	0.02	0.05	6	29.52

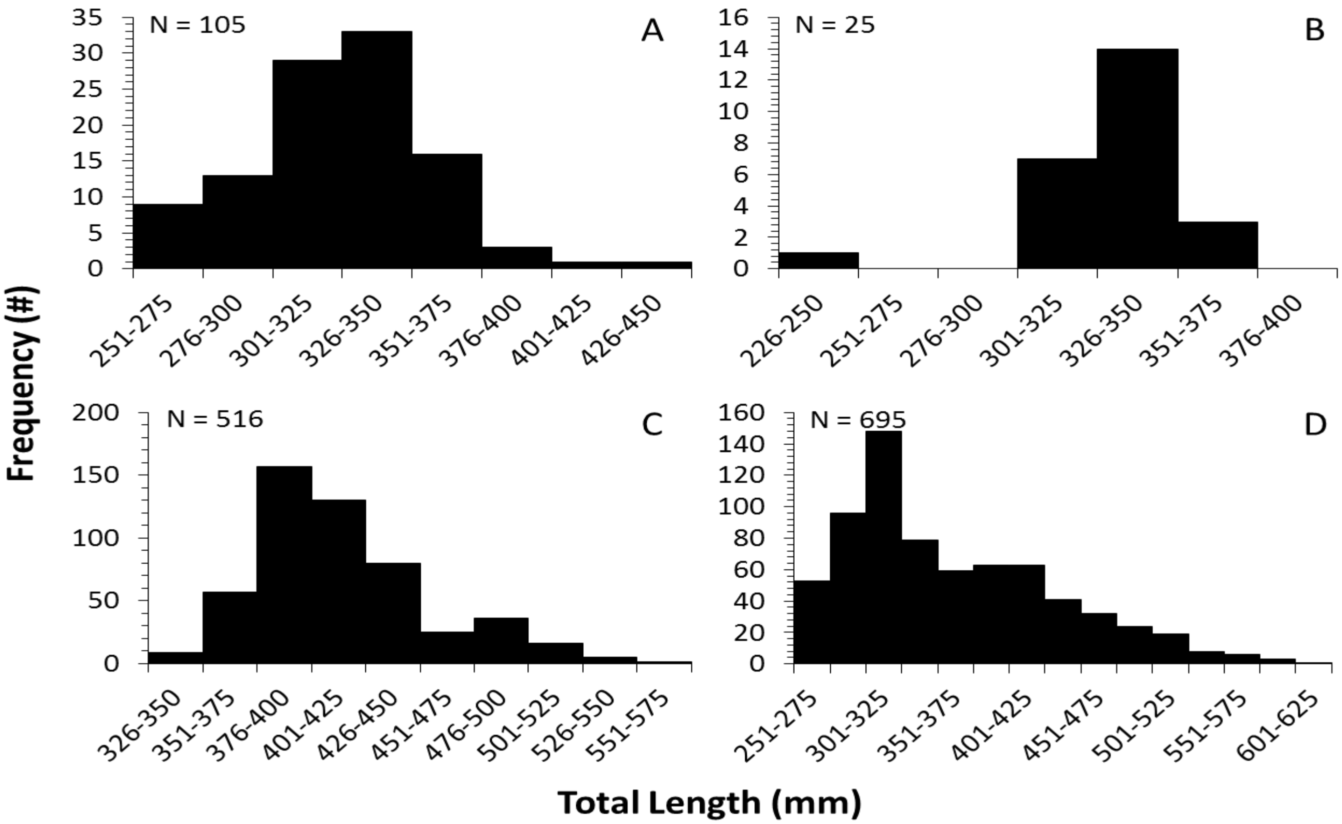

FIGURE 3.1. Length frequency histograms for PIT tagged Largemouth Bass of four different origins. One of the origins was hatchery raised F_1 and Fx hybrids stocked into Grand Lake in December, 2011 (A), one of the origins was hatchery raised pure northern parental type Largemouth Bass with one F_1 hybrid stocked into Grand Lake in December, 2011 (B), and one of the origins was pure Florida parental type wild caught Largemouth Bass from the state of Florida stocked into Grand Lake in February and March, 2012 (C). The last origin was native caught Largemouth Bass from Grand Lake which were sampled from May, 2012 – September, 2014 (D).

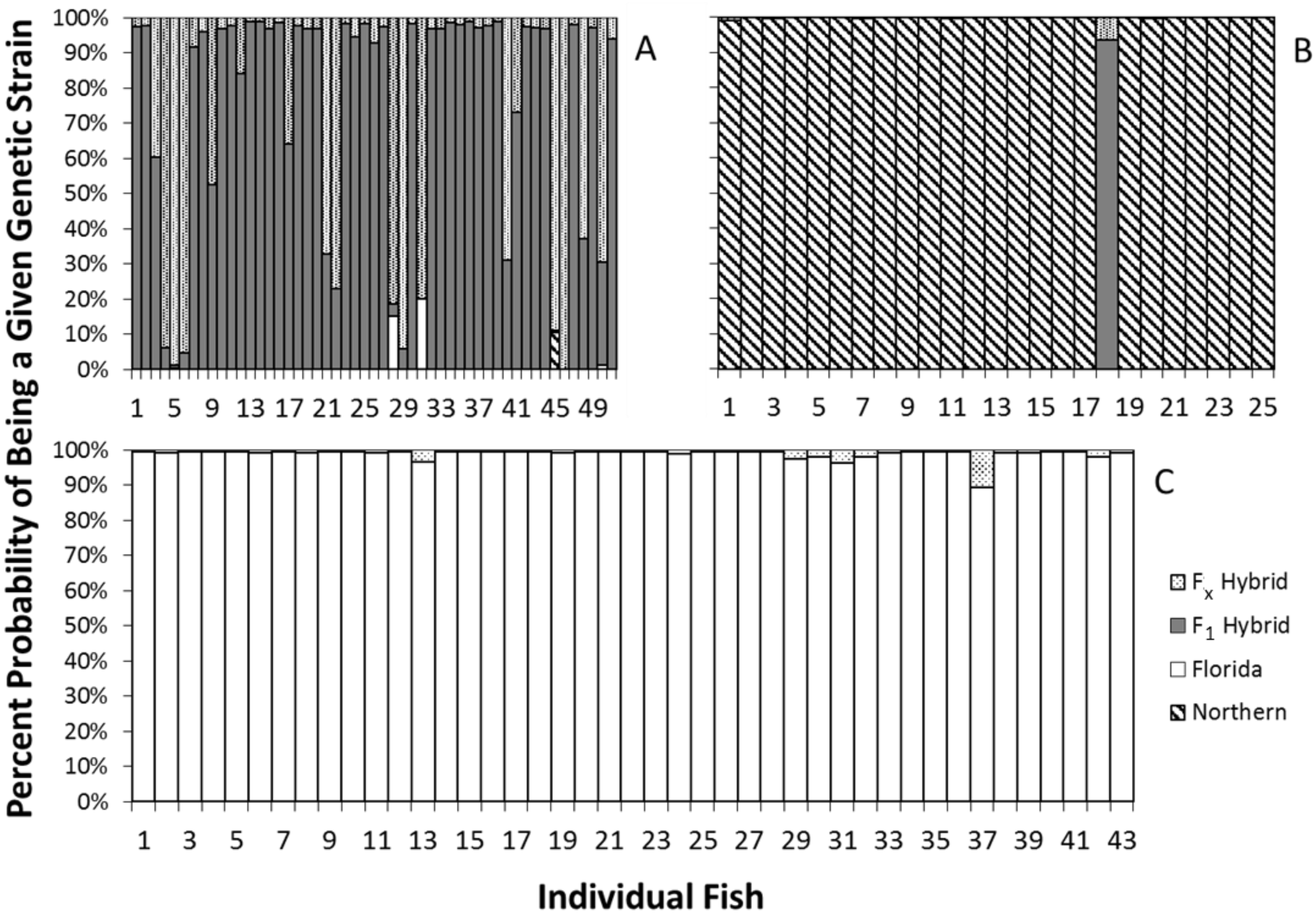

FIGURE 3.2. Percent probability of an individual Largemouth Bass from three different source populations stocked into Grand Lake, Texas being pure northern parental type (Northern), pure Florida parental type (Florida), an F_1 hybrid (F_1 Hybrid), or an F_x hybrid (F_x Hybrid). Source populations were expected to be hatchery raised F_1 Tiger Largemouth Bass (A), hatchery raised pure Florida parental type Largemouth Bass (B), and wild caught Florida parental type Largemouth Bass from the state of Florida (C).

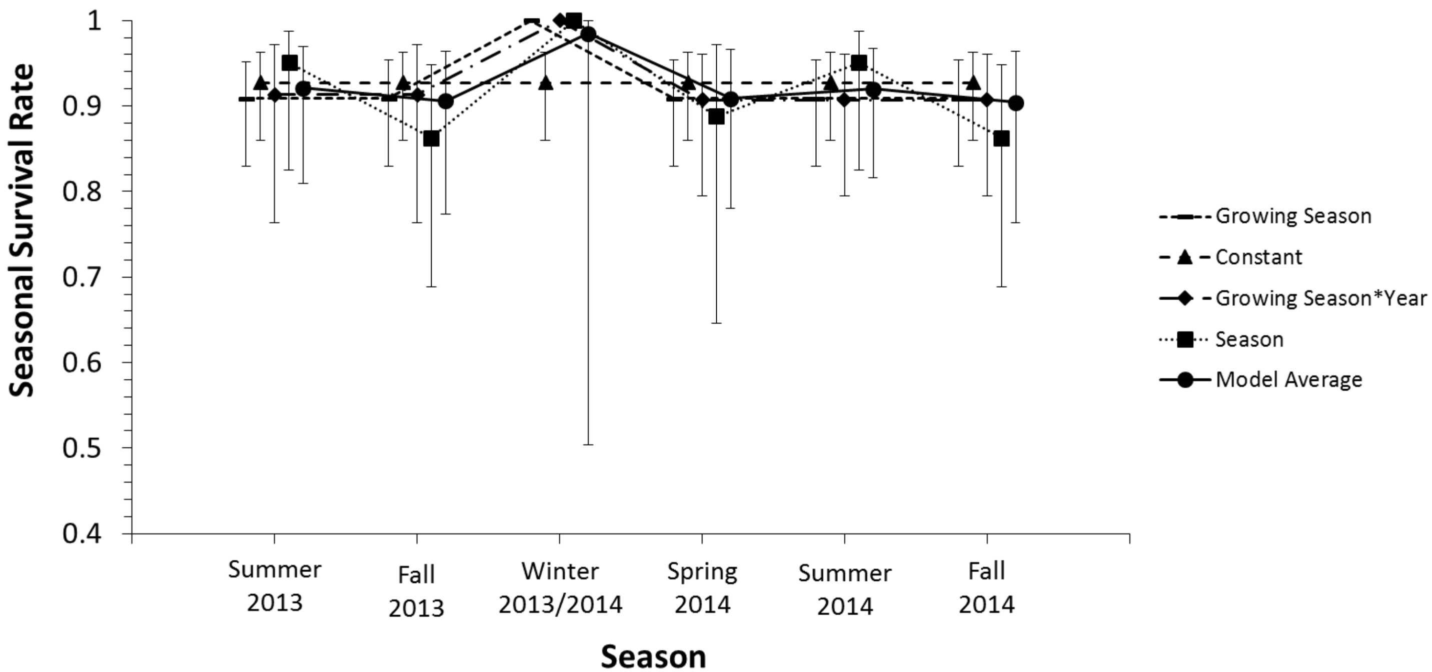

FIGURE 3.3. Seasonal (3 month) survival of Grand Lake radio tagged Largemouth Bass sampled from June, 2013 through the end of October, 2014. Error bars represent 95% confidence intervals.

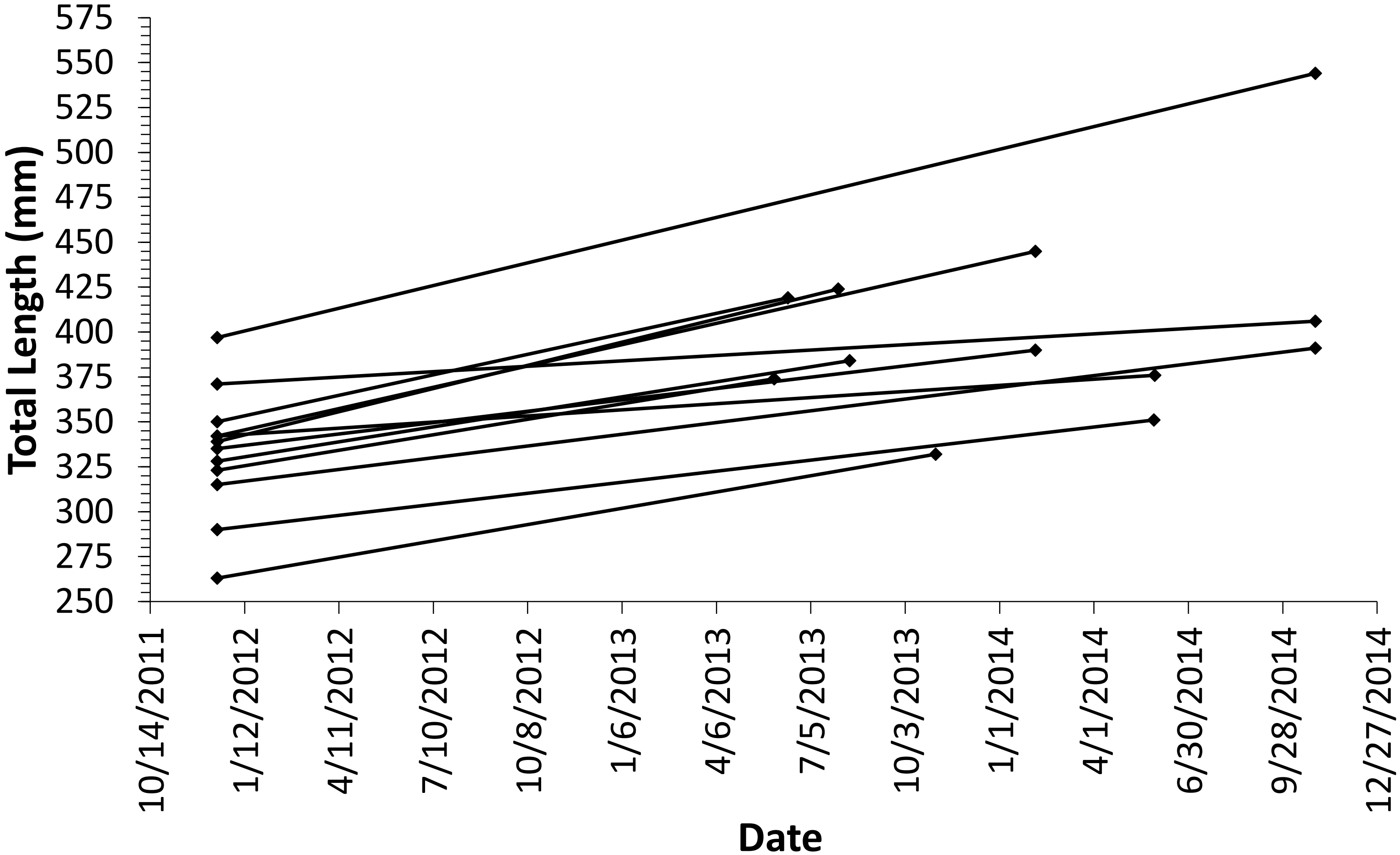

FIGURE 3.4. Growth (changes in total length) of hybrid Largemouth Bass that were stocked in December, 2011 and were recaptured between May, 2012 and October, 2014 from Grand Lake, TX.

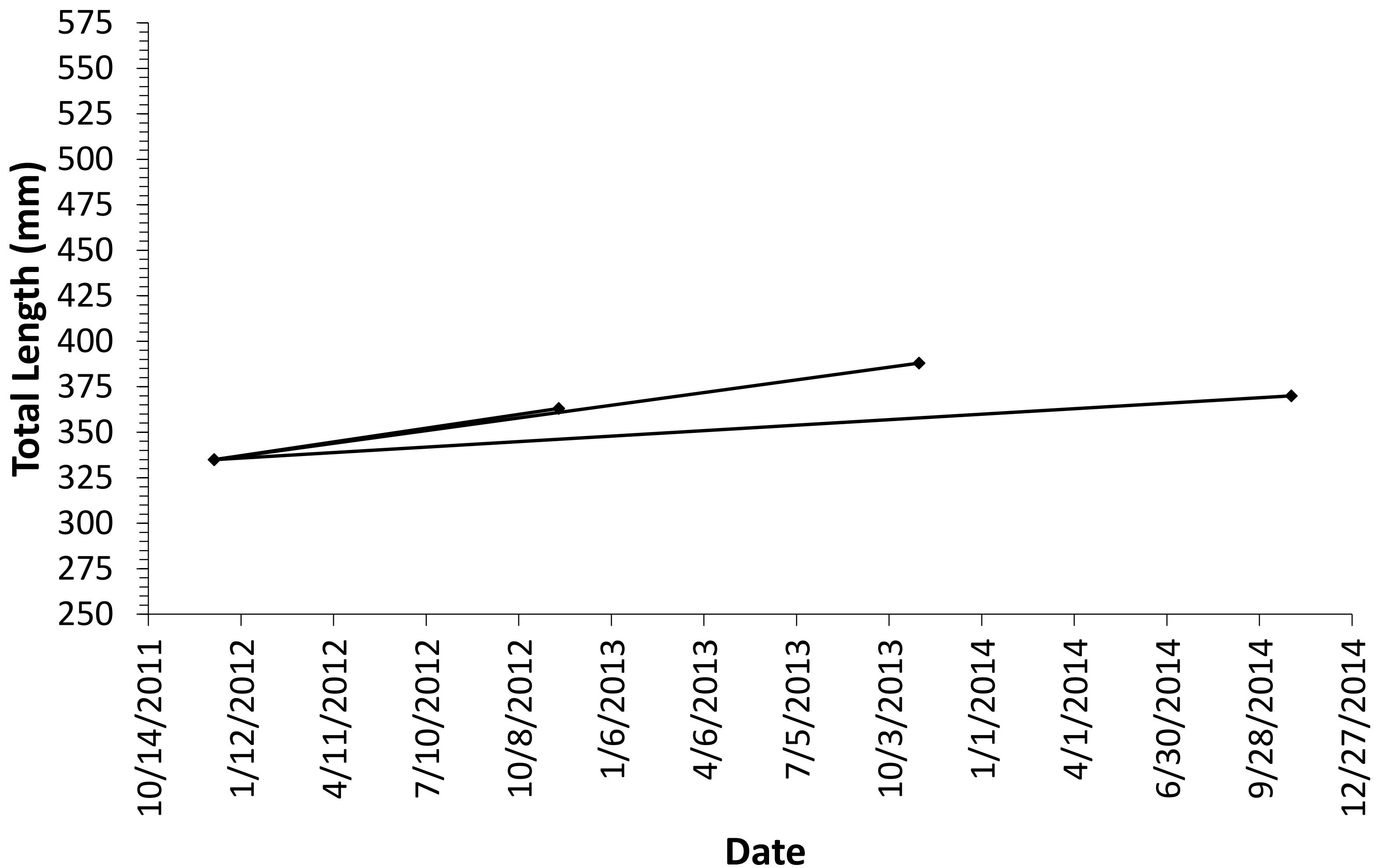

FIGURE 3.5. Growth (changes in total length) of northern parental type Largemouth Bass that were stocked in December, 2011 and were recaptured between May, 2012 and October, 2014 from Grand Lake, TX.

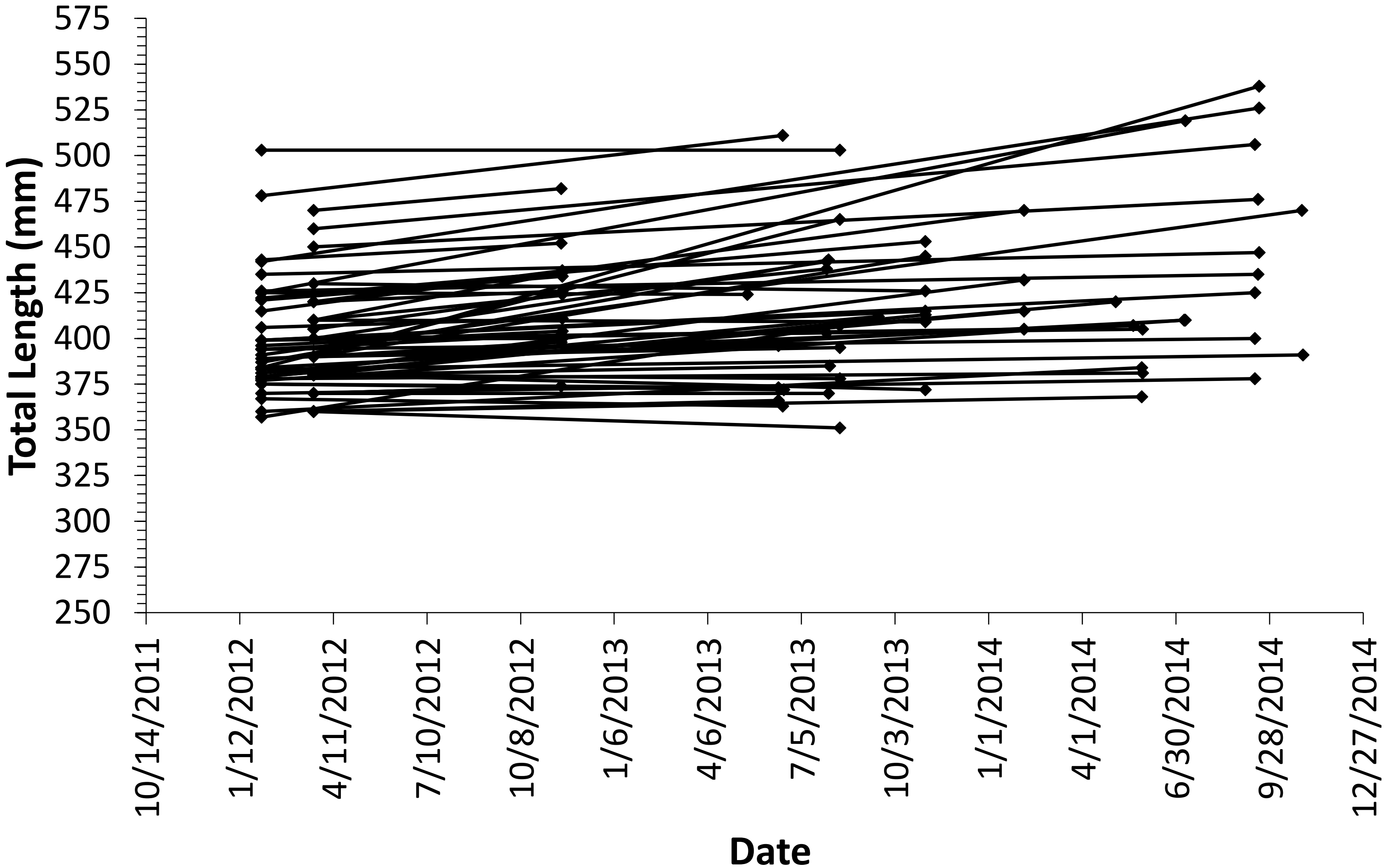

FIGURE 3.6. Growth (changes in total length) of Florida Largemouth Bass that were stocked in February and March, 2012 and were recaptured between May, 2012 and October, 2014 from Grand Lake, TX.

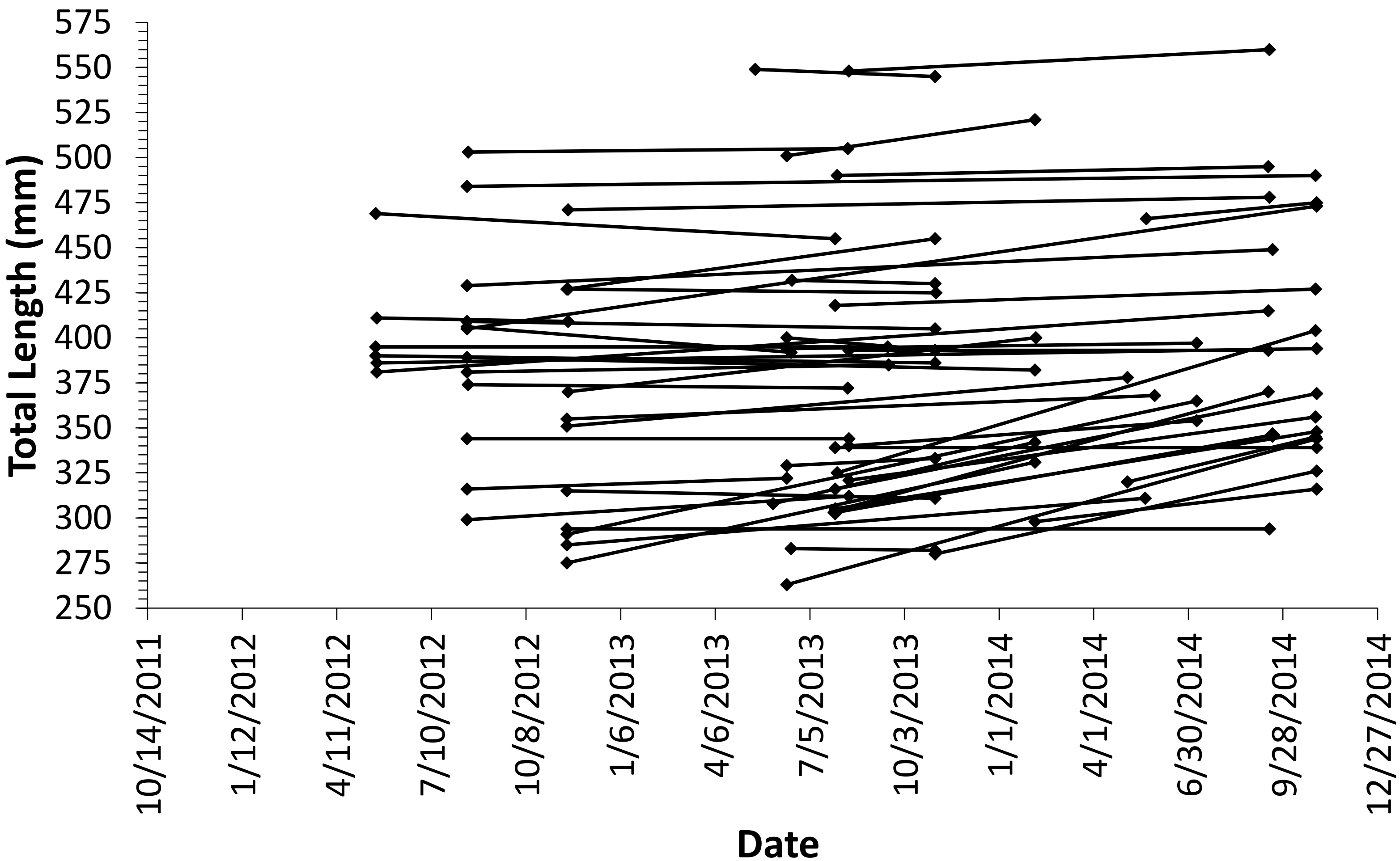

FIGURE 3.7. Growth (changes in total length) of native Largemouth Bass that were captured between May, 2012 and September 2014 and recaptured between June, 2012 and October, 2014 from Grand Lake, TX.

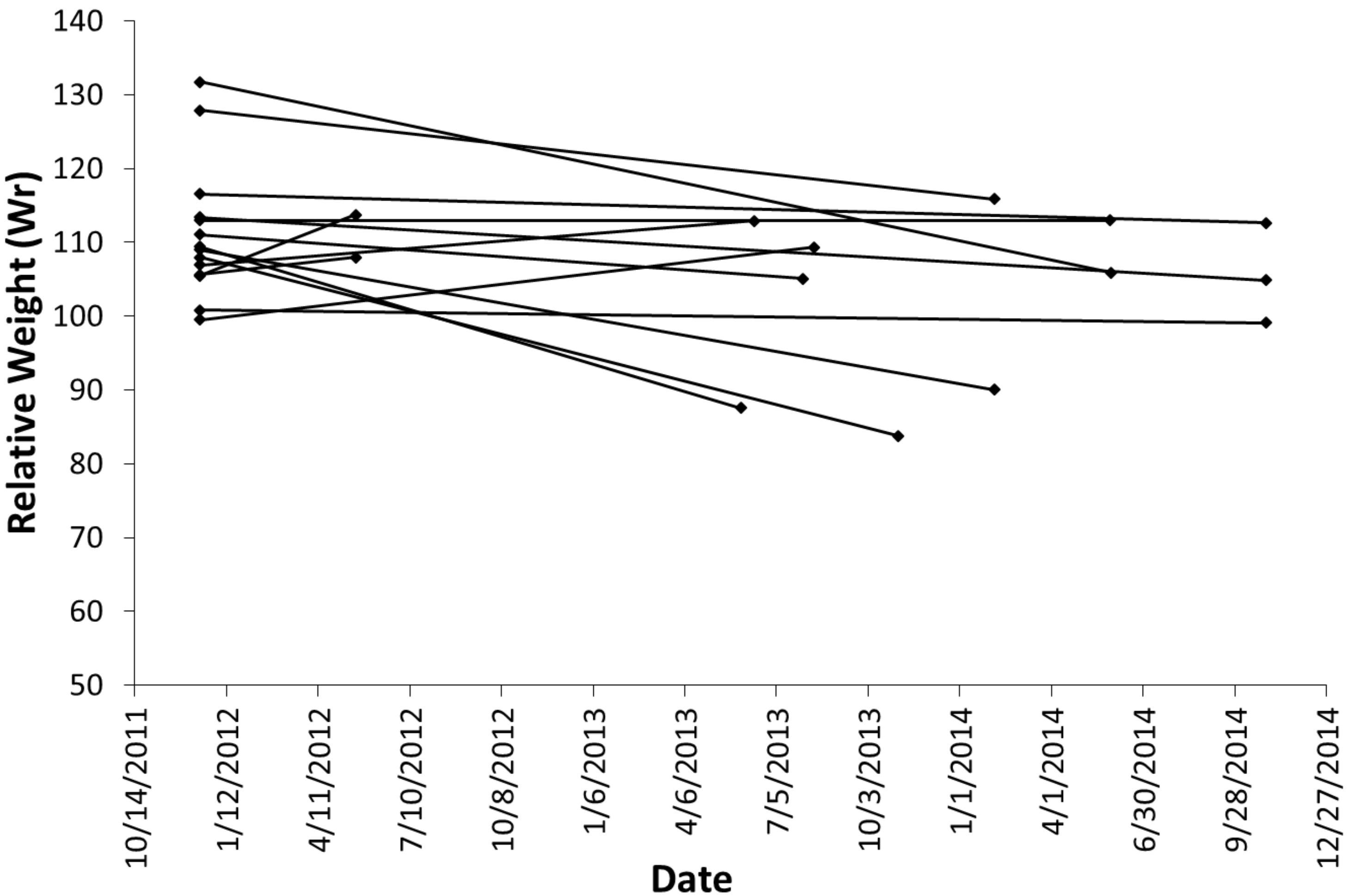

FIGURE 3.8. Changes in condition (relative weight [W_r]) of hybrid Largemouth Bass that were stocked in December, 2011 and were recaptured between May, 2012 and October, 2014 from Grand Lake, TX.

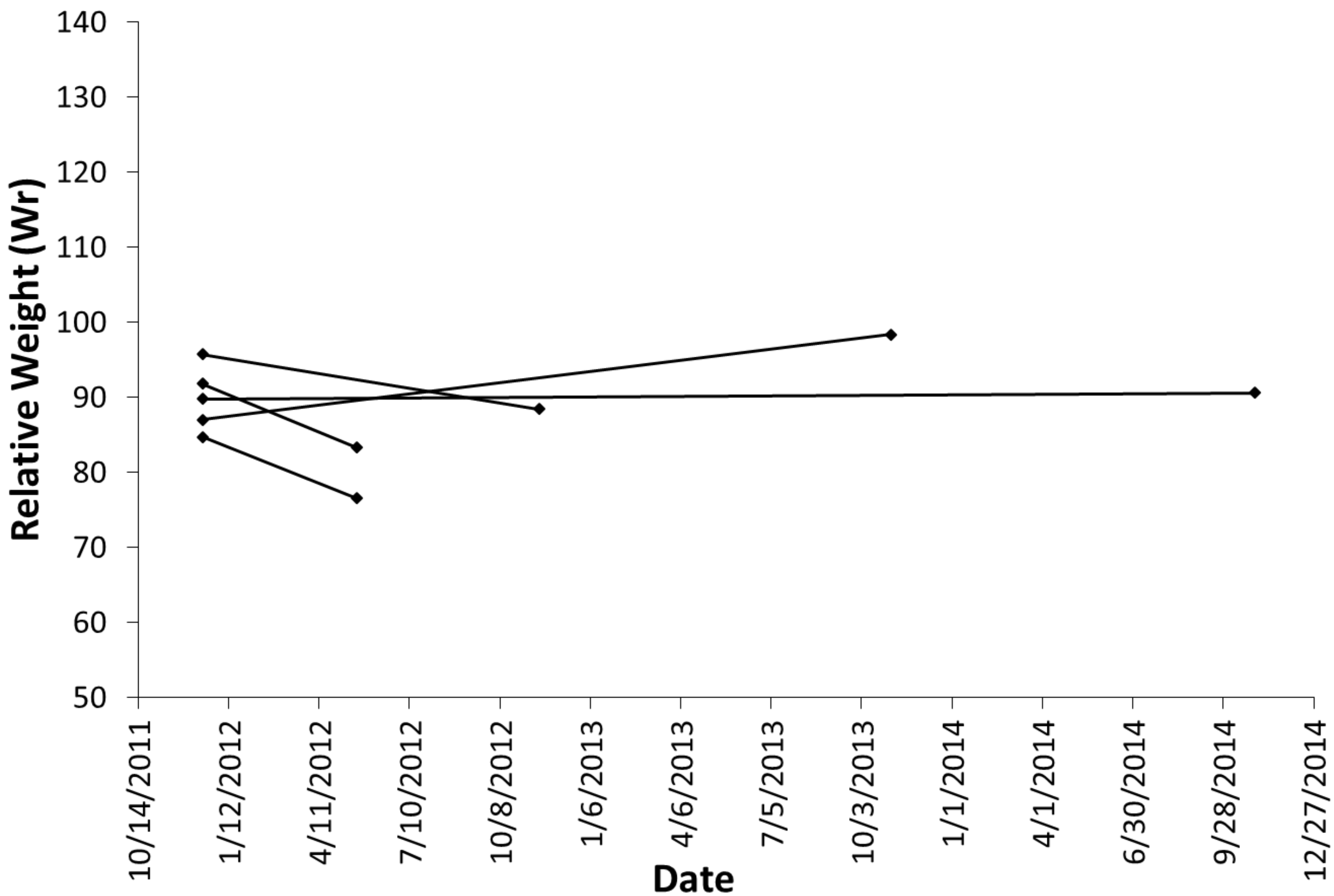

FIGURE 3.9. Changes in condition (relative weight [W_r]) of northern parental type Largemouth Bass that were stocked in December, 2011 and were recaptured between May, 2012 and October, 2014 from Grand Lake, TX.

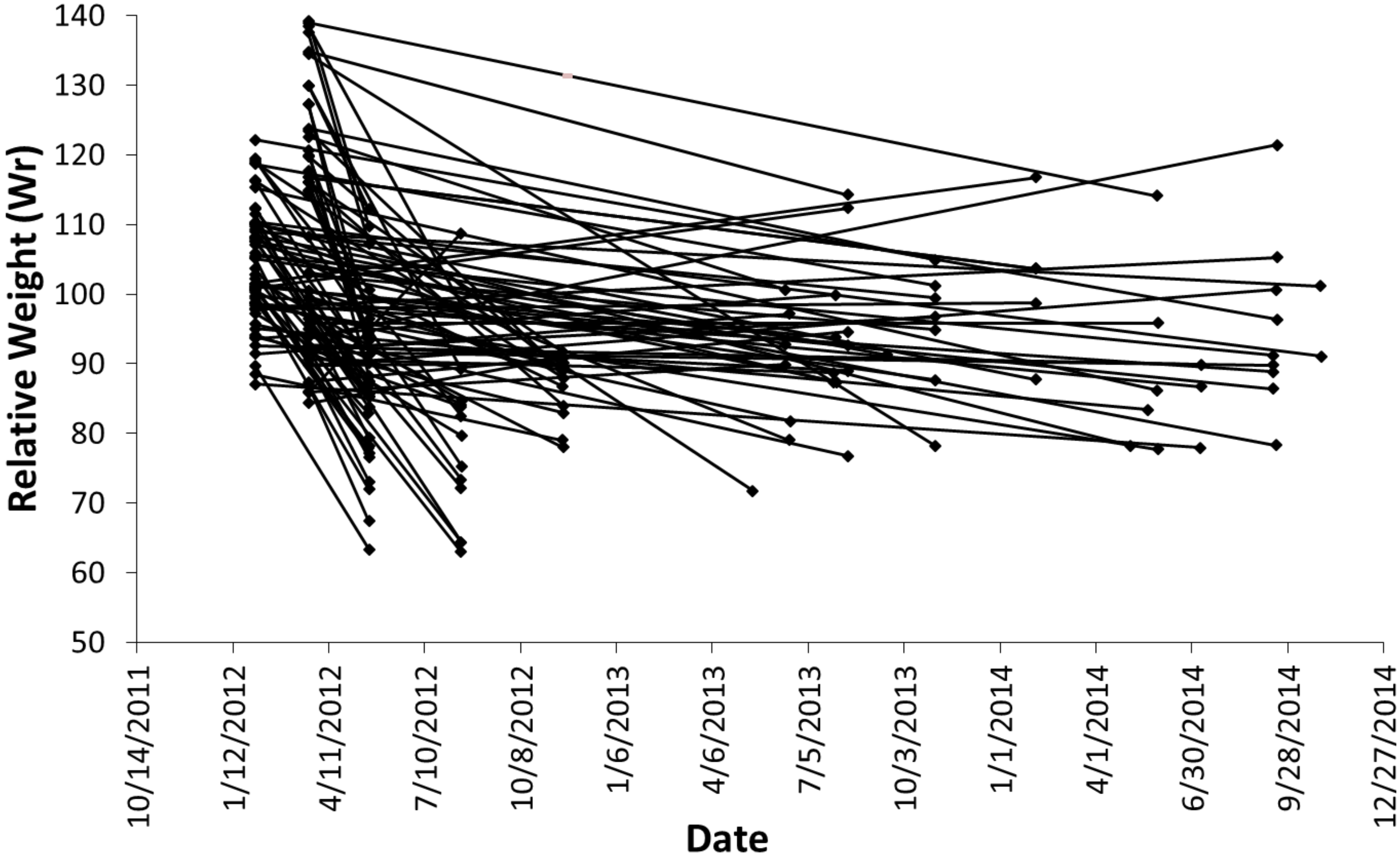

FIGURE 3.10. Changes in condition (relative weight [W_r]) of Florida parental type Largemouth Bass that were stocked in February and March, 2012 and were recaptured between May, 2012 and October, 2014 from Grand Lake, TX.

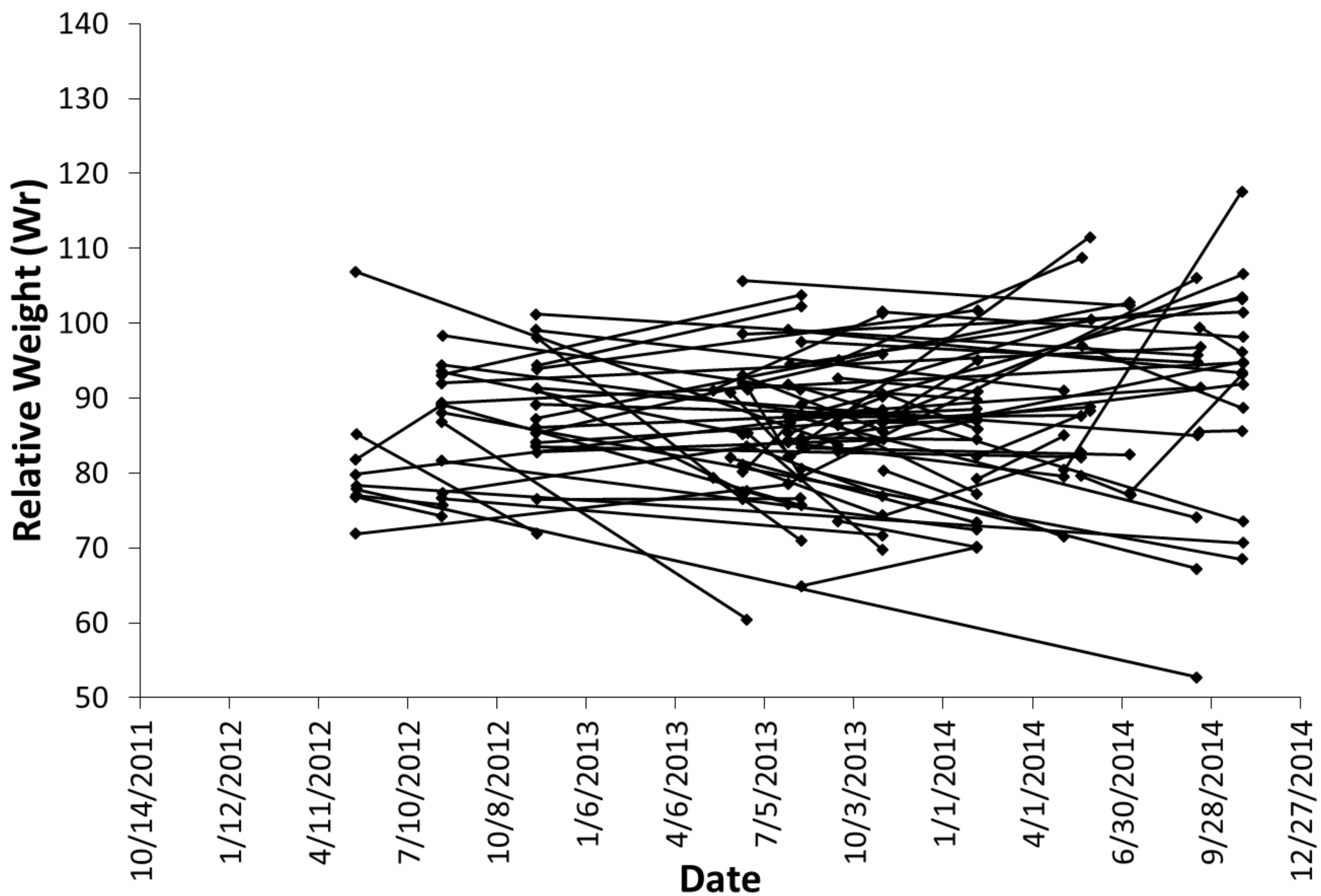

FIGURE 3.11. Changes in condition (relative weight [W_r]) of native Largemouth Bass that were captured between May, 2012 and September 2014 and recaptured between June, 2012 and October, 2014 from Grand Lake, TX.

CHAPTER 4: EFFECTS OF DIET AND TEMPERATURE ON GROWTH POTENTIAL OF LARGEMOUTH BASS IN A TEXAS IMPOUNDMENT WITH IMPLICATIONS FOR CLIMATE CHANGE

Abstract

Optimal quantity and quality of prey resources combined with optimal water temperatures are necessary to maximize the growth potential of Largemouth Bass. Furthermore, future water temperatures as a result of climate change may limit growth of Largemouth Bass in lakes and impoundments at the southern edge of their range. Largemouth Bass diets were assessed over three years in a private Texas impoundment and bioenergetics models were used to simulate growth of Largemouth Bass over different diet scenarios and future temperature models. Largemouth Bass tended to consume a mix of fish (i.e., 30-40% by weight) and crayfish (i.e., 20-40% be weight) during spring and then switched to feeding on a diet of primarily fish (i.e., >60% by weight) from mid-summer through the rest of the growing season. Largemouth Bass will have to increase consumption by 5-25% under future temperature scenarios just to meet baseline metabolic demands. If current rates of consumption are maintained under future predicted temperature scenarios, Largemouth Bass growth will decrease with some size classes failing to even meet their baseline metabolic demands. Largemouth Bass will have to increase p-values from 0.35-0.4 to 0.45-0.5 in order to meet baseline metabolic demands and begin to grow under a diet of 100% crayfish and observed 2013 and 2014 water temperatures. However, Largemouth Bass can meet their baseline metabolic demands and begin to grow at p-values as low as 0.3 under a diet of 100% Shad spp and observed 2013 and 2014 water temperatures. Management strategies (e.g., aerators)

should be used to ensure water temperatures are as close to those that optimize growth, especially in the face of future temperature models. Additionally, management strategies such as stocking prey fish should be used to optimize available prey in all seasons.

Keywords: Diet, temperature, Largemouth Bass, climate change, bioenergetics

Introduction

Quantity and quality of food resources can affect growth rate and condition of all living organisms. For example, Kaibab mule deer (*Odocoileus hemionus*) that used reseeded areas of their summer range designed to provide higher quality food sources returned to good condition earlier in the spring than mule deer in reference areas. (Hungerford 1970). Additionally, a 24.5% increase in the number of fawns was also observed following reseeding due to better summer food supply (Hungerford 1970). In another example, Walleye (*Sander viterus*) are a piscivorous fish that have been shown to grow faster and achieve larger sizes when consuming fish compared to invertebrates (e.g., Graeb et al. 2008). Furthermore, Walleye were shown to grow faster in Lake Erie when diets consisted of Gizzard Shad (*Dorosoma cepedianum*), a species with high energetic value, compared to diets of Emerald Shiner (*Notropis atherinoides*) and Spottail Shiner (*N. hudsonius*) or White Perch (*Morone americana*) and Walleye growth in Upper and Lower Red Lake, MN was positively correlated to strong year classes of Yellow Perch (*Perca flavescens*; Hartman and Margraf 1992; Ostazeski and Spangler 2001). Thus, providing adequate food resources for a desired organisms must be a goal of any fisheries or wildlife manager.

Historically, many fisheries, and especially small impoundments, were viewed and managed as a way to provide a source of food throughout the United States (Willis and Neal 2012). Additionally, small impoundments were often stocked with a wide variety of species, plants, and invertebrates, making management complex and outcomes difficult to predict (Wright and Kraft 2012). To more effectively manage small impoundments and have predictable management outcomes, Swingle (1949) moved to simplify the fish community within small impoundments, using only Largemouth Bass (*Micropterus salmoides*), Bluegill (*Lepomis macrochirus*), and minnows. Additionally, Swingle (1950) developed metrics based on the composition of forage fish and carnivorous fish within an impoundment to be used to assess simple fish communities and provided management recommendations based on the goals and results of assessemnts of these simple fish communities. Following Swingle's work, fisheries managers have been manipulating food webs through stocking standardized combinations of prey fish and predators or specialized combinations of fishes to achieve the goals of private impoundment owners or public constituents (e.g., Modde 1980; Ney 1981; Dauwalter and Jackson 2005; Wright and Kraft 2012). More recently, many fisheries managers have seen a shift among anglers in the way they view fisheries from one of primarily subsistence to a more recreational view in which quality fishing opportunities are preferred (i.e., catch trophy fish; Weithman and Anderson 1978). Largemouth Bass anglers may be leading the paradigm shift to the creation of trophy fisheries (e.g., Forshage and Fries 1995).

Largemouth Bass are currently one of the most popular freshwater sport fish species throughout the world and one of the most intensively managed sport fish species throughout North America. According to the 2011 national survey of fishing, hunting, and wildlife associated recreation, 10.6 million anglers and 171 million fishing days were spent targeting Black Bass (*M. spp.*), making them the most popular freshwater sportfish in the United States outside of the Great Lakes (USDI 2011). Additionally, since the time of Swingle in the 1930s and 40s, Largemouth Bass and Bluegill have been the most commonly stocked fish species throughout the southern United States and 34 of the 48 lower states in the United States have recommendations for stocking rates and ratios for Largemouth Bass and Bluegill in small impoundments (Dauwalter and Jackson 2005; Wright and Kraft 2012). Due to their popularity with anglers, Largemouth Bass have been stocked throughout much of the world including most of the United States outside their native range, southern Canada, Central America, South America, Europe, Asia, and Africa (e.g., Powers and Bowes 1967; Robins and MacCrimmon 1974; Azuma and Motomura 1999; Weyl and Hecht 1999; Gratwicke and Marshall 2001; Jackson 2002; Bernardo et al. 2003; Maezono and Miyashita 2003; Schulz and Leal 2005).

Fisheries managers who are trying to create trophy Largemouth Bass fisheries must be cognizant of the food web within the water body they are trying to manage as diets of Largemouth Bass have been shown to affect growth rates of all life stages of the species. For example, first year growth of Largemouth Bass in Lake Conroe, TX was significantly faster for age-0 Bass that switched to piscivory at 60 mm total length (TL) following vegetation removal compared to age-0 Bass that switched to piscivory at 100 mm TL prior to vegetation removal (Bettoli et al. 1992). Similarly, Gutreuter and Anderson (1985) found differential growth rates of some age-0 Largemouth Bass based on availability of proper size and type of food with age-0 Bass that consumed Gizzard

Shad growing faster than age-0 Bass that in ponds without availability of Gizzard Shad. Several other studies have also showed age-0 Largemouth Bass growth to be dependent on types, sizes, and numbers of available prey with Largemouth Bass that consume fish often growing faster than Bass that consume other diets such as invertebrates (e.g., Shelton et al. 1979; Timmons et al. 1980; Adams and DeAngelis 1987). In a study of the effects of coarse woody habitat removal on feeding and growth of Largemouth Bass, Sass et al. (2006) found that following removal of coarse woody habitat from the treatment basin of Little Rock Lake, WI, Largemouth Bass in the treatment basin of consumed fewer yellow perch and other aquatic prey species, consumed a higher proportion of terrestrial prey, overall consumed a lower weight of prey and grew significantly slower than Largemouth Bass in the unaltered reference basin.

Given the fact that Largemouth Bass are ectotherms, water temperature may also affect their growth rates with Largemouth Bass having an optimal growth temperature range of 26-28 °C (Coutant & Cox 1976). Additionally, as climate change progresses, increased temperatures will increase a fish's basal metabolic demands necessary to maintain cardiac function and respiration (Brown et al. 2004; Breeggemann et al. 2015) leading to increased consumption necessary to meet basal metabolic needs and potentially a reduction in growth as a result (Christie & Regier 1988). It is likely that the effects of climate change will be most severe at the southern edge of a fish's range where temperatures are already near the upper thermal limit of tolerance (e.g., Magnuson 2001; Casselman 2002; Breeggemann et al. 2015). Although Breeggemann et al. (2015) did not show significant decreases in growth of Largemouth Bass as a result of climate change near the center of their range in the Sandhills of Nebraska, the possibility exists that climate change could have a more significant impact of Largemouth Bass growth in southern states such as Texas. As of yet, no research has been conducted to explore the potential effects of climate change on Largemouth Bass growth in the southern United States.

Grand Lake is a 45ha private impoundment located in eastern Texas with a current fisheries goal of growing 6.8kg Largemouth Bass. The current management strategy includes an enhanced food web which consists of Bluegill, Redear Sunfish (*Lepomis microlophus)*, Redbreast Sunfish (*Lepomis auritus*), Gizzard Shad, Black Crappie (*Pomoxis nigromaculatus*), White Crappie (*Pomoxis annularis*), Channel Catfish (*Ictalurus punctatus*), and Black Bullhead (*Ameiurus melas*), among others as prey fish with self-sustaining populations as well as stocking of Threadfin Shad (*Dorosoma petenense)* and Mozambique Tilapia (*Oreochromis mossambicus*) every year because these two species die every fall due to thermal limitations. However, it is not known which if any of these species make up a significant portion of Largemouth Bass diets in Grand Lake. Furthermore, it is not known which prey fish species or combination of prey fish species will maximize growth of Largemouth Bass in Grand Lake nor are the effects of water temperature on growth of Largemouth Bass in Grand Lake known. Knowledge of the effects of prey and water temperature on growth of Largemouth Bass could aid in the management (e.g., adjust stocking regimes or add aeration to adjust water temperatures) of this systems as well as other systems throughout the world. The objectives of our study were to 1) quantify seasonally important diet items from Largemouth Bass in Grand Lake, TX; and 2) simulate changes in growth and consumption of Largemouth Bass under predicted future climate change scenarios, different diet scenarios, and a combination of predicted future climate change scenarios and diets.

Methods

Study site

Grand Lake is a 45ha private impoundment located just east of Athens, TX. Grand Lake was built in the 1950s and is intensively managed as a trophy Largemouth Bass fishery. Grand Lake is considered a eutrophic (secchi disc readings ≤ 0.75 m year round) impoundment with a mean depth of 3.2 meters and a maximum depth of 7.9 meters. In order to enhance the population genetics of Grand Lake, over 600 adult pure Florida parental type Largemouth Bass and over 100 adult feed trained F_1 hybrid Largemouth Bass were stocked into the lake over the winter of 2011-2012 (Chapter 2). Additionally, the food web is intensively managed every year through stocking of different prey fish species (see introduction for a complete description) as well as an intensive feeding program that consists of two floating feeders and 11 feeders dispersed around the lake on the shore or docks. The goal of the feeders is to enhance prey fish production that can then support higher Largemouth Bass production. No exploitation of Largemouth Bass occurs in Grand Lake except to reduce densities when density-dependent competition is evident.

Field sampling

Pulsed DC electrofishing was used to sample Largemouth Bass from Grand Lake multiple times each year beginning in spring 2012 and ending in fall 2014. Three sampling events occurred throughout 2012: mid-May, mid-August, and mid-November. Four sampling events occurred in 2013: late-May/early-June, late-July/early August, mid-

September, and late-October. Five sampling events also occurred in 2014: early-February, mid-May, early-July, mid-September, and late-October. During each sampling event, total length (mm; TL) and weight (g) of all Largemouth Bass collected were measured. Diet samples were collected from all Largemouth Bass with a TL ≥250mm using pulsed gastric lavage (Kamler and Pope 2001). A stratified random sampling design was used based on lengths of Largemouth Bass to ensure a representative diet sample was collected during each sampling event. Therefore, the goal during each sampling event was to collect at least 20 diets from Largemouth Bass 250-381mm TL, 20 diets from Largemouth Bass 382-508mm TL, and as many diets as could be collected from Largemouth Bass >508mm TL knowing diets from the largest size class would be rare. Upon collection, all diet samples were preserved in 10% formalin.

Twelve HOBO® Pendant® temperature loggers (Onset® Computer Corporation) were deployed on two towers in Grand Lake, one tower in the north central region and the other in the south central region. The north temperature logger tower consisted of seven temperature loggers affixed to a rope that extended from the surface to the bottom. One temperature logger was affixed to the rope at approximately 0.5m below the surface and each subsequent temperature logger was affixed at a distance of at approximately 1m apart starting at 1.5m below the surface (i.e., 1m below the temperature logger closest to the surface). The temperature logger tower in the south central region had the same configuration (i.e., one temper logger 0.5m below the surface and a temperature logger evenly spaced every meter below the one closest to the surface), except only five temperature loggers were used due to shallower water. The two towers were initially deployed in May 2013, and then all temperature loggers were replaced with new ones in

May, 2014 using the same configuration described above and then all temperature loggers were removed from Grand Lake in November, 2014. All temperature loggers were programmed to record water temperatures every hour.

Lab processing

Following preservation, all diet samples were transferred to water and then stored in 70% ethanol. All diet samples for individual Largemouth Bass were identified to the lowest possible taxonomic resolution (i.e., species for fish and other vertebrates and family for invertebrates). All diet items of a given taxon for an individual Largemouth Bass were weighed to the nearest 0.01g for large diet items and to the nearest 0.0001g for small diet items (e.g., Odonata wings).

Food habits

The relative importance of major prey categories (i.e., fish, Cambaridae, vegetation, invertebrates other than Cambaridae, vertebrates other than fish [frogs, salamanders, turtles, snakes], pellets from feed trained Bass, and other prey) in seasonal Largemouth Bass diets was quantified using mean percent composition by wet weight. Vegetation was included as a descriptor and was presumed to be consumed unintentionally when consuming other prey items such as Cambaridae or fish. Percent composition by wet weight was calculated for the entire population as a whole, as well as the three size classes discussed previously (i.e., 250-381mm TL, 382-508mm TL, and >508mm TL). Furthermore, frequency of occurrence (i.e., the percentage of stomachs in which a given diet item was found; Chipps and Garvey 2007) and prey specific abundance (PSA; Amundsen et al. 1996) were also calculated for individual prey types (i.e., family for invertebrates and species for vertebrates). Prey-specific abundance was calculated as:

$$PSA = \frac{\sum S_i}{\sum S_{ti}} * 100,$$

where PSA equals the prey-specific abundance of prey item i, S_i equals the stomach contents (by weight) comprised of prey i, and S_{ti} equals the total stomach contents (by weight) of only the predators with prey item i in their stomach (Amundsen et al. 1996). Frequency of occurrence and PSA were calculated for all Largemouth collected within each of the 12 sampling events and for each of the three size classes of Largemouth bass described above collected within each sample (i.e., 250-381mm TL, 382-508mm TL, and >508mm TL). Results of the Amundsen plots are all presented in Appendix A.

Bioenergetics simulations

Bioenergetics models (Fish Bioenergetics 4.0; Chipps et al. 2016) were used to simulate the effects of prey and temperature (i.e., climate change) on growth and consumption of Largemouth Bass. Energy densities of Largemouth Bass prey items used in bioenergetics simulations were taken from the following published sources (Cummins and Wuycheck 1971; Kelso 1973; Miranda and Muncy 1989; Pope et al. 2001; Eggelton and Schramm 2002; Vatland et al. 2008; James et al. 2012). Mean observed daily water temperatures were calculated by taking the average of all hourly water temperatures recorded from the four temperature loggers that were closest to the surface on each of the two temperature logger towers described above. Only the top four temperature loggers from each tower were used because these loggers were located above the hypolimnion where adequate oxygen was available for Largemouth Bass survival during stratified periods. Diet samples collected during the 2013 and 2014 growing seasons were used in bioenergetics simulations. Vegetation and pellets were removed from diet proportion for bioenergetics simulations because vegetation was considered an inadvertent diet item consumed while eating other prey and is also of little benefit energetically to a top level piscivore and pellets were considered to be consumed only by stocked feed-trained F_1 hybrid Largemouth Bass and not representative of the greater Largemouth Bass population as a whole. Bioenergetics simulations for the 2013 growing season were simulated over the period of June 1 through October 31 encompassing the four diet samples that took place during this time period described above. Bioenergetics simulations for the 2014 growing season were simulated over the period of May 15 through October 30 and also included four diet samples as described previously.

Due to the inaccuracies and imprecision associated with using non-lethal calcified structures (e.g., scales or fin spine) to estimate ages of Largemouth Bass along with the need for non-lethal sampling methods, no calcified structures were collected from Bass during sampling to assign ages for modeling of age specific cohorts. However, size groups corresponding to individual age classes were assigned to all individual Largemouth Bass collected during each sampling event based on a von Bertalanffy growth curve fitted to mean back-calculated lengths at age derived from sectioned sagittal otoliths collected from Largemouth Bass in Grand Lake during December, 2011 (Chapter 1 of this dissertation). Initial lengths for each age class (i.e., size class) used for bioenergetics models were the observed mean back-calculated lengths at age from the December, 2011 sample. Final lengths used in simulations in which probable growth was modeled were the length at one year older under the assumption that most of the growth was completed by the end of October in each year when simulations ended. For example, the final length for the two year old age class was based on the mean back-calculated length at age three assuming that the two year olds had now completed three full growing seasons. All starting and ending lengths for both sampling seasons (i.e., 2013 and 2014) were derived from the sample taken in December, 2011. Initial and final weights for each age class in each year were derived from length-weight regressions built from fish collected during the initial (i.e., May/June) or final (i.e., October) sample of Largemouth Bass collected in each growing season.

The mid-length between two adjacent lengths at age was used to assign individual Largemouth Bass to a given size/age class. For example, the predicted mean back-calculated length at age two and three were 280 and 335 mm TL, respectively. Therefore, 307 mm TL (i.e., the mid-point between lengths at age two and three) was used separate individuals into size/age classes for initial and final samples, or samples at the start or end of the growing season. For samples taken in the middle of the growing season (e.g., July), it was assumed that Largemouth Bass had completed half of their growth for that growing season. Therefore, lengths at age were assumed to be the mid-length between their starting and ending lengths. The same process described above where the mid-point between lengths at age was used to assign individual Largemouth Bass to a size/age class was also used to separate individual Largemouth Bass into size/age classes during the middle of the growing season using the mid-season predicted lengths at age. Changes and growth and consumption were modeled for seven age/size classes (i.e., ages 2 through 8) for each growing season. Starting and final lengths and weights for each age class for each growing season are presented in Table 4.1. Evidence from individual growth trajectories from PIT tag data (Chapter 2 of this dissertation) shows that population growth has not changed much since 2011, justifying the use of the methods described above to assign growth increments.

Bioenergetics simulations were then used to assess the effects of climate change on Largemouth Bass growth and consumption in a southern climate. For purposes of comparison across studies, the same predicted monthly temperature changes from each of three climate change models (i.e., MPI, USGS, and GFDL) and two predicted time intervals in the future (i.e., 2040 and 2060) from Breeggemann et al. (2015) were applied to baseline temperatures (i.e., observed Grand Lake water temperatures) to simulate the effects of climate change on the Grand Lake Largemouth Bass population (Table 4.2). Furthermore, two of the same simulations run by Breeggemann et al. (2015) were run for this study. Initially, observed (i.e., 2013 and 2014) diets and temperature scenarios from Grand Lake were used to build a baseline model of total cumulative consumption necessary to meet baseline metabolic needs (i.e., a no growth scenario). Subsequently, the percent change in total cumulative consumption was then quantified for each of the seven age classes in each of the two years (i.e., 2013 and 2014) across all three climate change models and two future time intervals to assess additional consumption necessary to meet baseline energetic demands under future predicted climate scenarios. Additionally, total consumption necessary to meet probable growth scenarios for each age class (i.e. using predicted initial and final weights under projected growth conditions) was quantified under baseline (i.e., 2013 and 2014) conditions. Subsequently, consumption (i.e., p-values from baseline models) was held constant and predicted end weight under all climate change models (i.e., each of the three models across both time periods) were simulated to assess changes in growth under predicted future climate scenarios.

Bioenergetics simulations were also used to simulate the effects of different diet scenarios on growth potential of Largemouth Bass in Grand Lake under observed temperature conditions. The three diet scenarios modeled were the observed diet (i.e., baseline diet), a diet consisting of 100% shad (i.e., a mix of Gizzard Threadfin Shad), and a diet of 100% crayfish. The fit to consumption model was used to quantify growth (i.e., percent change in initial weight) for all seven age classes in each year feeding on each of the three diet scenarios over a range of p-values (i.e., percent maximum consumption). P-values modeled ranged from 0.3 to 0.5 and were modeled over increments of 0.05.

Results

Seasonally Important Diet Items

The Largemouth Bass from all size classes (i.e., population) sampled from Grand Lake were consuming primarily a mix of fish and crayfish (Cambaridae) during the mid-May, 2012 sampling event (Figure 4.1). Fish composed the highest percent composition by weight at just under 50% followed by crayfish at 32% (Figure 4.1). Fish observed in diets included Bluegill, Largemouth Bass, Ictaluridae, Gizzard Shad, and Lepomis spp. Also present in diets of all fish combined were invertebrates which were primarily Odanata and Dipterans (Figure 4.1). Crayfish made up the higest percentage of weight for the smallest size class of Largemouth Bass during the May, 2012 sample at 36% followed by fish and invertebrates at 26% and 19% of percentage by wet weight respectively (Figure 4.1). The two larger size classes were consuming primarily fish as fish comprised 57% of the weight for the middle size class and 67% of the weight for the largest size class (Figure 4.1). Crayfish made up the majority of the rest of the diets for the middle and largest size classes in mid-May, 2012 (Figure 4.1).

By mid-August, Largemouth Bass in Grand Lake had switched over to feeding primarily on fish with fish making up between 59 and 100% of the wet weight of diet items for all size classes including all Lagemouth Bass combined (Figure 4.1). Identifiable fish were primarily Bluegill and both Gizzard Shad and Threadfin Shad. Aside from fish, the Largemouth Bass were comsuimg primarily invertebrates such as Odonata and terrestrial crickets Gryllidae (Figure 4.1). Diets during mid-November, 2012 were similar to mid-August, 2012, being composed primarily of fish with fish making up >75% of the weight for all size classes and all Largemouth Bass combined (Figure 4.1). Observed fish from the November, 2012 sample included Gizzard and Threadfin Shad, Largemouth Bass, *Pomoxis* spp., and members of both the Centrarchidae and Ictaluridae families (Figure 4.1). Aside from fish, Largemouth Bass were consuming invertebrates such as Coleopterans and also some vertebrates such as salamnders and one turtle (Figure 4.1). Vegetation made up a small (~5%) proportion of the weight for all 2012 sampling events but was again assumed to be eaten incidentally (Figure 4.1). We also sampled some pellets from feed trained Largemouth Bass stocked into Grand Lake in December, 2011 (Figure 4.1).

Diets collected during 2013 sampling showed similar seasonal trends to 2012 sampling. Crayfish and fish comprised the majority of the weight of diet items during the May/June, 2013 sampling event (Figure4. 2). Fish and crayfish comprised about 80% of the weight of the May/June 2013 sample when all Largeouth Bass diets were combined, with fish making up just over 55% and crayfish making up 25% (Figure 4.2). However, differences were observed in diets for different size classes during this sample with the smalles size class eating primarily fish (60% of the weight compared to only 20% for crayfish) whereas the middle size class consumed primarily caryfish (61% of the weight compared to 28% for fish; Figure 4.2). Invertebrates observed in diets included Dipterans (e.g., Culicidae), Odonata, and terrestrial grasshoppers (Acrididae). By mid-summer (late July/early August) 2013, Largemouth Bass in Grand Lake had again switched over to feeding primarily on fish with fish making up ≥50% of the weight of diets for all size classes (Figure 4.2). Observed fish in diets included Gizzard and Threadfin Shad, Bluegill, and Ictalurid spp. The smallest size class of Largemouth Bass was consuming priamrily fish with fish making up 75% of the weight of diet items (Figure 4.2). Crayfish did compries 10-16% of the weight of the diets of the small and middle size classes of Largemouth Bass (Figure 4.2). Two diets weer collected from Largemouth Bass >508mm TL and one contained a Bluegill while the other contained an unidentified salamander (Figure 4.2).

During mid-September, the trend of Largemouth Bass feeding primarily on fish continued as >68% of the weight of diets was fish for the two size classes in which diets were sampled as well as all diets combined (Figure 4.2). The majority of fish observed in diets were Threadfin Shad but Gizzard Shad, Bluegill, and Largemouth Bass were also observed. Additionally, one frog (Ranidae) was also observed along with one Cambaridae (Figure 4.2). During early-November, 2013, fish were still an important component of the Largemouth Bass diets comprising between 40-50% of the weight for all fish combined and the small and medium size classes (Figure 4.2). Only one diet was collected from Largemouth Bass >508mm and it contained a Bluegill (Figure 4.2). The majority of fish observed in diets were Bluegill, but also observed were Threadfin Shad and Largemouth Bass. Cambaridae comprised between13-17% of the weight of diets for the small and medium size classes as well as the population as a whole (Figure 4.2). An increase in consumption of vertebrates was also observed during early-November, most of which were unidentified salamanders and snakes (Figure 4.2). Similar to 2012, vegetation was found throughout the diets, again presumed to be incidentally consumed, and pellets were also found in some Largemouth Bass diets (Figure 4.2).

February, 2014 was the only winter diet sample collected and the majority of the weight of diet items was again fish (Figure 4.3). Fish comprised at least 57% of the weight of diets from all size classes including the population as a whole (Figure 4.3). Bluegill and Largemouth Bass were the two fish species identified in diets collected during winter. Other observed diet items include invertebrates (i.e., Dipterans, and Ephemeropterans), Cambaridae, and also a Salamander (Figure 4.3). By mid-May, 2014, the Largemouth Bass population switched over to feeding on almost an even mixture of fish and crayfish with fish comprising between 44 and 53% of the weight of diets for the population as a whole and the small and medium size classes of Bass and crayfish comprising between 40 and 42% of the weight of diets for these same three groups (Figure 4.3). One diet was collected from the large size class of Largemouth Bass and it contained an adult Gizzard Shad (Figure 4.3). Fish species obderved in diets included Shad spp., Ictalurid spp., and Largemouth Bass. Also observed in May, 2014 diets were invervetrbates including Chironomidae and Odonata, which comprised approximately 10% of the weight of diet items for the small size class of Largemouth Bass (Figure 4.3).

By early-July, 2014, the Largemouth Bass population was still feeding on a mix of fish and Cambaridae (Figure 4.3). Fish comprised 66% of the weight of all Largemouth Bass diets collected but comprised 84% of the weight of diets for the small size class compared to 20% of the weight of the medium size class (Figure 4.3). Fish species observed in the diets included Threadfin Shad, Shad spp., Largemouth Bass, and Lepomis spp. Cambaridae also remained an important diet item comprising 30% of the weight of all diets combined and 76% of the weight of diets for the middle size class of Largemouth Bass (Figure 4.3). By mid-September, 2014, the Largemouth Bass population had again switched over to feeding primarily on fish, with fish comprising 73% of the weight of diets of all Largemouth Bass sampled, 82% of the weight of diets of the smallest size class, and just under 50% of the weight of the middle size class (Figure 4.3). Fish species ocurring in the diets included Threadfin Shad, Shad spp. Largemouth Bass, and Ictalurid spp. Cambaridae were also observed in the diets, consisting of 3% of the weight of diets for the smallest size class and 14% for the middle size class (Figure 4.3). Invertbrates (i.e., Odonata and Coleoptera) were also observed in the diets with invertbrates comprising 8-14% of diet weights for the different size classes (Figure 4.3).

The dominance of fish in Largemouth Bass diets continued into late-October, 2014 with fish making up 62-75% of the weight of diets for all size classes observed (Figure 4.3). Fish species observed in diets included Threadfin Shad, Gizzard Shad, Largemouth Bass, Ictalurid spp., and Lepomis spp. Crayfish were also observed but contributed only 4-8% of the weight if diet items for different size class of Largemouth Bass (Figure 4.3). Also observed were invertebrates, coprising 10-15% of the weight of diet items for the different size classes as well as vertebrates making up 7-8% of the weight of diet items (Figure 4.3). Invertbrates observed in the diets included Hemipterans and Odonata while the vertebrates observed included unidentified snakes, unidentified salamanders and one snake of the family Crotalidae. Throughout all sampling events in

2014, vegetation was again sparsely observed in the diets and considered a byproduct of consuming other prey items such and fish and Cambaridae and pellets were observed but were less common than in previous years.

Under predicted 2040 temperature scenarios, all age classes across both the 2013 and 2104 growing seasons required a 6-16% increase in total consumption to meet baseline energy requirements (Figure 4.4). Furthermore, the three different temperature change models showed high variability in the percent change in total consumption necessary to meet baseline energy requirements with the USGS model requiring the lowest increase in consumption at 6-7% and the GFL model requiring the highest increase in consumption at 11-15% for all age classes across both growing seasons (Figure 4.4). Under predicted 2060 temperature scenarios, the percent increase in consumption necessary to meet baseline energy requirements increased compared to 2040 temperature models with all age classes across all years requiring a 14-23% increase in consumption (Figure 4.4). The variability in percent increases in consumption necessary to meet baseline energy requirements was much lower among the three models under predicted 2060 temperature scenarios (Figure 4.4).

Future temperature increases could reduce the growth capacity of Largemouth Bass in already warm climates such as those in TX. When consumption was held constant to the observed 2013 or 2014 p-values under full growth models, no age class of Largemouth Bass was able to grow as much under predicted 2040 temperature scenarios compared to observed temperatures for either the 2013 or 2014 growing season (Figure 4.5). When consumption was held constant to the 2013 or 2014 scenarios, all age classes would have lost weight (i.e., were not able to consume enough to meet baseline energetic requirements) under the predicted 2040 GFDL temperature scenario (Figure 4.5). However, the younger age classes under 2013 consumption p-values were able to grow under the 2040 MPI and USGS temperature scenarios, just not as much as they would have under the 2013 temperature scenarios (Figure 4.5). Furthermore, when consumption was held to 2013 levels but temperatures were simulated out to 2040 scenarios, older age classes again lost weight under the MPI and USGS models (Figure 4.5). When consumption from the 2014 growing season was simulated out to 2040 temperature scenarios, all age-classes but one (i.e., age-8) would still have grown but none would have grown as much as they had during the 2014 growing season (Figure 4.5). When consumption was held to 2013 or 2014 p-values, no age class was able to even meet baseline energetic demands (i.e., all lost weight) under the predicted 2060 temperature scenarios for all three models (Figure 4.5). All age class had at least a 35% reduction in end weight compared to predicted 2013 or 2014 end weights under the full growth models with some age classes having as much as a 70% reduction in end weight (Figure 4.5).

Diet also had an impact on the growth potential of Largemouth Bass in Grand Lake. Most age classes of Largemouth Bass needed to consume at a p-vlaue of 0.35-0.4 under the observed (baseline) 2013 and 2014 diet scenarios in order to meet their baseline energy requirements and begin to grow (i.e., have a 0% change in initial weight; Figures 4.6-4.9). However, all age classes of Largemouth Bass would have to consume prey at p-values of 0.45-0.5 in order to meet baseline energy requirements and begin to consume enough energy to grow under a diet of 100% crayfish during both the 2013 and 2014 growing seasons (Figures 4.6-4.9). Furthermore, when feeding on a diet of 100% shad (i.e., the most energetically beneficial fish species sampled in diets of Grand Lake Largemouth Bass), all age classes in both the 2013 and 2014 growing seasons were able to meet baseline energy requirements and begin to grow at p-values as low as 0.3 and always by a p-value of 0.35 (Figures 4.6-4.9).

Discussion

A wide variety of prey items were observed in Largemouth Bass diets sampled from Grand Lake; however, from mid-summer through the end of fall, Largemouth Bass diets consisted of primarily fish from the families Centracrchidae, Ictaluridae, and Clupeidae. In many other systems, adult Largemouth Bass have been shown to feed primarily on fish when proper sized prey fish are available (Minckley 1982; Moyle 2002; Sass et al. 2006). However, Largemouth Bass have been shown to be opportunistic and even when fish are available Largemouth Bass may consume a wide variety of diet organisms including amphibians such as tadpoles and frogs (Lewis et al. 1961) and crayfish (Wheeler and Allen 2003). Similar to what these previous studies have shown, crayfish and vertebrates other than fish (e.g., salamanders, frogs, and snakes) were the most common diet items other than fish. As with other studies as well, aquatic and terrestrial invertebrates other than crayfish were also found to make up small percentages of Largemouth Bass diets throughout the year, providing evidence of their opportunistic and flexible feeding strategy (e.g., Schindler et al. 1997; Sass et al. 2006; Ahrenstorff et al. 2009).

Aside from fish, crayfish were the largest contributor to Largemouth Bass diets in Grand Lake. Furthermore, crayfish contributed the highest proportion by weight during our spring (i.e., May) sampling events in each year. We hypothesize that crayfish contributed such a high proportion during spring due to lower amounts of available prey fish in Grand Lake during the spring as most age-0 prey fish are not yet large enough to be beneficial to adult Largemouth Bass. Additionally, Threadfin Shad were one of the most abundant prey fish in Grand Lake by mid-summer due to their high reproductive potential and were also a common fish species observed in Largemouth Bass diets. However, Threadfin Shad do not overwinter in Grand Lake and thus one of the most important prey fish is not available during spring. Research has shown that Largemouth Bass will often feed on prey sources that are most available to them (Schindler et al. 1997) making crayfish a likely diet item when prey fish are not available. Research has also shown that even when ample prey fish are available to Largemouth Bass, they still may feed on crayfish (Lewis et al. 1961; Wheeler and Allen 2003).

Available habitat along with less available prey fish could also be contributing to Largemouth Bass relying more heavily on crayfish during spring. For example, Ahrenstorff et al. (2009) showed that differing amounts of course woody habitat in Wisconsin lakes affected both consumption and the amounts of fish and invertebrates observed in Largemouth Bass diets. Furthermore, Anderson (1984) developed an optimal foraging model for Largemouth Bass based on search time, encounter rates, and capture success, of different prey types in different densities of vegetation and his model showed that Largemouth Bass will feed on different prey types when different habitat is available. Grand Lake is an aging reservoir with little habitat. Reduced habitat as a result of being a reservoir that is 60+ years old combined with fewer available prey fish may mean that search time, encounter rates, and energy spent trying to capture fish in the spring is not as energetically beneficial as feeding on crayfish.

The results of our bioenergetics simulations show that predicted increased temperatures as a result of climate change will significantly impact consumption and growth of Largemouth in climates that are already considered warm such as Texas. Consumption by Largemouth Bass in Grand Lake will need to increase by 6-16% under predicted 2040 temperature models and 15-25% under predicted 2060 temperature models just to meet baseline energetics requirements. The percent increases in cumulative consumption observed in Grand Lake are similar to those observed in other studies as Breeggemann et al. (2015) observed similar increases in percent change in total cumulative consumption necessary to meet baseline energetic demands for both Largemouth Bass and Northern Pike (*Esox lucius*) in West Long Lake, NE. However, predicted 2040 and 2060 water temperatures in Grand Lake are beyond a Largemouth Bass' thermal optimum temperature for most of the growing season and thus maximum consumption will be reduced under future predicted temperatures (Rice et al. 1983). As a result, Largemouth Bass will have to devote a higher proportion of available consumption to meet baseline energetic demands and less will be available for growth, thus limiting the growth potential of Largemouth Bass in Grand Lake.

Growth of Largemouth Bass in Grand Lake was predicted to be much slower under future predicted temperatures when consumption is held at the same rate as was observed in 2013 and 2014. Furthermore, some age classes were predicted to lose weight (i.e., fail to consume enough to meet baseline energy requirements) under some of the 2040 temperature models and all of the 2060 temperature models. Therefore, consumption rates in 2040 and 2060 will have to increase above 2013 and 2014 consumption rates just to meet baseline energy requirements and will have to increase even higher for Largemouth Bass growth to occur. Reduced growth can be attributed to two factor; first, reduced maximum consumption due to water temperatures exceeding the thermal optima of a Largemouth Bass and second, due to increased metabolic demands associated with increased temperature (Rice et al. 1983). While some research has shown that climate change may have little effect on the growth of species in the center of their range (i.e., Largemouth Bass in Breeggemann et al. 2015) and that climate change may actually increase growth in species at the northern edge of their range (i.e., King et al. 1999; Pease and Paukert 2014), climate change will likely have a negative impact on growth of species near the southern edge of their range as in this study and also with Northern Pike in West Long Lake, NE (Breeggemann et al. 2015). Although our results showed significant decreases in growth over the time periods modeled, it may be possible that Largemouth Bass growth increases earlier in the spring (i.e., April and early May) and later in the fall (i.e., November) when water temperatures increase closer to the thermal optima, offsetting some of the losses in growth observed during the peak summer months.

Reduced growth of Largemouth Bass may affect other dynamic rate functions, prey fish species composition, as well as overall fishing quality. For example, reduced growth could delay maturation rates, fecundity, and fitness of the population (Roff 1984; Shuter & Meisner 1992) as well as affect recruitment and egg development (Straile et al. 2007; Karjalainen et al. 2014). If consumption is extended later into the fall due to higher temperatures, more prey fish may get consumed thus affecting year class strength of prey fish species and future production of prey fish populations. Breeggemann et al. (2015) showed that prey fish production will have to increase in order to maintain similar prey fish populations in the face of increased predation. Furthermore, fishing historically was viewed as a way to provide protein for a family. Over the past several decades, this perspective has changed with more anglers desiring quality fishing experiences with the opportunities to catch trophy fish (Weithman and Anderson 1978; Forshage and Fries 1995). Reduced growth due to climate change could reduce the growth potential of Largemouth Bass in the southern United States and thus complicate management in order to overcome this hurdle.

Bioenergetics models also showed that Largemouth Bass in Grand Lake would grow better on a diet that consists of 100% shad compared to observed baseline diets. Other researchers have shown that age-0 Largemouth Bass growth is significantly faster when consuming fish compared to other available diet items (Shelton et al. 1979; Timmons et al. 1980; Gutreuter and Anderson 1985; Adams and DeAngelis 1987). Sass et al. (2006) found that adult Largemouth Bass growth was higher in section of a northern WI lake which had ample habitat and a strong Yellow Perch population compared to a section of the lake in which habitat was more limiting and Largemouth Bass were forced to consume primarily terrestrial invertebrates. Research on other piscivorous species such as the Walleye has also shown that growth of species that prefer fish is maximized on a diet consisting of primarily fish compared to a diet consisting of invertebrates (Hartman and Margraf 1992; Ostazeski and Spangler 2001; Graeb et al. 2008). Bioenergetics also showed that Largemouth Bass would lose weight or grow very little on a diet consisting of exclusively crayfish, which has also been shown with other piscivorous fish species as well (Ward et al. 2007).

Management Implications

This research highlights the effects of temperature and diet composition of the growth potential of Largemouth Bass at southern latitudes and sheds light on possible management recommendations to mediate the effects of climate change. First off, stocking Florida parental type Largemouth Bass could lessen the effects of climate change as Florida parental type Largemouth Bass can withstand warmer slightly water temperatures than their pure northern parental type counterparts (Fields et al. 1987; Beitinger et al. 2000). However, to the best of our knowledge, no researchers have created a bioenergetics model for Florida parental type Largemouth Bass and therefore we used the northern parental type Bass model for our simulations. The Largemouth Bass population in Grand Lake is already composed primarily of pure Florida parental type Largemouth Bass and their hybrids so the effects of climate change may not be as severe as shown by our simulations. An added benefit to stocking pure Florida parental type Largemouth Bass is that in some aquatic systems where water temperatures are already warm, pure Florida parental type Bass and their hybrids have been shown to grow faster and reach larger attainable sizes than their northern counterparts (Rieger and Summerfelt 1976; Inman et al. 1977; Bottroff and Lembeck 1978; Pelzman 1980; Maceina et al. 1988).

Management of the food web will also be critical in order to ensure growth of Largemouth Bass is maximized under future warmer climates. Most important is going to be ensuring proper amounts and sizes of prey fish are available throughout the entire year because the added growth potential of Largemouth Bass on a diet consisting of exclusively fish could offset the increased metabolic demands associated with warmer water temperatures. In our study, spring diets were when invertebrates and particularly crayfish had the highest contribution to Largemouth Bass diets. Our hypothesis as to the strong influence of crayfish early in the spring was the lack of small prey fish due to overwinter consumption and no age-0 prey fish available to Largemouth Bass yet because they are too small. One way to increase the probability of increased consumption of fish during spring could be to stock a high energy cool water prey fish such as a Rainbow Trout (*Oncorhynchus mykiss*) during late winter or early spring. Furthermore, Grand Lake is stocked with both Threadfin Shad and Mozambique Tilapia every spring and these species could be stocked at the earliest possible time given water temperatures to ensure that most fish are available earlier in the year. Managers could also stock Bluegill or another prey fish that can withstand cooler water earlier in the spring to provide a pulse of prey fish for Largemouth Bass.

Creation of cool water refuges could also provide water temperatures that maximize Largemouth Bass growth even if that majority of the water within a given system is above the thermal optima for the species. Aeration systems could be used to mix cooler hypolimnetic waters with warmer surface waters, thus providing cooler overall temperatures. However, care must be taken to ensure that anoxic waters and toxins are not mixed in with the epilimnion to the point that a fish kill occurs. Additionally, technology could be used to create a system in which oxygen could be injected directly into the cold waters of the hypolimnion without trying to mix water through aeration. Directly injecting oxygen into the hypolimnion would provide the coolest cool water refuge for Largemouth Bass while still ensuring all of the Bass' other needs (i.e., food and habitat) are being met.

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TABLE 4.1. Initial and final lengths (mm), initial and final weights (g), and growth increments (g) for Largemouth Bass ages two through eight sampled from Grand Lake, TX during the 2013 and 2014 growing seasons used for bioenergetics modeling to simulate the effects of diet and future predicted climate change temperatures on growth and consumption.

	2013 and 2014 Lengths (mm)		2013 Weights (g)			2014 Weights (g)		
Age	**Initial**	**Final**	**Initial**	**Final**	**Increment**	**Initial**	**Final**	**Increment**
2	280	335	275	485	210	274	512	238
3	335	377	479	701	222	480	745	265
4	377	408	689	898	209	694	958	264
5	408	433	879	1082	203	888	1158	270
6	433	450	1056	1220	164	1070	1309	239
7	450	464	1189	1343	154	1206	1442	236
8	464	476	1307	1455	148	1328	1564	236

TABLE 4.2. Predicted temperature changes from three climate change models over two time intervals into the future used to simulate the effects of temperature on growth and consumption of Largemouth Bass in Grand Lake, TX.

	Mean Monthly Predicted Temperature Changes					
	2040			2060		
Month	**MPI**	**USGS**	**GFDL**	**MPI**	**USGS**	**GFDL**
May	1.23	-0.1	1.34	3.03	1.31	3.06
June	0.96	0.28	2.32	2.4	1.09	2.96
July	0.96	0.94	2.07	2.34	2.84	3.36
August	0.94	1.33	2.17	2.84	2.99	3.14
September	1.73	0.77	1.96	2.5	2.1	1.73
October	2.01	1.3	0.98	2.65	2.93	3.51

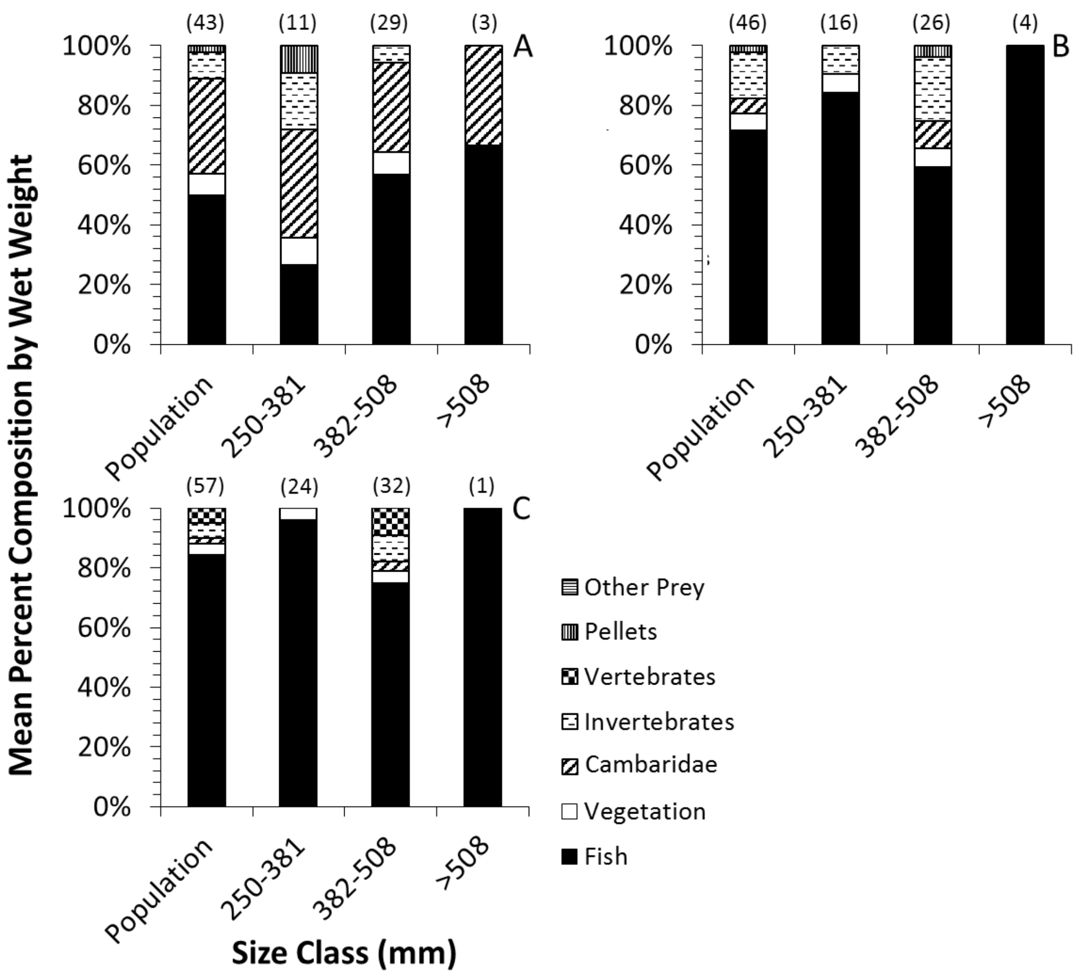

FIGURE 4.1. Mean percent composition by weight of major diet items collected from different size classes of Largemouth Bass sampled from Grand Lake, TX in May (A), August (B), and November (C), 2012. Numbers in parentheses represent sample sizes for different size classes.

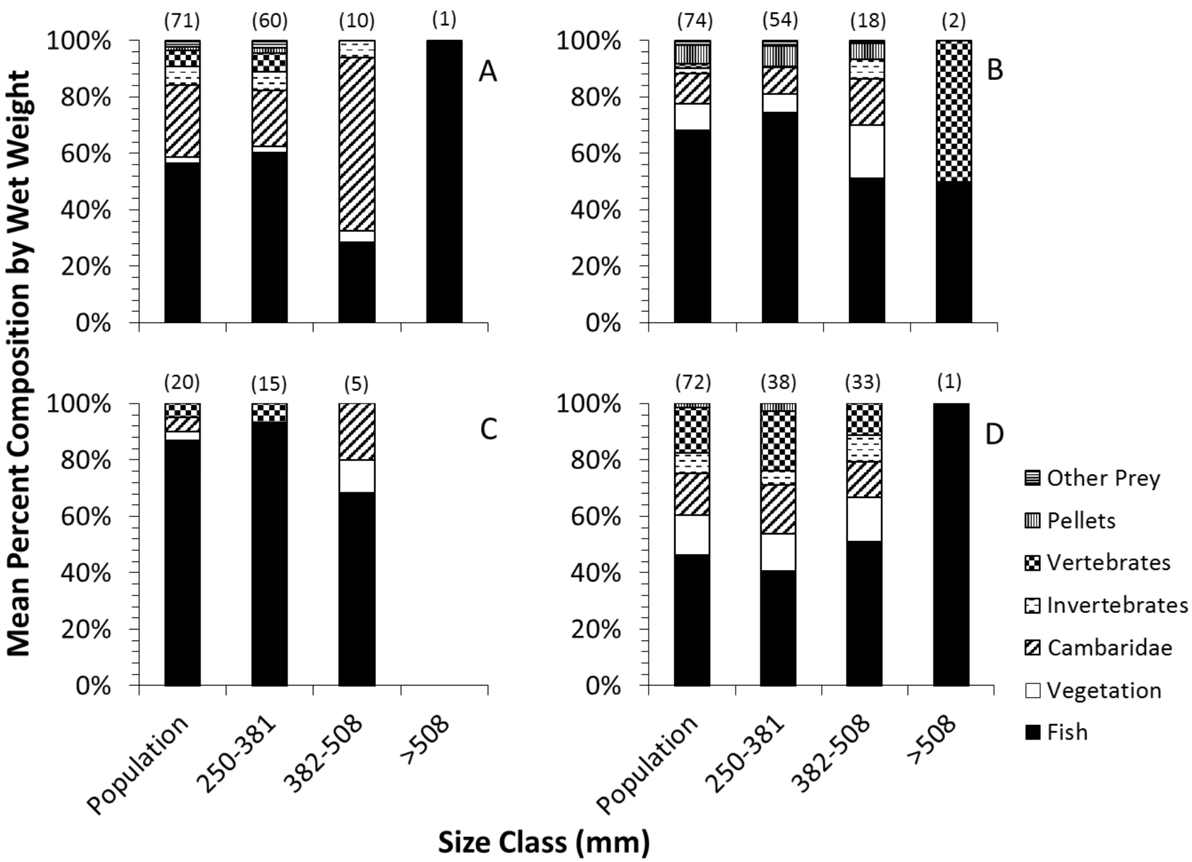

FIGURE 4.2. Mean percent composition by weight of major diet items collected from different size classes of Largemouth Bass sampled from Grand Lake, TX in May/June (A), July/August (B), September (C), and November (D), 2013. Numbers in parentheses represent sample sizes for different size classes.

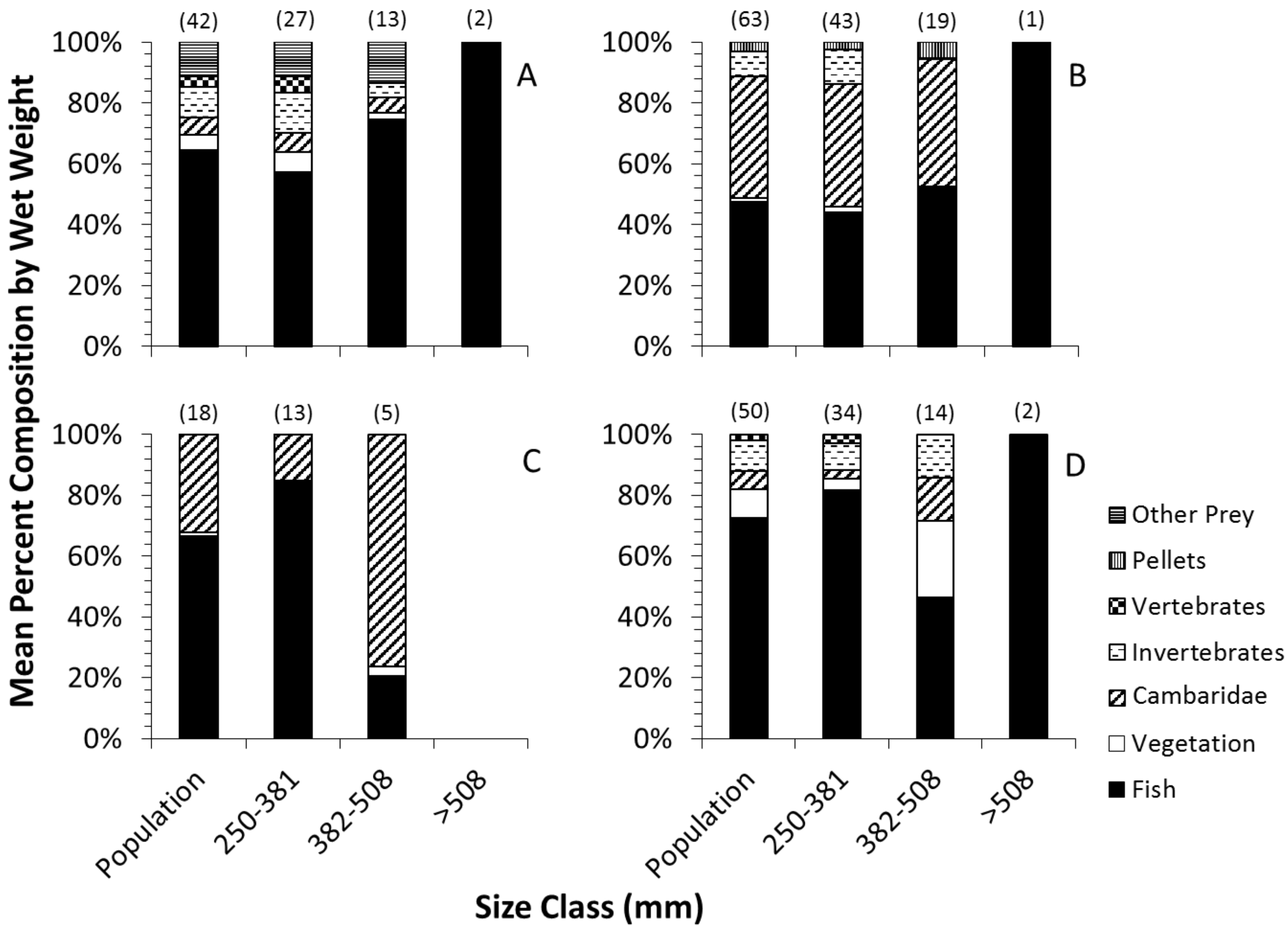

FIGURE 4.3. Mean percent composition by weight of major diet items collected from different size classes of Largemouth Bass sampled from Grand Lake, TX in February (A), May (B), July (C), and September (D), 2014. Numbers in parentheses represent sample sizes for different size classes.

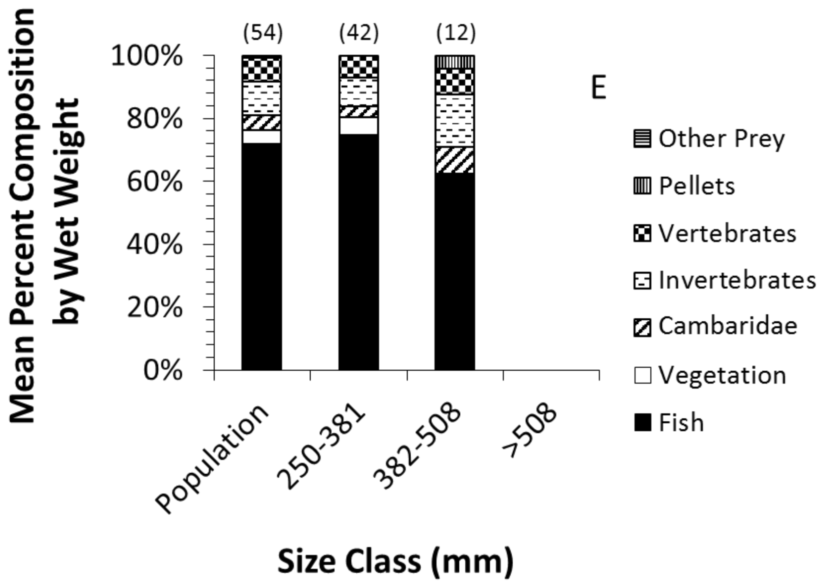

FIGURE 4.3 CONTINUED. Mean percent composition by weight of major diet items collected from different size classes of Largemouth Bass sampled from Grand Lake, TX in October (E), 2014. Numbers in parentheses represent sample sizes for different size classes.

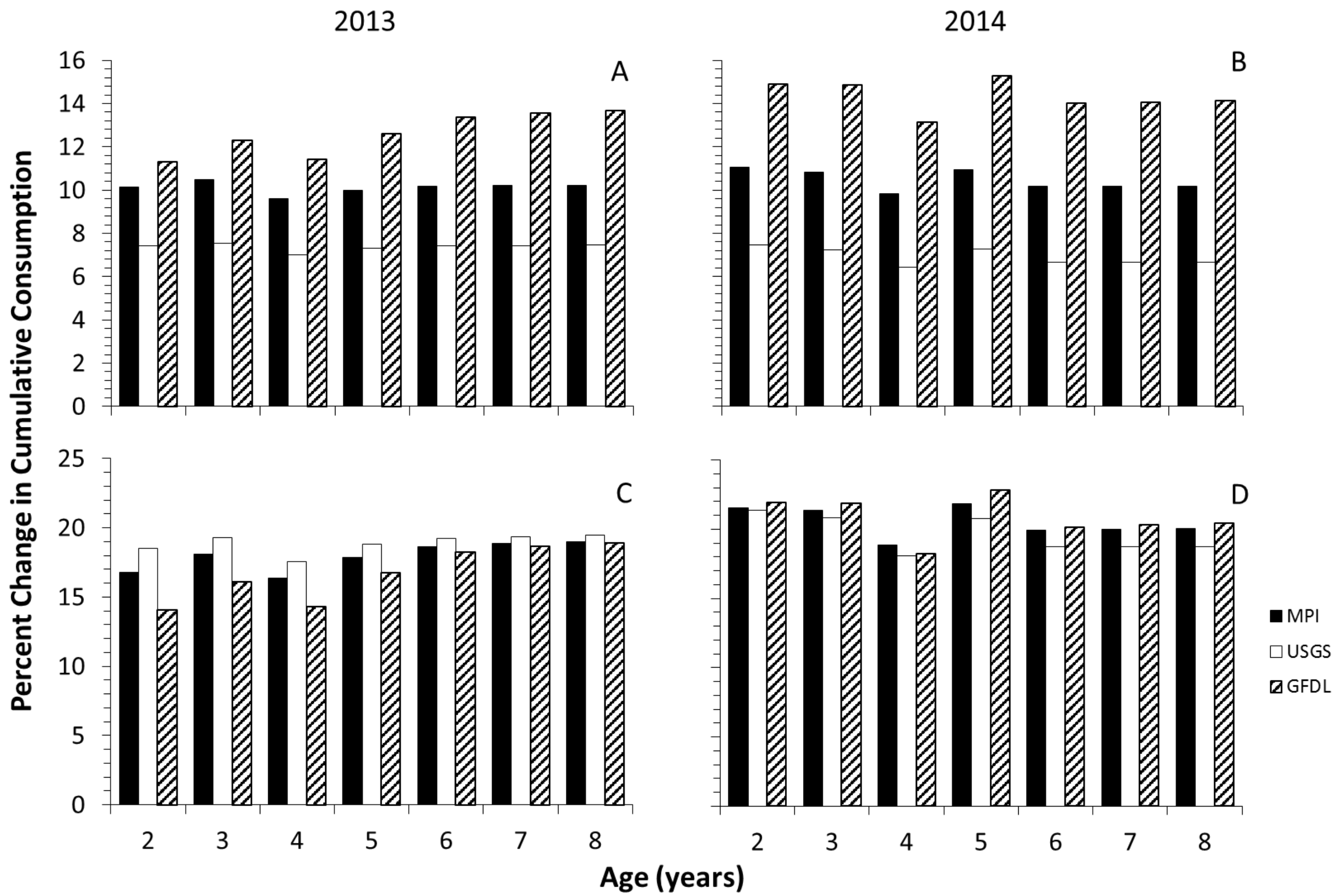

FIGURE 4.4. Percent Change in cumulative consumption of different age classes of Grand Lake Largemouth Bass simulated over three different climate change scenarios at two different time periods in the future. The top row represents Largemouth Bass sampled during the 2013 growing season (A) and 2014 growing season (B) simulated out to predicted 2040 temperature scenarios. The bottom row represent Largemouth Bass sampled during the 2013 growing season (C) and 2014 growing season (D) simulated out to predicted 2060 temperature scenarios.

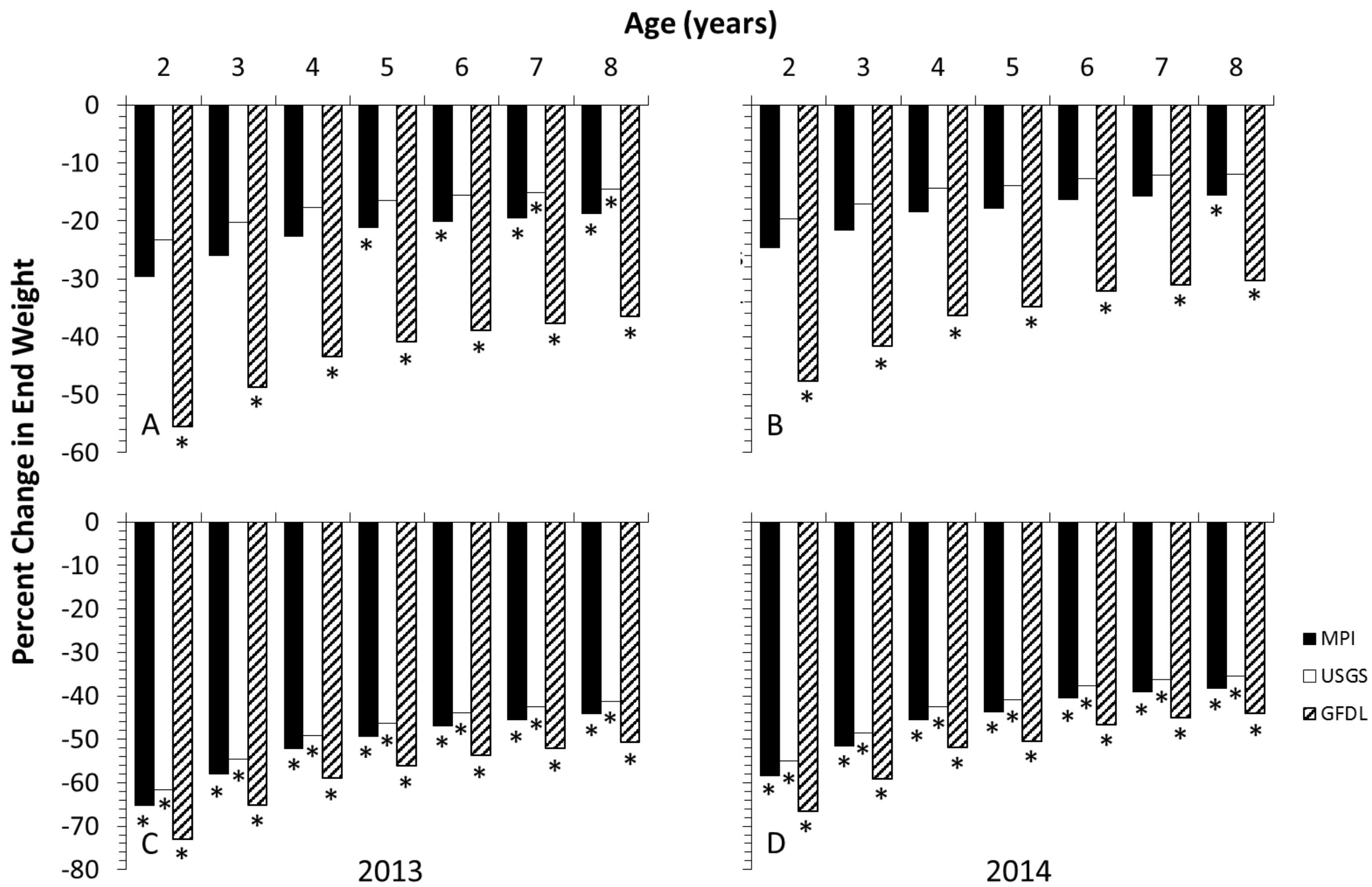

FIGURE 4.5. Percent change in end weights of different age classes of Grand Lake Largemouth Bass simulated over three different climate change scenarios at two different time periods in the future. The top row represents Largemouth Bass sampled during the 2013 growing season (A) and 2014 growing season (B) simulated out to predicted 2040 temperature scenarios. The bottom row represent Largemouth Bass sampled during the 2013 growing season (C) and 2014 growing season (D) simulated out to predicted 2060 temperature scenarios. Asterisks denote weight loss (i.e., did not consume enough to maintain baseline energetic requirements).

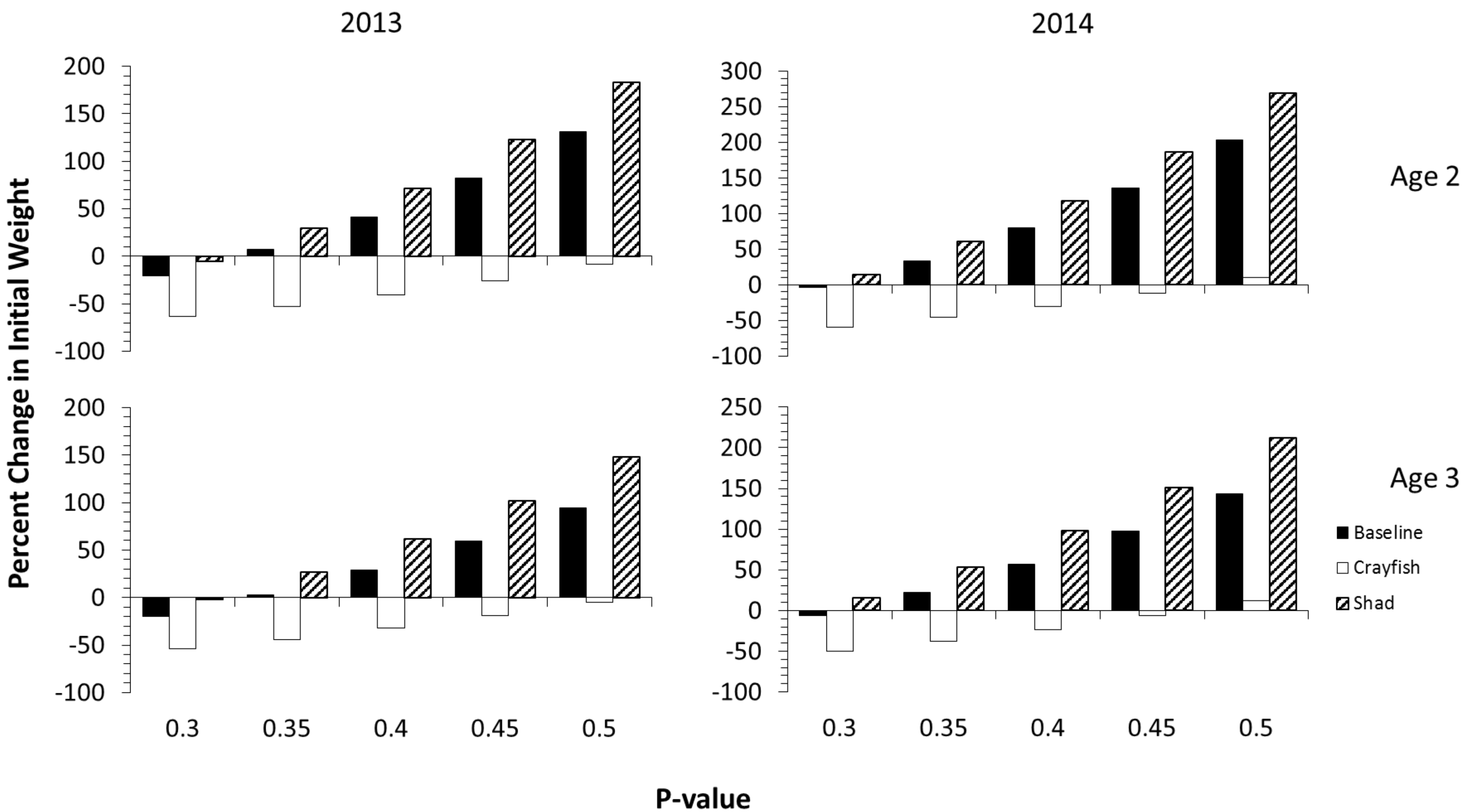

FIGURE 4.6. Percent change in initial weight for age-2 and age-3 Largemouth Bass sampled in Grand Lake, TX during the 2013 and 2014 growing seasons simulated over a range of p-values and three different diet scenarios (i.e., observed baseline diet, a diet of 100% crayfish, and a diet of 100% shad).

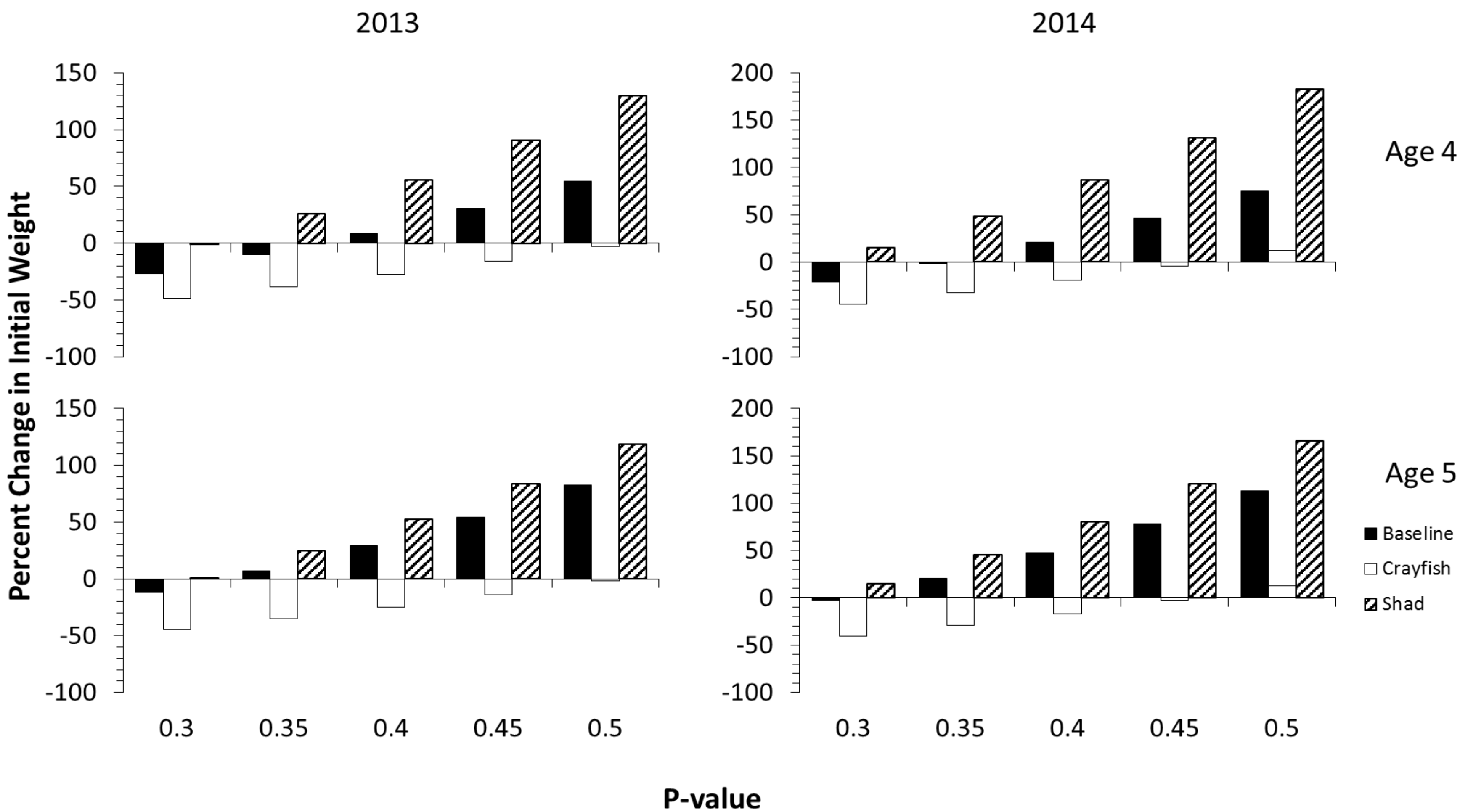

FIGURE 4.7. Percent change in initial weight for age-4 and age-5 Largemouth Bass sampled in Grand Lake, TX during the 2013 and 2014 growing seasons simulated over a range of p-values and three different diet scenarios (i.e., observed baseline diet, a diet of 100% crayfish, and a diet of 100% shad).

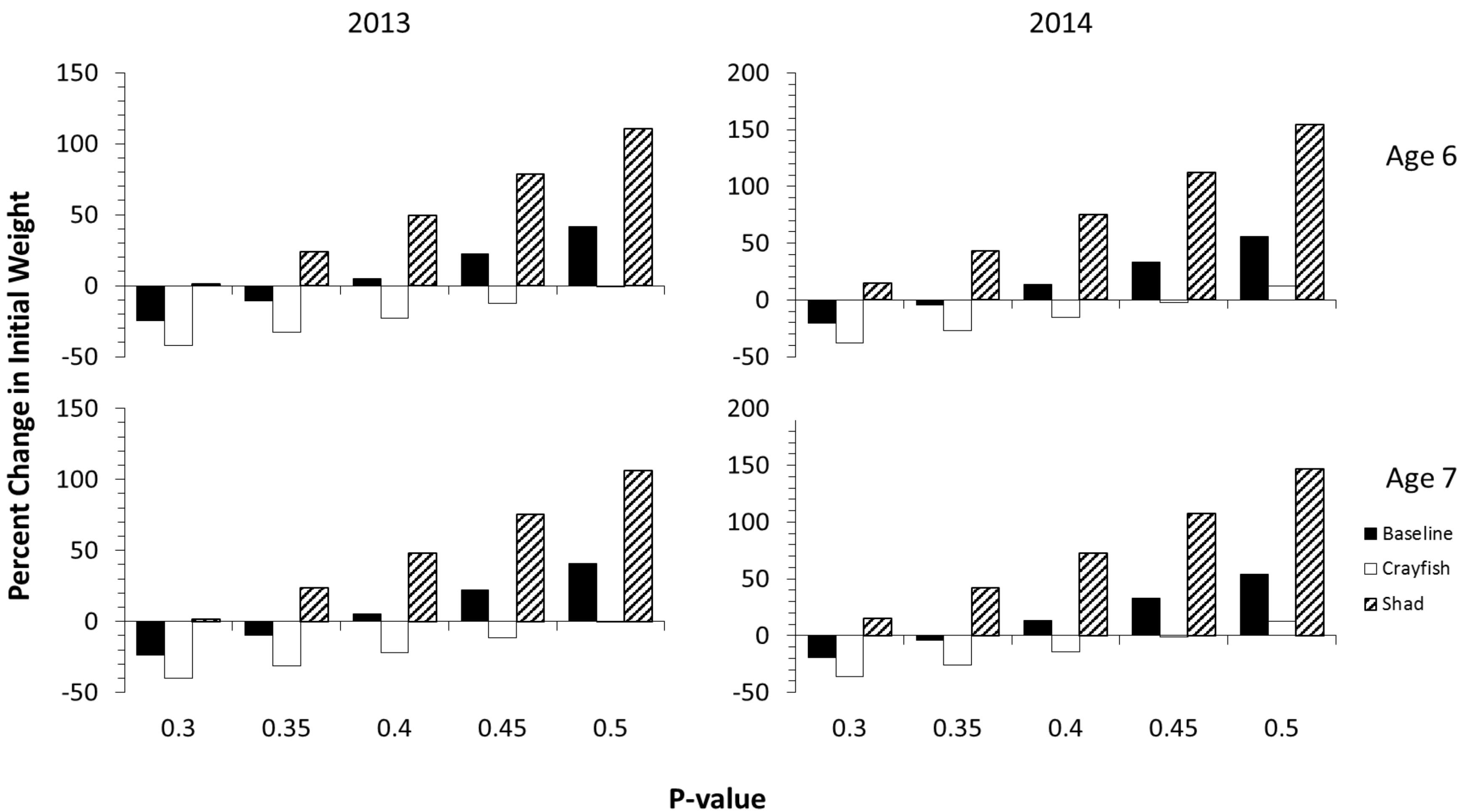

FIGURE 4.8. Percent change in initial weight for age-6 and age-7 Largemouth Bass sampled in Grand Lake, TX during the 2013 and 2014 growing seasons simulated over a range of p-values and three different diet scenarios (i.e., observed baseline diet, a diet of 100% crayfish, and a diet of 100% shad).

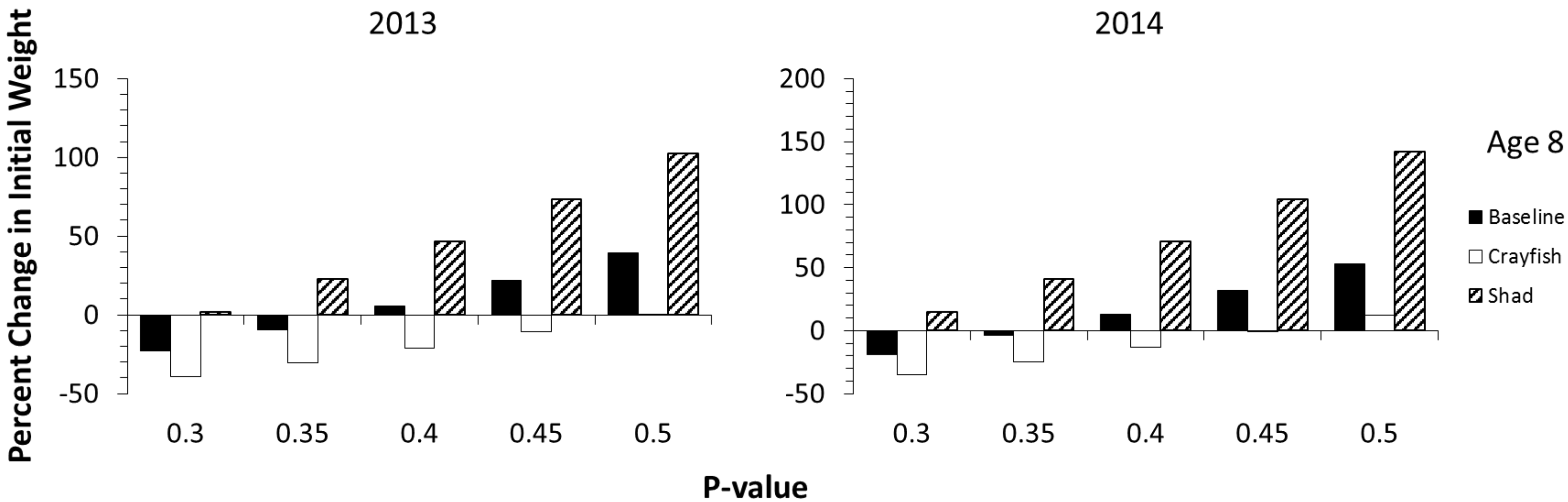

FIGURE 4.9. Percent change in initial weight for age-8 Largemouth Bass sampled in Grand Lake, TX during the 2013 and 2014 growing seasons simulated over a range of p-values and three different diet scenarios (i.e., observed baseline diet, a diet of 100% crayfish, and a diet of 100% shad).

CHAPTER 5: HABITAT PREFERENCE, HOME RANGE SIZE, AND MOVEMENT OF LARGEMOUTH BASS IN AN AGING RESERVOIR

Abstract

Habitat is essential for the recruitment/reproduction, growth, condition, survival of all animal species. Fisheries managers throughout the world face the challenge of managing habitat in aging reservoirs. As reservoirs age and habitat quality and quantity declines, fish movements may change and performance may decline. We quantified Largemouth Bass daily, seasonal, and annual use areas, daily movement rates, and habitat preferences (e.g., distance from shore, depth of water used, depth of Largemouth Bass) over 15 months in an aging reservoir to evaluate the effects of reduced habitat on movement and performance of Largemouth Bass. Seasonal use areas were large (mean of 4-5 ha) during the growing season but decreased during spring spawning. Annual use areas were also large with a mean >9 ha. Largemouth Bass showed seasonal movement patterns staying on average 30-50 m from shore throughout most of the growing season and winter and then moving closer to shore to spawn and then moving offshore again once spawning is complete. Largemouth Bass tended to use the coolest water in which optimal amounts of oxygen (i.e., >5 ppm) were still available. Daily movement rates (m/h) were significantly different among seasons with Largemouth Bass having the highest movement rates during the summer, although the only time of year when movement rates were significantly lower was during spring spawning. Largemouth Bass also showed significant differences in activity patterns throughout the day, being most active during low light periods (i.e., dawn and dusk). Daily telemetry showed that Largemouth Bass were closest to shore during spring, were an intermediate distance from

shore during winter, and were farthest from shore during summers and fall. Lack of habitat due to reservoir aging has resulted in large daily, seasonal, and annual activity patterns and is likely limiting the growth potential of Largemouth Bass in Grand Lake.

Keywords: Habitat preference, home range, movement, Largemouth Bass, aging reservoir

Introduction

Critical habitat type, quality, and quantity, is essential for the recruitment/reproduction, growth, condition, survival of animal species (e.g., Roth et al. 1996). If critical habitat is missing at any life stage of a species, health may decline, growth may slow, survival may decrease, the number of individuals an ecosystem can support may go down, or the species may even go extinct (e.g., Leidy and Moyle 1998; Dudgeon et al. 2006; Jelks et al. 2008). Several researchers have shown the importance of critical habitat to the performance of many animal species. For example, Kaibob mule deer (*Odocoileus hemionus*) had a 24.5% higher fawn crop following a significant habitat enhancement to their summer range and deer using the areas that received the habitat enhancement recovered from their poor winter condition much earlier in the spring than those deer that used areas that did not receive a habitat enhancement (Hungerford 1970). Additionally, Pough et al. (1987) found fewer salamanders in recently (i.e., <7 years) clearcut areas compared to old-growth forests and above ground activity was positively correlated with depth of leaf litter and percent cover of understory vegetation. Researchers have tried to predict how many acres of old-growth coniferous forests in the

Pacific Northwest must be preserved in order to prevent the northern spotted owl (*Strix occidentalis caurina*), a strict old-growth coniferous forest specialist, from going extinct (Lande 1988). Other examples of a species' need for critical habitat, the effects of habitat research and habitat management on a species of interest, and areas where information regarding critical habitat needs for a particular species abound in peer-reviewed literature (e.g., Guthery 1997; Herrnkind et al. 1999; Minns 2001; Miller et al. 2003; Hanley 2005).

Reservoirs and other man-made small impoundments can be found in most places where humans live throughout the world (Downing et al. 2006). Recent estimates of the number of small (i.e., <40 acres) man-made water bodies in the United States range from at least 2.6 million (Smith et al. 2002) to between 2.6 and 9 million (Renwick et al. 2005) and it has been estimated that these man-made water bodies cover approximately 21,000 km^2 (Smith et al. 2002; Downing et al. 2006). Additionally, many of these impoundments have different management objectives that may range from a balanced Bluegill (*Lepomis macrochirus*) and Largemouth Bass (*Micropterus salmoides*) fishery (Swingle 1950) to a trophy hybrid Striped Bass fishery (*Morone chrysops x Morone saxatillis*; Wright and Kraft 2012). Despite their frequency throughout the world, small man-made impoundments and reservoirs provide a unique challenge to maintain and manage critical habitat because of their aging (Kimmel and Groeger 1986). Immediately following completion of a reservoir or impoundment, there is often an initial spike in labile detritus and available habitat which coincides with a spike in plankton production followed by a significant pulse in fish production (Kimmel and Groeger 1986). However, this initial spike in overall system productivity is short lived as availability of detritus and habitat usually decrease due to basin filling, decreased internal nutrient loading, and habitat decomposition (Kimmel and Groeger 1986). Based on mean annual rate of reservoir filling, Kimmel and Groeger (1986) predicts that 50% of small reservoirs with a volume less than 123,348 m^3 would completely fill with sediment in 67 years and their usefulness would be impaired in just 30 years. Similarly, Renwick et al. (2006) predicted that between 30-90% of ponds constructed in the 1950s had either filled in with sediment or been converted to other land uses by 2000.

Since fishing is one of the most common uses of reservoirs and small impoundments in the United States (e.g., Kimmel and Groeger 1986; Dauwalter and Jackson 2005), managing fisheries in these water bodies can be difficult for fisheries managers given the rapid impoundment aging process and subsequent loss of habitat and production. Largemouth Bass are one of the most commonly stocked fish species in public and private impoundments (Dauwalter and Jackson 2005) and more anglers and fishing days were spent targeting Black Bass (*Micropterus spp*), than any other freshwater fish category in the U.S. (USDI 2011). Additionally, over the past several decades, there has been an increase in the desire among anglers to have quality fishing experience (i.e., catch trophy fish; Weithman and Anderson 1978) and especially among Largemouth Bass anglers (Forshage and Fries 1995). As a result, managers have been trying to create more trophy Largemouth Bass fisheries, especially in the southern United States (e.g., Gilliland and Whitaker 1989; Forshage and Fries 1995).

As fisheries managers try to create more trophy Largemouth Bass fisheries in reservoirs and small impoundments and especially aging impoundments, they must carefully evaluate and manage habitat in a water body of interest. Managing habitat is important because habitat has been shown to affect movement patterns, feeding strategy, and coincidentally growth of Largemouth Bass. For example, Wiley et al. (1984) found a parabolic relationship between aquatic macrophyte standing crop and Largemouth Bass production in small ponds, indicating an intermediate level of vegetation maximized Largemouth Bass production. Additionally, Sass et al. (2006) removed 75% of the coarse woody habitat from a treatment section of Little Rock Lake, WI and left a reference basin unaltered to compare feeding and growth of Largemouth Bass following a significant removal of habitat. Prior to the woody habitat removal in Little Rock Lake, Largemouth Bass in both basins consumed primarily aquatic prey (Sass et al. 2006). Following the woody habitat removal, Largemouth Bass in the treatment basin consumed less fish and grew more slowly than Largemouth Bass in the reference basin (Sass et al. 2006). In a similar study, Ahrenstorff et al. (2009) found that Largemouth Bass in lakes in northern Wisconsin with lower densities of coarse woody habitat had significantly larger home ranges and consumed less prey. In that same study, Ahrenstorff et al. (2009) hypothesized that when coarse woody debris densities decreased, Largemouth Bass switched from a sit-and-wait foraging strategy to one which Bass actively searched for prey. When using an actively searching foraging strategy Ahrenstorff et al. (2009) proposed that Largemouth Bass spend extra energy searching for food and growth may slow.

Furthermore, Largemouth Bass are ectotherms whose behavior and physiological processes can be influenced by temperature (McCauley and Kilgour 1990). Largemouth Bass are considered a warm water fish species with an optimal temperature range of 26 – 28°C (Coutant & Cox 1976) with equilibrium loss occurring at approximately 36°C and death occurring between 36 and 42°C for Largemouth Bass acclimated to water temps >24°C at the start of experiments to test upper thermal maxima under dynamic thermal changes (Smith and Scott 1975; Fields et al. 1987; Smale and Rabeni 1995; Beitinger et al 2000). If water temperatures in a given part of a waterbody exceed the upper limit for which a Largemouth Bass could account for increased water temperatures through physiological processes such as increased cardiac function, Largemouth Bass may seek out other portions of the water body with more preferred temperatures. For example, Schreer and Cooke (2002) found that Smallmouth Bass (*Micropterus dolomieu*) adjusted for changes in water temperature by adjusting cardiac function when water temperatures were low during winter and spring. However, when water temperatures reached 25-30°C, Smallmouth Bass attempted to locate thermal refuge by moving to different areas of the lake with cooler water because their cardiac function alone could not account for increased water temperatures (Schreer and Cooke 2002). Knowledge of Largemouth Bass behavioral responses and movement patterns to summer water temperatures that may exceed the range for which their body can account for by increasing cardiac function could aid in the management of this species.

Grand Lake is a 45ha private impoundment located in eastern Texas that was built in the 1950s. The current management goal of Grand Lake is to be able to consistently grow 6.8kg Largemouth Bass. To achieve this goal, Grand Lake was intensively managed through maintenance of the food web. Available prey fish in Grand Lake include Bluegill, Redear Sunfish (*Lepomis microlophus)*, Redbreast Sunfish (*Lepomis auritus*), Gizzard Shad (*Dorosoma cepedianum*), Threadfin Shad (*Dorosoma petenense)*, Mozambique Tilapia (*Oreochromis mossambicus*), Black Crappie (*Pomoxis nigromaculatus*), White Crappie (*Pomoxis annularis*), Channel Catfish (*Ictalurus punctatus*), and Black Bullhead (*Ameiurus melas*), among others. Additionally, an intense feeding program is used on Grand Lake including10 fish feeders. Grass Carp (*Ctenopharyngodon idella)* have been stocked to remove all submersed aquatic vegetation and water lotus (*Nelumbo lutea*) are chemically treated each year. Aside from vegetation control, little is known about available habitat for Largemouth Bass in Grand Lake, and not much additional habitat management takes place. Given that Grand Lake is over 50 years old and all aquatic vegetation is removed from the lake, this reservoir could be experiencing the effects of an aging reservoir and habitat could be limiting growth of Largemouth Bass. Additionally, given Grand Lake's southern latitude, summer water temperatures could easily exceed the upper thermal optimum for Largemouth Bass, at least in part of the water column, thus affecting behavior of Largemouth Bass and habitat available to them during warm water periods. The objectives of our study were to: 1.) Quantify seasonal and annual use areas of Largemouth Bass in Grand Lake; 2.) Quantify seasonal patterns in Largemouth Bass movement patterns (i.e., distance from shore, depth of water used, and depth of Largemouth Bass during summer stratified months) in Grand Lake; 3.) Quantify daily movement rates, distances moved, daily home range size, and daily movement patters (i.e., distance from shore and depth of water used) in Grand Lake.

Methods

Study site

Grand Lake is a 45ha private impoundment located in eastern TX, USA. Grand Lake was built in the 1950's and was one of the first impoundments in the state of Texas stocked with pure Florida parental type Largemouth Bass (*Micropterus salmoides floridanus*) by the Texas Parks and Wildlife Department. Florida Largemouth Bass alleles continue to dominate the genetic makeup of the Largemouth Bass population in Grand

Lake (Chapter 1). A detailed bathymetric map was created by PondMedics© in January, 2012 and the lake border and 0.305m contours (GIS shapefiles) from that mapping were used in this study (Figure 5.1) Grand Lake is a eutrophic (secchi disc readings $\leq$ 0.75 m year round) impoundment with a mean depth of 3.2 meters, a maximum depth of 7.9 meters, and fairly steep banks throughout most of the littoral zone as shown by the 0.305m contours (Figure 5.1). The fish community of Grand Lake is very diverse including all species listed in the introduction as well as Coppernose Bluegill (*Lepomis macrochirus purpurescens*), Flathead Catfish (*Pylodictis olivaris*), Common Carp (*Cyprinus carpio*), and Brook Silverside (*Labidesthes sicculus*). As mentioned earlier, Grand Lake is depauperate of any submersed aquatic vegetation and rooted floating aquatic plants due to biological and chemical control, yet the majority of the water <1m in depth is composed of a diverse community of emergent aquatic plants.

Field methods-Weekly Telemetry

Forty two Largemouth Bass had Advanced Telemetry Systems© (ATS) F1235 Fish Body Implant tags (dimensions = 18 x 78 mm; weight = 30 g) surgically implanted into their abdominal cavity between May, 2013 and May, 2014. F1235 radio tags are also temperature sensitive and can be used to asses depth of radio tagged Largemouth Bass when there is a range of water temperatures within a given water body (e.g., during stratification). Radio tags were implanted in 22 Largemouth Bass between May 25, 2013 and June 11, 2013. Two of these Largemouth Bass died within two weeks after surgery and their tags were collected and implanted in Largemouth Bass in later surgeries. Radio tags were also surgically implanted in 11 Largemouth Bass between November 1, 2013 and November 2, 2013 and nine Largemouth Bass between May 28, 2014 and May 30,

2014. Largemouth Bass were sampled via a combination of angling (N = 10) and pulsed DC electrofishing (N = 32). Surgically implanted Largemouth Bass ranged in size from 446-601mm Total Length (TL; Figure 5.2) and weighed between 1345 and 4010g. All but two Largemouth Bass weighed 1500 grams, the minimum weight required to satisfy the 2% rule presented by Winter (1983, 1996). Of the two fish that for which the tags weighed more than 2% of the Largemouth Bass, the radio tags weighed 2.2 and 2.0004% of the weight Bass; thus they were very close to satisfying the 2% rule. Additionally, other researchers have suggested that radio tags that weigh 2-3% of the body mass can be used without affecting the physiology or behavior fish (Lefrancois et al 2001; Jadot et al. 2005; Zale et al. 2005)

All surgeries to implant radio tags were completed following similar methods to those described by Cooke et al. (2003). Largemouth Bass were initially anesthetized in a tub containing 60ppm clove oil. Once anesthetized, Largemouth Bass length and weight were measured and they were transferred to a surgery trough made out of polyvinyl chloride (PVC) board. While in the surgery trough, water which contained 30ppm clove oil was continuously pumped over the Largemouth Bass' gills to keep the Largemouth Bass alive and anesthetized. A slit in the bottom of the surgery trough allowed for excess water to drain from the trough and keep water out of the incision during surgery. A small 20-25mm incision was made to the side of the midventral line using a disposable #10 scalpel. After the tag was inserted, the incision was sutured shut using four interrupted sutures using a 3-0, 3/8 circle reverse cut needle and 24mm black nylon monofilament suturing material. All non-disposable tools and tags were disinfected with an ethanol solution between all surgeries (Winter 1996). Following completion of surgery, all

Largemouth Bass were allowed to recover for at least a half hour in an aerated recovery tank and then released at the location from which they were captured at or off a dock near the location of the surgeries.

All Largemouth Bass were allowed a 2-3 week recovery period following release to resume normal behavior prior to the start of tracking a fish. Tracking was conducted using an R4500 Challenger Receiver (3-5m accuracy; ATS) and a 3-way yagi antenna (ATS). The zero-point tracking method described by Nelson (1990) and Cooke et al. (2012) was used throughout the duration of this study to find all Largemouth Bass. In order to locate a fish using this method, the gain on the receiver was progressively turned down as the tracker approached the Largemouth Bass. Once the gain was turned to near zero and a strong signal was being received omnidirectionally, a GPS point was marked using the receiver or a Garmin© GPSMAP78 hand held GPS (3-5m accuracy). This was considered the location of the Largemouth Bass. All tracking was conducted using a 5m john boat with a 30 or 35lb thrust electric trolling motor so as not to disturb the Largemouth Bass. We estimate accuracy of this method to be ≤5m and were not concerned with this method interfering with fish behavior or disturbing individual fish because of the use of a poor water clarity (i.e., <.75m secchi disc depth year round) and the use of a small electric motor. In order to validate the accuracy of this method, individual tags were placed at different depths in the water column and a buoy was floated directly above the location. Relationships between distance from the buoy, the gain on the receiver, and the signal strength of the receiver were developed to aid the tracker in approximating distance from the tag based on gain and signal strength of the receiver.

Largemouth Bass were tracked and GPS locations recorded over two different sampling frequencies for the duration of the study. The first sampling frequency involved weekly tracking (i.e., every Largemouth Bass located once per week; e.g., Thomspon et al. 2005) beginning on June 15, 2013 and continued until September 10, 2014. Weekly tracking data was used to assess broad scale movement patterns and habitat preferences and asses seasonal and annual use areas. Three different eight hour time intervals were used (i.e., mid-day = 0800-1559, evening = 1600-2359, and overnight = 0000-0759) when conducting weekly telemetry to account for differences in movement and habitat use at different times of the day. The three different time intervals were used in a stratified random fashion with the evening time period used the week following mid-day time period and the overnight time period used the week following the evening time period, etc. The only exception was during the fall when dense fog on most nights prevented the use of the overnight time period some weeks. If fog prevented using the overnight time period, one of the other two time periods was randomly used to get location data each week.

For each weekly sampling event, tracking began at the start time for the assigned time interval for that week (i.e., 0800. 1600, or 0000) and ended at the end of the eight hour time period for that week. If all fish were not located within the eight hour time frame on the first day of tracking for the week, tracking began at the same start time the next day and continued on the second day until all fish were located. Tracking never took more than two days to find all Largemouth Bass within a given week and the assigned sampling time period. Additionally, the entire lake was searched until all Largemouth Bass were found each week within the confines of the assigned time interval.

Immediately after locating a fish, the temperature of that fish was recorded using the R4500 Challenger Receiver programmed with the regression formulas provided by ATS for each radio tag. A temperature/dissolved oxygen profile was taken at each of four evenly spaced locations throughout the length of the reservoir using an YSI ProODO Optical Dissolved Oxygen Instrument (YSI Inc/Xylem Inc©) beginning two hours and six hours into the time interval used (Figure 5.1). For example, for the mid-day time interval, temperature and dissolved oxygen profiles began at 1000 and 1400. This meant that each Largemouth Bass was located within two hours of a temperature/dissolved oxygen profile. A Largemouth Bass was considered dead if the fish did not move for 3 consecutive sampling locations and the last time that Largemouth Bass moved last location used for analyses.

Data Analysis-Weekly Telemetry

Weekly telemetry locations were used to calculate 95% and 50% seasonal use areas (Mohr 1947; Odum and Kuenzler 1955; Rogers and White 2007) for each Largemouth Bass. Seasons were three months in duration with summer extending from June through August, fall from September through November, winter from December through February, and spring from March through May. Seasonal use areas were only calculated for Largemouth Bass that had at least 10 marked locations for a given season. For example, if a Largemouth Bass died with only seven locations collected during a season, that individual Largemouth Bass was not included in seasonal use area calculations. The adehabitatHR, sp, and maptools packages in program R were used to calculate 95% and 50% minimum convex polygon seasonal use areas (Pebesma and Bivand 2005; Calange 2006; Bivand et al. 2013; Bivand and Lewin-Koh 2015; R Core

Team 2016). Subsequently, seasonal use areas were clipped by the lake border from the bathymetric map to calculate final use areas using the clip tool in ArcGIS 10.2.2. Both mean 95% and 50% seasonal use areas were compared using repeated measures linear mixed effects models in Program R (packages lme4, pbkrtest, and lsmeans; Bates et al. 2014; Halekoh and Højsgaard 2014; Lenth 2016) with season (i.e., summer 2013, fall 2013, winter 2013/2014, spring 2014, and summer 2014) as a main effect and individual fish as a random effect. To test whether significant differences existed among season, an ANOVA was used to compare a baseline mixed effects model (i.e., base) without season as a main effect to a mixed effect model with season (i.e., season) as a main effect. A TukeysHSD multiple range test was used to assess what seasons had different use areas if differences existed in seasonal use areas at an alpha of 0.05. Seasonal use areas (i.e., 95% and 50%) were natural log transformed to meet the assumptions of normality and equal variance. Annual use areas were calculated for Largemouth Bass tagged in May/June 2013 and November 2013 using the same methods described above to calculate seasonal use areas. The first year of tracking (i.e., June, 2013 – May, 2014) was used to calculate annual use areas for Largemouth Bass tagged in May/June, 2013. Tracking ended in September, 2014 and therefore, we do not have a full year of tracking data for Largemouth Bass tagged in November, 2013. Annual use areas were only calculated for Largemouth Bass with at least 10 GPS locations. No analyses were conducted on annual use areas due to only one year of data.

Weekly telemetry locations were also used to calculate mean distance from shore and mean depth of water used for each tracking event throughout the duration of weekly tracking (i.e., June, 2013 – September, 2014). The near tool in ArcGIS 10.2.2 was used to calculate the minimum distance from shore for each telemetry location. The lake border from the bathymetric map created in January 2012 was used as the shore for all distance from shore calculations. Reservoir levels fluctuated less than ~0.305 most of the year making this a representative shore edge. Depth of water in which the Largemouth Bass was located was also calculated using the near tool in ArcGIS 10.2.2. The nearest 0.305 contours from the bathymetric map was assumed to be the depth of water the Largemouth Bass was using. Mean available water temperature was calculated for each day that Largemouth Bass were located during weekly telemetry by calculating the mean of all water temperatures that had at least 2.5 mg/liter of O_2 (Cech et al. 1979) at the four locations where temperature and dissolved oxygen profiles were taken. Plots of mean distance from shore, mean available water temperature, and mean depth of water used were created to asses patterns in Largemouth Bass movement throughout the year.

The combination of the GPS location of a given Largemouth Bass, the observed water temperature of that Largemouth Bass, and the nearest temperature/dissolved oxygen profile taken at the closest time to the Bass' location were used to assign a depth to each Largemouth Bass using only days when Grand Lake was stratified during the months of June through August. Grand Lake was not stratified during most of the rest of the year. Additionally, depths were not assigned to Largemouth Bass located during the 0000-0759 sampling interval because Grand Lake surface temperatures cooled and depths were difficult to assign for this time period due to reduced stratification. Therefore, depths of Largemouth Bass were only assigned for tracking events between June and August that started at 0800 or 1600. Furthermore, if tracking took place over two days, all available water temperatures, fish temperatures, etc. were pooled across both days and considered one tracking event. The near tool in ArcGIS 10.2.2 was used to asses which temperature/dissolved oxygen profile was closest to the location of the Largemouth Bass on the date of tracking. When assigning a depth to an individual Largemouth Bass, an actual depth of water was assigned as well as the minimum and maximum possible depth based on +/- 0.5°C accuracy of the radio tags (ATS). For example, if the recorded temperature of a Largemouth Bass was 28.5°C, then the assigned depth was the depth of water at 28.5°C and the minimum and maximum depths of water that Largemouth Bass could have occurred were the depths associated with 29.0 and 28.0°C, respectively. Mean assigned depths and minimum depths and maximum depths were calculated for the 0800 and 1600 time periods for each of the two seasons in which water temperatures were stratified (i.e., June through September). Furthermore, the deepest water assigned to a Largemouth Bass was the depth of water the individual was found in or the depth of water with at least 2.5 mg/liter O_2 (Cech et al. 1979), whichever was shallower.

Mean maximum available temperature (i.e., mean temperature at 0.305 m under the surface), mean available temperature (i.e., mean temperature throughout the water column with at least 2.5 mg/liter O_2), mean minimum temperature with at least 2.5 mg/liter O_2, and mean minimum temperature were calculated from each of the four locations at which temperature/dissolved oxygen profiles were taken on each day a depth of water was assigned to Largemouth Bass. Additionally, mean maximum available dissolved oxygen (i.e., mean dissolved oxygen at 0.305 m under the surface), mean available dissolved oxygen (i.e., mean dissolved oxygen throughout the water column with at least 2.5 mg/liter O_2), mean minimum dissolved oxygen with at least 2.5 mg/liter O_2, and mean minimum dissolved oxygen were also calculated from each location where temperature/dissolved oxygen profiles were taken. Simple linear regression models were used to compare mean observed Largemouth Bass temperature to mean available water temperature as well as compare mean observed Largemouth Bass dissolved oxygen (dissolved oxygen at the assigned depth of each Largemouth Bass) to mean available dissolved oxygen. The response variable was in the regression models was either water dissolved oxygen or water temperatures and the main effects were date, fish temperatures, and the interaction between fish temperatures and date. All models were run using the lm function in Program R.

Field Methods-24 Hour Telemetry

The second sampling frequency involved daily tracking which was used to assess fine scale movement patterns and habitat preferences (i.e., depth and distance from shore). For each daily sampling event, five radio tagged Largemouth Bass were randomly selected and tracking of these five Bass began at 0800 hours using the methods described above and GPS locations were again marked using the R4500 Challenger Receiver or a Garmin© GPSMAP78 hand held GPS. These same five Largemouth Bass were then located every four hours (i.e., tracking began again at 1200, 1600, etc.) for a 24 hour period and tracking ended by finding the same five fish at 0800 the following day. This resulted in seven GPS points for each of the five fish over the 24 hours period. Twenty four hour telemetry was conducted four times during summer, 2013, two times during fall, 2013, three times during winter, 2013/2014, one time during spring, 2014, and four times during summer, 2014. Five different Largemouth Bass were randomly selected (i.e., random selection without replication) for each tracking event within a given season (i.e., summer 2013) to get account for variability in movements of individual fish. The only exception was summer, 2013 when one fish was tracked on two separate tracking occasions due to fewer than 20 Largemouth Bass available by the fourth tracking event.

Data Analysis-24 Hour Telemetry

The minimum distance (m) between consecutive tracking points was calculated for each Largemouth Bass for the duration of the 24 hour tracking period. Distances were constrained by the lake border from the bathymetric map, forcing all Largemouth Bass to travel within the lake boundary between consecutive points. Minimum distances were calculated in program R using the raster, gdistance, and rgdal packages (Hijmans 2015; van Etten 2015; Bivand et al. 2016). Initially, these packages converted the lake polygon into a raster data set with 1 m cells prior to calculating distances between points. Mean distances (m) between consecutive points were calculated for each time interval between four hour location events (i.e., 0800-1200) for each of the five seasons. Additionally, Largemouth Bass movement rates (m/h) were calculated by dividing the minimum distance between consecutive points by the time elapsed between each check for an individual Largemouth Bass. Movement rates were calculated because exactly four hours did not pass between each time an individual Largemouth Bass was located within a given tracking event. Mean movement rates were calculated for each time interval between four hour location events for each of the five seasons. A repeated measure mixed effect factorial was used to compare mean movement rates among seasons and times of day. Season, time of day, and the interaction between season and time of day were considered main effects with individual fish considered a random effect. To test whether a significant interaction existed between season and time of day, and ANOVA was used to compare a mixed effect model with a significant interaction term (i.e., Interaction) to a model with season and time of day as additive effects (i.e., Additive). If no interaction existed, mixed effects models with the main effect of only season (i.e., Season) and only time of day (i.e., Time of Day) were compared to a model without the main effects included (i.e., baseline) using ANOVA to quantify which main effect(s) were significant. Analyses were conducted in Program R using the lme4, pbkrtest, and lsmeans packages (Bates et al. 2014; Halekoh and Højsgaard 2014; Lenth 2016; R Core Team 2016). Data were natural log transformed to meet the assumptions of normality and equal variance. A TukeysHSD multiple range test was used to assess where movement rates differed in season or time of day if significant differences in movement rates were detected at an alpha of 0.05.

Additionally, the seven consecutive locations for an individual Largemouth Bass on each tracking event were used to calculate a 100% daily use area. The same methods and packages described above for seasonal use areas were used to calculate 100% daily use areas. Mean daily use areas were then compared among the five seasons using a repeated measure mixed effect model with season as a main effect and individual fish as a random effect. The same packages described above used to compare mean seasonal use areas from the weekly telemetry data were used to compare daily use areas across season. A TukeysHSD multiple range test was used to assess what seasons had different daily use areas if differences existed in mean daily use area at an alpha of 0.05. Daily use areas were natural log transformed prior to analyses to meet the assumptions of normality and equal variance. Using the same methods described above to calculate distance from shore and depth of water used by Largemouth Bass during weekly tracking, mean distance from shore and depth of water used were calculated for each starting time or time of day (e.g., 0800, 1200, 1600) for each season. A repeated measure mixed effect factorial was used to compare mean distance from shore among seasons and times of day. No analyses were conducted on depth of water used due to the correlation between distance from shore and depth of water used. Season, time of day, and the interaction between season and time of day were considered main effects with individual fish considered a random effect. The same methods used to determine if there was a significant interaction terms and main effects with movement rate as the response variable was repeated expect distance from shore was the response in this analysis. Analyses were conducted in Program R using the same packages described above. Data were natural log transformed to meet the assumptions of normality and equal variance. A TukeysHSD multiple range test was used to assess where distances from shore differed in season or time of day if significant differences in distance from shore were detected at an alpha of 0.05.

Results

Weekly Telemetry

Both 95% and 50% use areas differed significantly among seasons (Table 5.1; Table 5.2; Figure 5.3). In general, times of year with the highest water temperatures (i.e., summer and fall) had the highest seasonal use areas with summer, 2013 having a mean 95% seasonal use area of just under 5 hectares, summer, 2014 having a mean 95% seasonal use area of just under 4.5 hectares and fall, 2013 having a mean 95% seasonal use area of just under 4 hectares (Figure 5.3). Mean 50% seasonal use areas showed the same pattern with use areas ranging between 0.7 and 1.5 hectares for summer, 2013, summer, 2014 and fall, 2013 (Figure 5.3). Both 95% and 50% use areas were smallest during the spring season (i.e., March through May) when Largemouth Bass were spawning with a 95% seasonal use area of 1.6 ha and a 50% seasonal use area of 0.26 hectares (Figure 5.3). Mean winter 95% and 50% seasonal use areas were intermediate between spring seasonal use areas and seasonal use areas during both summers and fall and were not significantly different than either spring or warm water seasonal use areas (Figure 5.3). Annual use areas were large with a mean 95% annual use area of 9.25 hectares (standard error = +/- 1.51 ha) and a mean 50% annual use area of 2.6 hectares (standard error =+/- 0.65 ha).

Largemouth Bass distance from shore and depth of water used showed seasonal trends (Figure 5.4). During summer and fall, 2013, and winter, 2013/2014, Largemouth Bass tended to average 30-50 m from shore and used water between 2.5 and 4.0 m deep (Figure 5.4). Mean distance from shore and depth of water used during summer and fall, 2013 and winter, 2013/2014 was variable depending on the date, although no statistics were calculated to test for significant differences (Figure 5.4). As water temperatures began to warm in the beginning of March, 2014, Largemouth Bass distance from shore and depth of water used decreased to distances of approximately 20m from shore and 1.5m depth of water used (Figure 5.4). As water temperatures warmed beginning at the end of April/beginning of May, Largemouth Bass moved offshore again with mean distances from shore of 30-50m and mean depth of water used between 2.5 and 4m (Figure 5.4). Again, during warm water times during summer, 2014, distances from shore and depth of water used were variable depending on the date (Figure 5.4).

Grand Lake was polymictic throughout the summer, with the lake breaking stratification several times throughout the growing season (Figure 5.5, Breeggemann, unpublished data). Overall, slight differences were observed between mean fish temperatures and mean available water temperatures with fish often having slightly lower observed temperatures than available water temperatures, but these differences were not determined to be significant (Table 5.3). The only significant main effect in our model was date, indicating temperatures on different dates were significantly different from one another. Furthermore, no differences were detected between observed fish dissolved oxygen levels and mean available dissolved oxygen levels with the no significant main effects (Table 5.4). Additionally, mean depth of Largemouth Bass on days in which Grand Lake was stratified were approximately 2m on most days (Figure 5.6). Two meters of depth tended to coincide with the top of the thermocline in most instances. These results indicate that Largemouth Bass were selecting for the coolest available water in which dissolved oxygen levels were still comfortable. Temperatures were not adding so much stress that Largemouth Bass had to seek out the coolest available water with the bare minimum amounts of dissolved oxygen to still survive.

24-hour Telemetry

Daily 24-hour telemetry was conducted four times during summer, 2013, two times during fall, 2013, three times during winter, 2013/2014, one time during spring, 2014, and four times during summer, 2014. Daily movement rates (m/h) and daily distances move (m) were variable depending on season and time of day (Figure 5.7). Highest mean daily movement rate for any season and time of day was >60m/h whereas lowest mean daily movement rate for any season and time of day was <5m/h (Figure 5.7). A significant interaction term was not found when comparing mean movement rates across seasons and time of day, indicating that pattern in movement across different times of day was the same among seasons (Table 5.5). However, there were significant differences in movement rates when comparing main effects individually (i.e., seasons to one another and times of day to one another; Table 5.5). Similar to what was observed when comparing seasonal use areas to one another from weekly telemetry data, daily movement rates were highest during warm water seasons (i.e., summer, 2013, fall, 2013, and summer 2014; Figure 5.7; Figure 5.8). Furthermore, daily movement rates were the lowest during spring, 2014 which were significantly lower than all other seasons except fall, 2013 (Figure 5.7; Figure 5.8). Significant differences among movement rates (m/h) over different times of day were complicated, although Largemouth Bass tended to show crepuscular behavior, being most active during low light conditions, with the highest activity taking place between the hours of 16:00 and 20:00 (i.e., late afternoon towards dusk) and 04:00 and 08:00 (i.e., early morning towards dawn; Figure 5.7; Figure 5.8). Largemouth Bass daily movement rates were lowest overnight, although these rates were not significantly lower than some other times of the day (Figure 5.7; Figure 5.8).

Trends in daily use areas across seasons followed trends in daily movement rates across seasons. Significant differences existed in daily use areas across seasons with warm water periods having the highest daily use areas (Table 5.6; Figure 5.9). Observed daily use areas were highest during the summer, 2014 season with daily use areas averaging almost 4 ha (Figure 5.9). Daily use areas from summer, 2013, fall, 2013, and winter, 2013/2014 were smaller than summer, 2014 but were not significantly smaller (Figure 5.9). Daily use areas during spring, 2014 were significantly smaller than all other seasons except winter 2013/2014 with spring, 2014 having an observed daily use area of ~0.1ha (Figure 5.9). Small spring, 2014 daily use areas were likely due to spawning occurring during spring daily telemetry tracking. Back-transformed mean daily use areas for winter 2013/2014 were much smaller than observed daily use areas during winter 2013/2014 because two of the 15 daily use areas during this season were very large and the rest were <1ha and when data were log-transformed, these two large use areas had a much smaller influence on the mean daily use area for this season.

Again similar to what was observed from weekly telemetry data, distance from shore and depth of water used was variable among seasons from daily telemetry locations of Grand Lake Largemouth Bass (Figure 5.10). A significant interaction term was not detected when comparing season and time of day, indicating that patterns in distance from shore were similar across times of day and seasons (Table 5.7). A significant difference was only detected across seasons indicating differences in Largemouth Bass distances from shore did not vary across times of day when averaged within a season (Table 5.7). Largemouth Bass in Grand Lake had the highest distance from shore during summer, 2013 and fall, 2013 when Largemouth Bass distances from shore were approximately 50m across all times of day (Figure 5.10; Figure 5.11). Largemouth Bass were slightly closer to shore during summer, 2014 at approximately 40 m which was significantly closer than distances observed during summer, 2013 and fall, 2013 (Figure 5.10; Figure 5.11). Largemouth Bass were again significantly closer to shore during winter, 2013/2014 at a distance of approximately 30m from shore (Figure 5.10; Figure 5.11). Largemouth Bass were closest to shore during spring, 2014 when they were approximately 15m from shore and distance from shore during this season was significantly lower than any other season (Figure 5.10; Figure 5.11). Trends in depth of water used by Largemouth Bass from daily telemetry locations showed similar patterns to distance from shore, although statistical differences were not calculated on depth of water used (Figure 5.10).

Discussion

Seasonal use areas of Largemouth Bass in Grand Lake were variable among seasons and among individuals within a season. Given the management objective of creating a trophy Largemouth Bass fishery in Grand Lake, seasonal use areas were larger than we expected going into the study and larger than we hoped if the goal is trying to create a trophy fishery, assuming seasonal use areas represent energy spent on activity rather than growth. Although it is difficult to compare use areas and home ranges across studies due to differences in sampling techniques and, waterbody size, etc., several other studies have found that Largemouth Bass can have smaller home ranges and use areas than those observed in this study. For example, Winter (1977) found that maximum summer home range sizes for Largemouth Bass in Mary Lake, MN ranged from 0.3-1.4 hectares, which is much lower than summer seasonal use areas in either summer of our study. In a similar study, Mesing and Wicker (1986) tracked 22 Largemouth Bass for over 1.5 years yet only found that home ranges for these Bass ranged in size from 0.01-5.16 hectares. Despite Grand Lake being much smaller than either lake in the study by Mesing and Wicker (1986), maximum annual home range sizes from Largemouth Bass in Grand Lake were five times as large at just over 28 ha and four Largemouth Bass in Grand Lake had annual home ranges larger than 20 ha. In a last study, Fish and Savitz (1983) found that 3-6 month home range sizes of Largemouth Bass in Cedar Lake, IL ranged in size from 0.18-2.07ha, with maximum home range sizes in this study being smaller than mean home range sizes in our study.

One possible explanation for the large observed seasonal and annual use areas of Largemouth Bass in Grand Lake could be a lack of habitat as Largemouth Bass are considered a species that often associates with structure and cover and whose behavior may change depending on available habitat (Savino and Stein 1982; Anderson 1984). As mentioned earlier, Grass Carp have been stocked into Grand Lake to remove all submersed aquatic vegetation and the current management strategy involves chemically treating water lotus, thus removing most aquatic vegetation as habitat for Largemouth Bass in Grand Lake. Furthermore, side scan sonar imagery revealed a paucity of woody habitat for Largemouth Bass in Grand Lake (Breeggemann, unpublished data). Results from over 80 transects to map available habitat following methods described by Kaeser and Litts (2008), Kaeser and Litts (2010), and Kaeser et al. (2013) revealed approximately 22 woody structures (i.e., brush bundles, laydown log, stump, upright trees) per acre of lake surface area (Breeggemann, unpublished data). Thus, Grand Lake is experiencing the habitat effects of an aging reservoir. In a study of the effects of habitat on home range size and activity of Largemouth Bass in northern WI, Ahrenstorff et al. (2009) found that Largemouth Bass in lakes with lower densities of coarse woody habitat had significantly larger home ranges and consumed less prey. In that same study, Ahrenstorff et al. (2009) hypothesized that when coarse woody debris densities decreased, Largemouth Bass switched from a sit-and-wait foraging strategy to one which Bass actively searched for prey. When using an actively searching foraging strategy Ahrenstorff et al. (2009) proposed that Largemouth Bass spend extra energy searching for food and growth may slow. Other studies have also revealed that habitat manipulations affect Largemouth Bass movements and activity rates. For example, following a large removal of hydrilla from Lake Seminole Georgia, Largemouth Bass movement increased and they inhabited deeper water compared to pre-treatment of the hydrilla (Sammons et al. 2003). In a similar study, Colle et al. (1989) found that following elimination of submersed aquatic vegetation in Lake Baldwin, Florida, some Largemouth Bass moved offshore and associated, did not associate with any structure, and maintained large home ranges that average 21.0 hectares.

The lack of habitat due to reservoir aging and resulting large seasonal and annual use areas and movement could be limiting the growth potential of Largemouth Bass in Grand Lake, thus preventing achievement of the goal to create a trophy Largemouth Bass fishery. Although percent coverage was not quantified from mapped habitat features describe earlier, percent coverage of habitat in Grand Lake was much lower than percent habitat coverage that maximized Largemouth Bass production in other studies. For example, Wiley et al. (1984) found that 40-50% coverage of aquatic macrophytes maximized Largemouth Bass production in small ponds in Illinois. Additonally, Durocher et al. (1984) evaluated seven biotic and abiotic factors to assess what factors were driving standing crop of Largemouth Bass in Texas reservoirs and vegetation coverage was found to be the only significant variable of those evaluated. Furthermore, standing crop of Largemouth Bass increased with vegetation coverages up to 20% highlighting the importance of habitat for the growth and production of Largemouth Bass in Texas reservoirs. In a last study, Sass et al. (2006) removed 75% of the coarse woody habitat from a treatment section of Little Rock Lake, WI and left a reference basin unaltered to compare feeding and growth of Largemouth Bass following a significant removal of habitat. Prior to the woody habitat removal in Little Rock Lake, Largemouth

Bass in both basins consumed primarily aquatic prey (Sass et al. 2006). Following the woody habitat removal, Largemouth Bass in the treatment basin consumed less fish and grew more slowly than Largemouth Bass in the reference basin (Sass et al. 2006).

Largemouth Bass in Grand Lake tended to stay fairly far from shore (i.e. >30-40 m) and use deep water (i.e., >2.5-3.5 m) during most of the growing seasons. Three possible factors could explain these movement patterns. First, littoral habitat could be limiting and Largemouth Bass could be moving offshore as a results. For example, six of sixteen Largemouth Bass stayed predominantly in water deeper than 3.5 m following removal of submersed aquatic vegetation in Lake Baldwin, Florida (Colle et al. 1989). Additionally, Sammons et al. (2003) also noted that Largemouth Bass used deeper water after removal of the majority of hydrilla in Lake Seminole, Georgia. A second explanation could be Largemouth Bass are seeking cooler water offshore. Largemouth Bass growth is optimized at a temperature range of 26 – 28°C (Coutant & Cox 1976). Surface temperatures and shallow water temperatures in Grand Lake exceeded this optimal temperature for much of the growing season. Therefore, Largemouth Bass may have moved offshore to deeper, cooler water closer to their thermal optima. When water temperatures reached 25-30°C, Smallmouth Bass (*Micropterus dolomieu*) attempted to locate thermal refuge by moving to different areas of the lake with cooler water because their cardiac function alone could not account for increased water temperatures (Schreer and Cooke 2002). Largemouth Bass in Grand Lake could be exhibiting the same response. The last explanation could be prey. Diet analyses of Largemouth Bass in Grand Lake have revealed that Shad spp. are a significant component of Largemouth Bass diets. Given that Gizzard Shad and Threadfin Shad are pelagic, Largemouth Bass could be moving offshore to feed. Other studies have shown Gizzard Shad to be important in diets of Largemouth Bass thus indicating they move offshore in other systems to feed as well (Storck 1986; Michaletz 1997).

Although water temperatures that Largemouth Bass were using were not significantly cooler than mean available water temperatures during stratified times, Largemouth Bass were likely moving in response to water temperatures. For example, differences between water temperatures Largemouth Bass were using and mean available water temperatures were highest when water temperatures were warmest and Largemouth Bass were avoiding the warmest water in the lake. Also, depth of water that a Largemouth Bass was in was slightly higher when water temperatures were warmer, although these differences in depth of water used were slight. Water temperatures and depth of water Largemouth Bass were using in response to available water temperatures could show a behavioral response in that Largemouth Bass are seeking water temperatures closer to their thermal optimum, similar to the response of Smallmouth Bass to warmer water presented earlier (Schreer and Cooke 2002).

Furthermore, water temperatures to Largemouth Bass in Grand Lake were warmer than the thermal optima of 26 – 28°C (Coutant & Cox 1976), yet Largemouth Bass did not seek out the coolest available water temperatures with enough oxygen to survive. Additionally, mean water temperatures as well as the water temperatures Largemouth Bass were using in Grand Lake were not close to the temperatures at which Largemouth Bass begin to lose equilibrium and death occurs (i.e., 36°C; Smith and Scott 1975; Fields et al. 1987; Smale and Rabeni 1995; Beitinger et al 2000). Additionally, Largemouth Bass activity rates (i.e., movement and use area) were high despite temperatures above the thermal optima, indicating that Largemouth Bass in Grand Lake were not severly limited by water temperatures. However, given the fact that Largemouth Bass were using water temperatures above their thermal optima during extended periods of the growing season, growth could be slowed by water temperatures. Additionally, slight increases in water temperatures (1-2°C) could dramatically lower growth of Largemouth Bass in Grand Lake as observed water temperatures are getting so far past the thermal optimum of Largemouth Bass that metabolic activity may slow dramatically (Rice et al. 1983; Chapter 3).

Grand Lake is considered polymictic and broke stratification several times throughout both summers of this study. When Grand Lake broke stratification, water temperatures dropped closer to thermal optima for Largemouth Bass, but dissolved oxygen levels dropped with maximum observed dissolved oxygen levels below 4ppm (Breeggemann, unpublished data). Given high water temperatures of Grand Lake, even when the lake breaks stratification, dissolved oxygen levels below 4ppm are getting very close to the threshold at which Largemouth Bass can survive at these temperatures (Cech et al. 1979). High water temperatures combined with low dissolved oxygen when Grand Lake breaks stratification lends evidence to the consideration of adding an aeration system or some other system (e.g., directly injecting oxygen into the hypolinium) to maintain high oxygen levels at temperatures that are as close to the thermal optima of Largemouth Bass as possible. Cool water with adequate levels of oxygen may be crucial in the future as global climate change increases water temperatures if creating a trophy fishery is the desired management goal (Chapter 3).

Similar to seasonal and annual use areas, daily movement rates and daily home range sizes during warm water periods in Grand Lake were larger than we expected given the goal of creating a trophy Largemouth Bass fishery. Daily Largemouth Bass movement rates and home range sizes were larger than what other researchers have observed in other reservoirs and is likely driven by the lack of habitat in Grand Lake due to reservoir aging. For example, daily Largemouth Bass movement rates and home range sizes in Grand Lake were similar to those in a 25 ha lake in Colorado in following a water level drawdown and significant loss of habitat for Largemouth Bass (Rogers and Bergersen 1995). In the same study in Colorado, Largemouth Bass in a lake with a water level drawdown had significantly larger movement rates and daily home ranges compared to a lake in which there was not a drawdown (Rogers and Bergersen 1995). Additionally, Sammons et al. (2003) noted that Largemouth Bass exhibited greater movement in Lake Seminole, Georgia following removal of most of the hydrilla in the lake.

Daily activity rates of Largemouth Bass in Grand Lake were highest during both the summer of 2013 and summer of 2014. Mesing and Wicker (1986) found that greatest average daily movements of Largemouth Bass in two central Florida Lakes occurred during June, May, and February, and that smallest movement rates occurred during August. Greatest daily movement rates of Largemouth Bass in Grand Lake occurred during July and August in our study. Surprisingly, no differences were detected in Largemouth Bass distances from shore at different times of day from daily telemetry. I hypothesized that during warm water periods, Largemouth Bass would have moved closer to shore during the overnight and early morning hours when water temperatures were coolest in shallow areas of the lake. However, lack of littoral habitat as well as adequate pelagic prey (i.e., Shad spp.) could have precluded Largemouth movements toward shore during low light periods.

Management Implications

Daily, seasonal, and annual movements and use areas observed in this study highlight the effects of reservoir aging on Largemouth Bass behavior. I hypothesize that the reservoir aging process proposed by Kimmel and Groeger (1986) has resulted in significant habitat losses in Grand Lake and Largemouth Bass have responded with high movement rates and activity patterns as a result. In a study of lakes in northern WI, Ahrenstorff et al. (2009) found that Largemouth Bass in lakes lower densities of coarse woody habitat had significantly larger home ranges and consumed less prey. In that same study, Ahrenstorff et al. (2009) hypothesized that when coarse woody debris densities decreased, Largemouth Bass switched from a sit-and-wait foraging strategy to one which Bass actively searched for prey. When using an actively searching foraging strategy Ahrenstorff et al. (2009) proposed that Largemouth Bass spend extra energy searching for food and growth may slow. Habitat loss due to reservoir aging has the same effect as removing habitat in a lake. Increased activity patterns in Grand Lake as a result of habitat loss has likely resulted in the slow growth rates of Largemouth Bass in Grand Lake (Chapter 2 and Chapter 3). All other factors necessary to optimize Largemouth Bass growth are present in Grand Lake (i.e., Florida Largemouth Bass genetics, high energy forage, and high survival) lending further evidence to the effects of reservoir aging and lack of habitat as the factor limiting growth of Largemouth Bass in Grand Lake. Furthermore, management strategies aimed at maintaining water temperatures and dissolved oxygen at levels that maximize Largemouth Bass should be considered in southern latitudes especially as water temperatures are predicted to rise in the face of climate change. This study highlights the need to consider managing habitat to enhance Largemouth Bass growth especially in aging reservoirs. Furthermore, habitat should be considered in all systems in which the goal is to optimize growth of Largemouth Bass. For example, lakeshore development may be removing habitat from lakes as home owners prevent coarse woody debris from entering aquatic systems and this may also contribute to reduced growth of Largemouth Bass in natural lakes at more northerly latitudes (Gaeta et al. 2011).

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TABLE 5.1. Summary statistics to test whether differences exist among 95% seasonal use areas for Largemouth Bass sampled from Grand Lake, TX between June, 2013 and August, 2014. Use areas were calculated from weekly telemetry locations.

Model	D.F.	AIC	Log-likelihood	Chi-square statistic	P-value
base	3	344.18	-169.09		
season	7	326.88	-156.44	25.297	<0.01

TABLE 5.2. Summary statistics to test whether differences exist among 50% seasonal use areas for Largemouth Bass sampled from Grand Lake, TX between June, 2013 and August, 2014. Use areas were calculated from weekly telemetry locations.

Model	**D.F.**	**AIC**	**Log-likelihood**	**Chi-square statistic**	**P-value**
base	3	394.67	-194.34		
season	7	374.37	-180.19	28.3	<0.01

TABLE 5.3. Results of regression model to test if observed water temperatures Largemouth Bass were using were significantly different than mean available water temperatures on different dates in Grand Lake, TX over the 2013 and 2014 growing seasons.

Parameter	Estimate	Standard Error	t-value	Pr(>|t|)
Intercept	30.95	0.14	227.71	<0.01
Fish	-0.34	0.25	-1.38	0.17
Date 6/2/2014	-3.07	0.15	-20.70	<0.01
Date 6/21/2013	0.17	0.18	0.93	0.35
Date 7/14/2014	1.18	0.16	7.15	<0.01
Date 7/16/2013	-2.39	0.16	-15.13	<0.01
Date 7/2/2014	-1.24	0.15	-8.31	<0.01
Date 7/23/2014	-1.55	0.17	-9.07	<0.01
Date 7/9/2013	-0.74	0.16	-4.60	<0.01
Date 8/21/2013	-1.39	0.16	-8.85	<0.01
Date 8/25/2014	-0.39	0.16	-2.42	0.02
Date 8/26/2013	-0.57	0.16	-3.56	<0.01
Date 8/5/2013	0.74	0.16	4.66	<0.01
Date 9/16/2013	-1.20	0.16	-7.47	<0.01
Fish 6/2/2014	0.26	0.31	0.84	0.40
Fish 6/21/2013	0.04	0.34	0.12	0.91
Fish 7/14/2014	0.08	0.31	0.28	0.78
Fish 7/16/2013	0.32	0.32	1.00	0.32
Fish 7/2/2014	0.37	0.30	1.24	0.22
Fish 7/23/2014	-0.34	0.31	-1.10	0.27
Fish 7/9/2013	0.08	0.33	0.24	0.81
Fish 8/21/2013	0.25	0.33	0.77	0.44
Fish 8/25/2014	-0.05	0.30	-0.16	0.88
Fish 8/26/2013	0.30	0.33	0.91	0.36
Fish 8/5/2013	-0.09	0.33	-0.26	0.79
Fish 9/16/2013	-0.08	0.33	-0.24	0.81

TABLE 5.4. Results of regression model to test if observed dissolved oxygen levels Largemouth Bass were using were significantly different than mean available dissolved oxygen levels on different dates in Grand Lake, TX over the 2013 and 2014 growing seasons.

Parameter	Estimate	Standard Error	t-value	Pr(>|t|)
Intercept	6.45	0.53	12.25	<0.01
Fish	-0.25	1.15	-0.21	0.83
Date 6/2/2014	1.23	0.55	2.23	0.03
Date 6/21/2013	0.19	0.63	0.31	0.76
Date 7/14/2014	-0.04	0.59	-0.06	0.95
Date 7/16/2013	-1.97	0.57	-3.45	<0.01
Date 7/2/2014	1.12	0.55	2.02	0.04
Date 7/23/2014	1.15	0.60	1.91	0.06
Date 7/9/2013	-0.09	0.58	-0.16	0.87
Date 8/21/2013	-0.55	0.57	-0.97	0.33
Date 8/25/2014	0.71	0.58	1.24	0.22
Date 8/26/2013	-0.63	0.57	-1.10	0.27
Date 8/5/2013	-0.17	0.57	-0.30	0.77
Date 9/16/2013	-0.15	0.58	-0.26	0.79
Fish 6/2/2014	1.20	1.27	0.95	0.34
Fish 6/21/2013	-0.16	1.33	-0.12	0.91
Fish 7/14/2014	-0.38	1.26	-0.30	0.76
Fish 7/16/2013	0.14	1.29	0.11	0.91
Fish 7/2/2014	0.80	1.24	0.65	0.52
Fish 7/23/2014	-1.66	1.26	-1.32	0.19
Fish 7/9/2013	0.23	1.30	0.18	0.86
Fish 8/21/2013	0.44	1.30	0.34	0.74
Fish 8/25/2014	-0.44	1.26	-0.35	0.72
Fish 8/26/2013	0.06	1.30	0.05	0.96
Fish 8/5/2013	-0.48	1.29	-0.37	0.71
Fish 9/16/2013	-0.91	1.31	-0.70	0.49

TABLE 5.5. Summary statistics to test whether differences exist among movement rates over different seasons and times of day for Largemouth Bass sampled from Grand Lake, TX between June, 2013 and August, 2014. Movement rates were calculated from 24-hour daily telemetry locations.

Model	D.F.	AIC	Log-likelihood	Chi-square statistic	P-value
Additive	12	1348.6	-662.28		
Interaction	32	1371.9	-653.96	16.645	0.676
Baseline	3	1381.0	-687.48		
Time of Day	8	1364.6	-674.32	26.314	<0.01
Season	7	1365.9	-675.96	23.04	<0.01

TABLE 5.6. Summary statistics to test whether differences exist among daily use areas for Largemouth Bass sampled from Grand Lake, TX between June, 2013 and August, 2014. Use areas were calculated from 24-hour daily telemetry locations.

Model	**D.F.**	**AIC**	**Log-likelihood**	**Chi-square statistic**	**P-value**
base	3	283.11	-138.55		
season	7	269.34	-127.67	21.767	<0.01

TABLE 5.7. Summary statistics to test whether differences exist among distance from shore over different seasons and times of day for Largemouth Bass sampled from Grand Lake, TX between June, 2013 and August, 2014. Distances from shore were calculated from 24-hour daily telemetry locations.

Model	D.F.	AIC	Log-likelihood	Chi-square statistic	P-value
Additive	13	862.56	-418.28		
Interaction	37	890.59	-408.3	19.97	0.699
Baseline	3	954.92	-474.46		
Time of Day	9	958.12	-470.06	8.8	0.19
Season	7	861.43	-423.71	101.49	<0.01

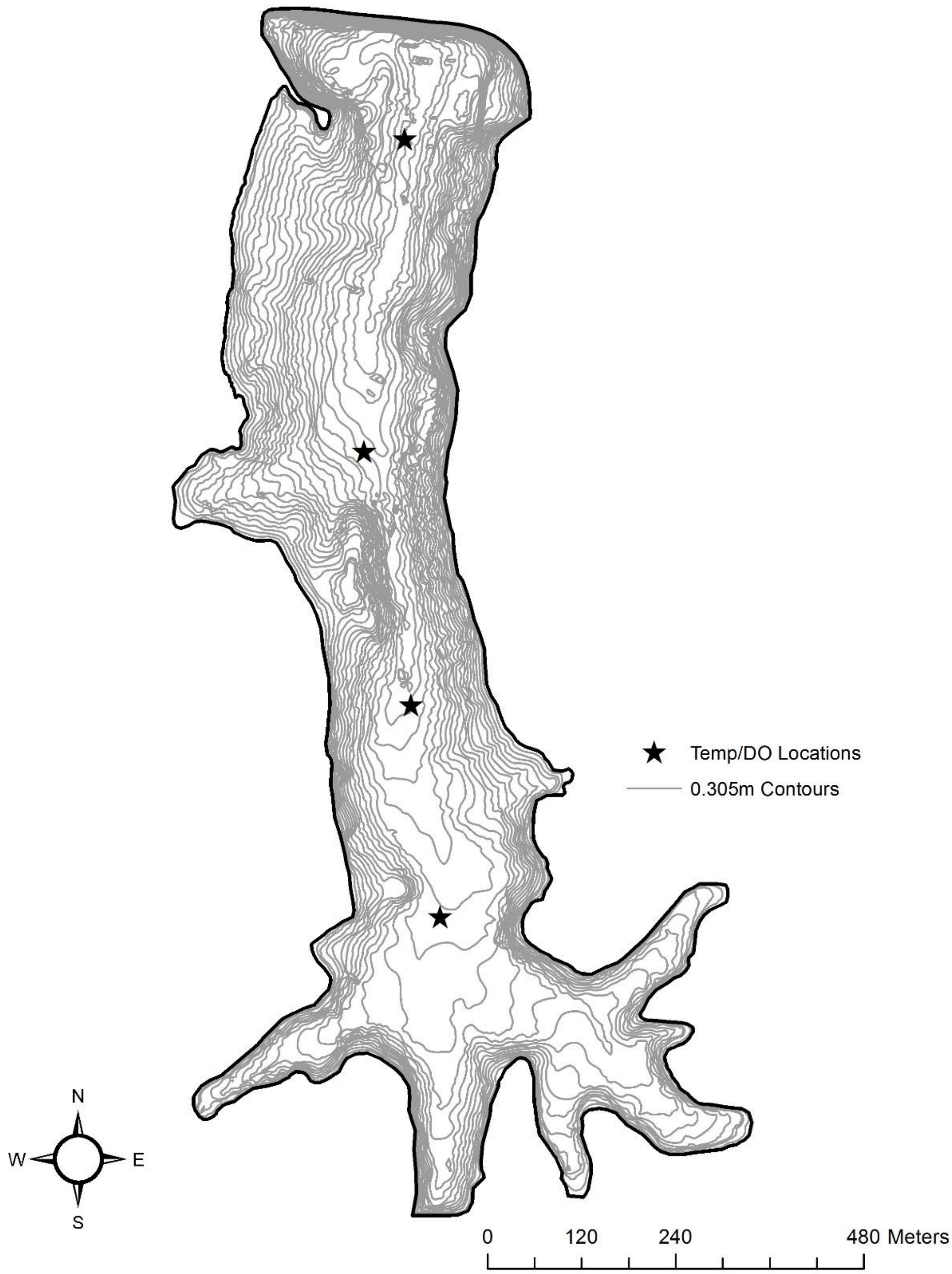

FIGURE 5.1. Detailed bathymetric map of Grand Lake, Texas showing 0.305m contours. Stars represent locations where temperature/dissolved oxygen profiles were taken during weekly telemetry.

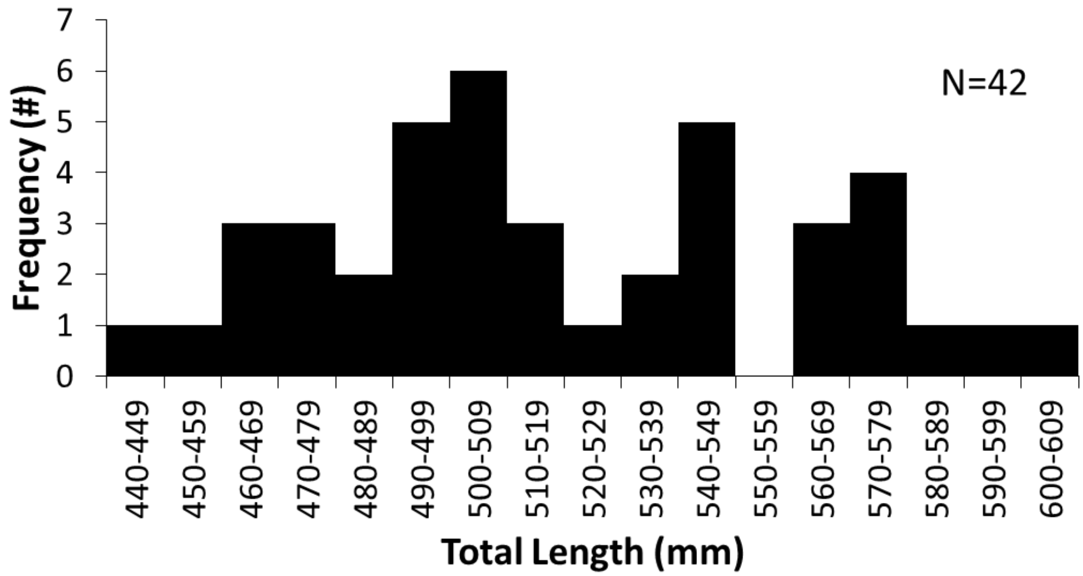

FIGURE 5.2. Length frequency histogram of Largemouth Bass sampled from Grand Lake, TX between May, 2013 and May, 2014 which had radio tags surgically implanted in them.

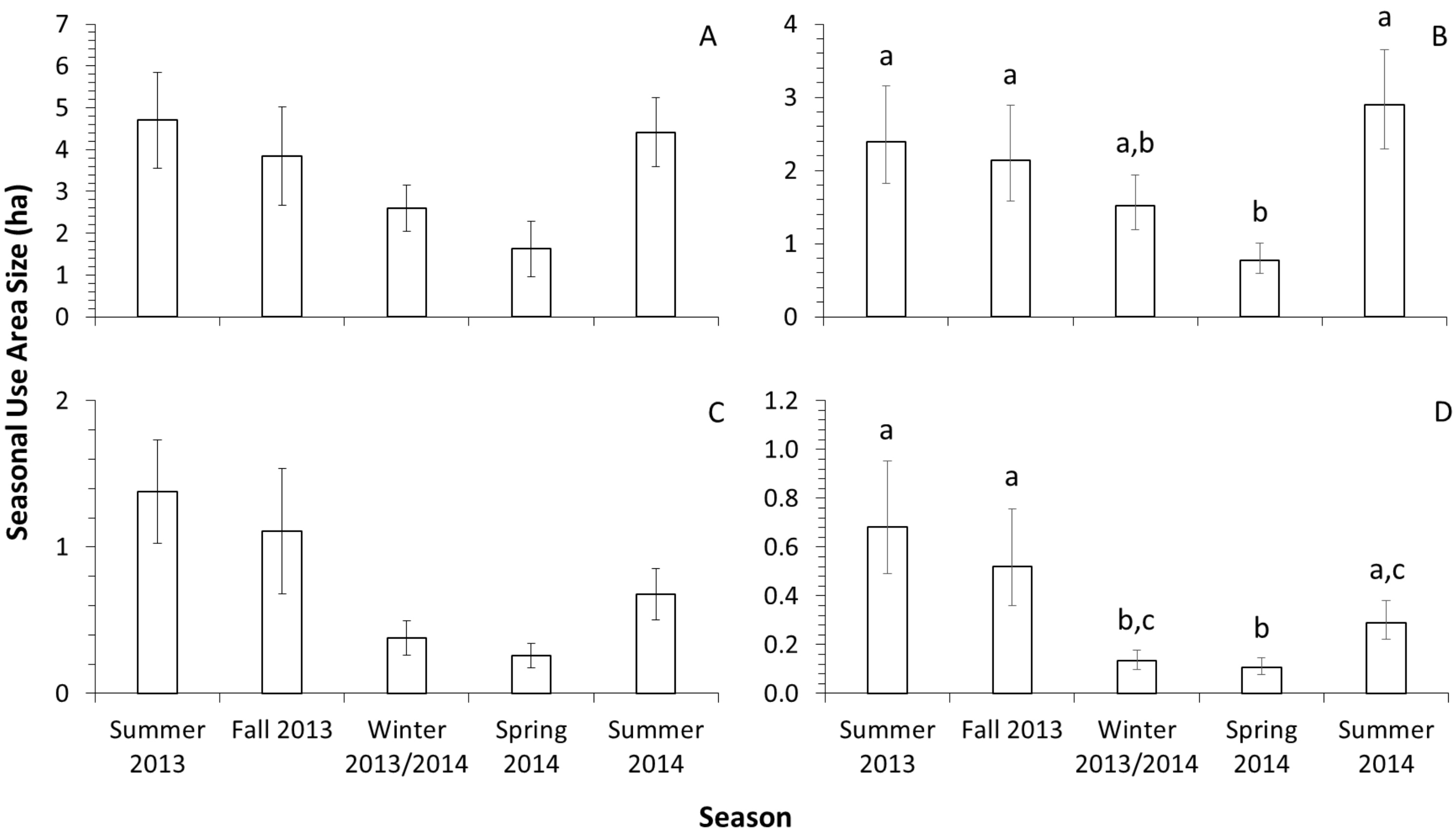

FIGURE 5.3. Observed 95% (A) and 50% (C) seasonal use areas and back-transformed 95% (B) and 50% (D) seasonal use areas for Largemouth Bass sampled from Grand Lake, TX between June, 2013 and August, 2014. Back-transformed seasonal use areas are from the natural log transformed seasonal use areas used to analyze difference between seasonal use areas. Error bars represent standard errors.

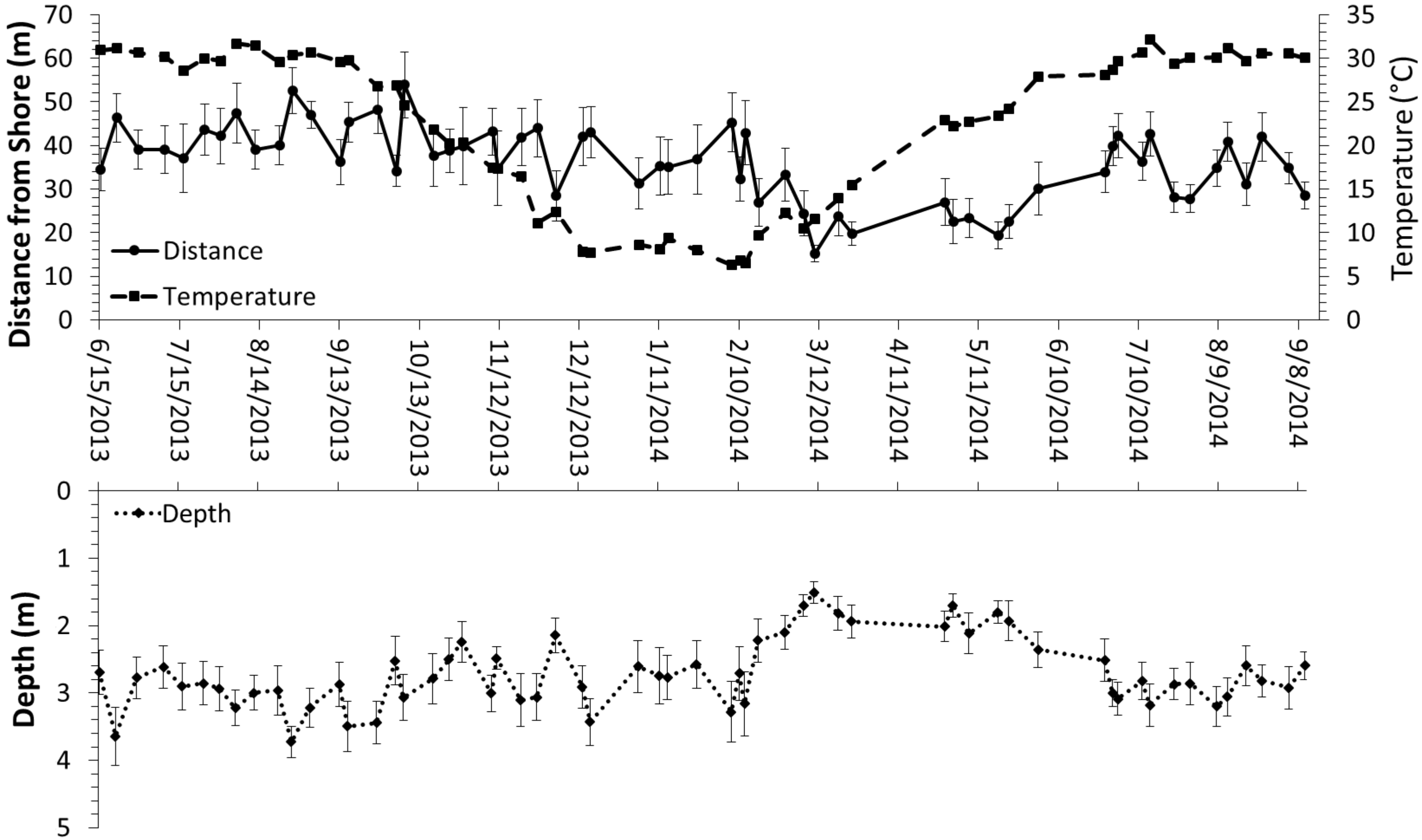

FIGURE 5.4. Mean distance from shore, available water temperature, and depth of water used by Largemouth Bass sampled from Grand Lake, TX between June, 2013 and September, 2014. Each point represents a tracking event from weekly telemetry tracking. Error bars represent standard errors.

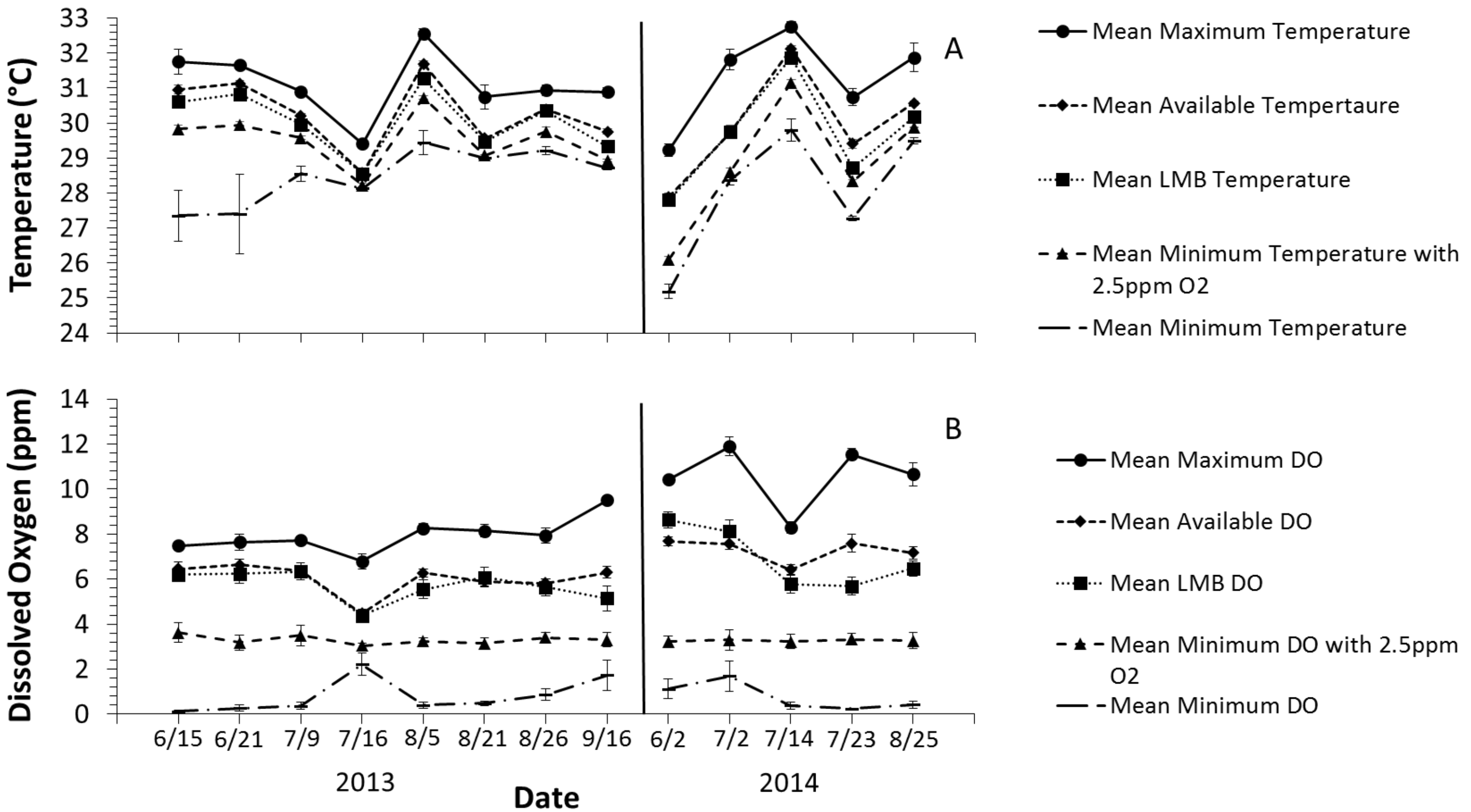

FIGURE 5.5. Mean maximum temperature and dissolved oxygen (DO), mean available temperature and dissolved oxygen, mean Largemouth Bass temperature and dissolved oxygen, mean minimum temperature and dissolved oxygen with 2.5 ppm oxygen, and mean minimum temperature and dissolved oxygen in Grand Lake, TX during stratified times of the year of the 2013 and 2014 growing seasons. Each point represents a tracking event from weekly telemetry tracking. Error bars represent standard errors.

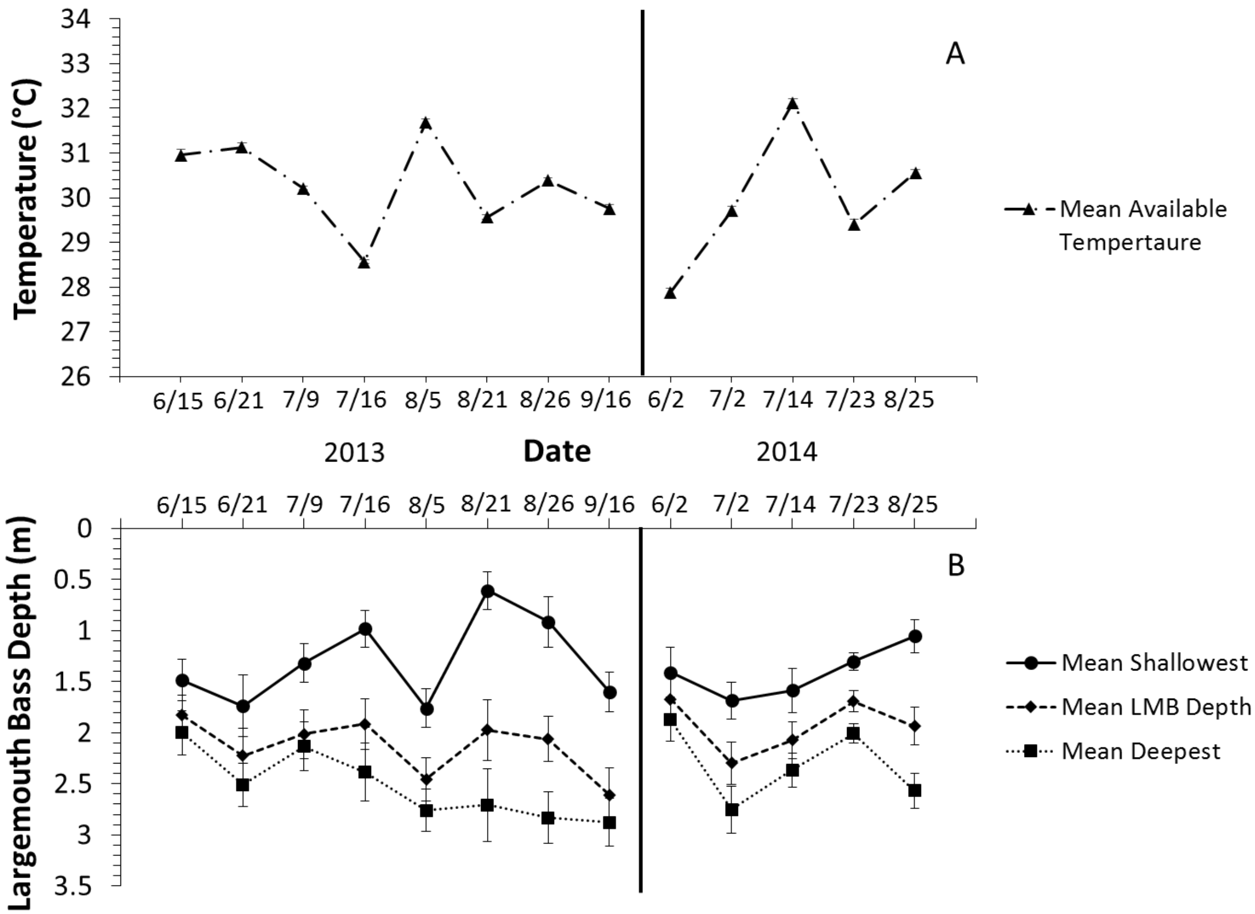

FIGURE 5.6. Mean Largemouth Bass depth, shallowest Largemouth Bass depth, deepest Largemouth Bass depth, and mean available temperature for Largemouth Bass in Grand Lake, TX during stratified times of the year of the 2013 and 2014 growing seasons. Each point represents a tracking event from weekly telemetry tracking. Error bars represent standard errors.

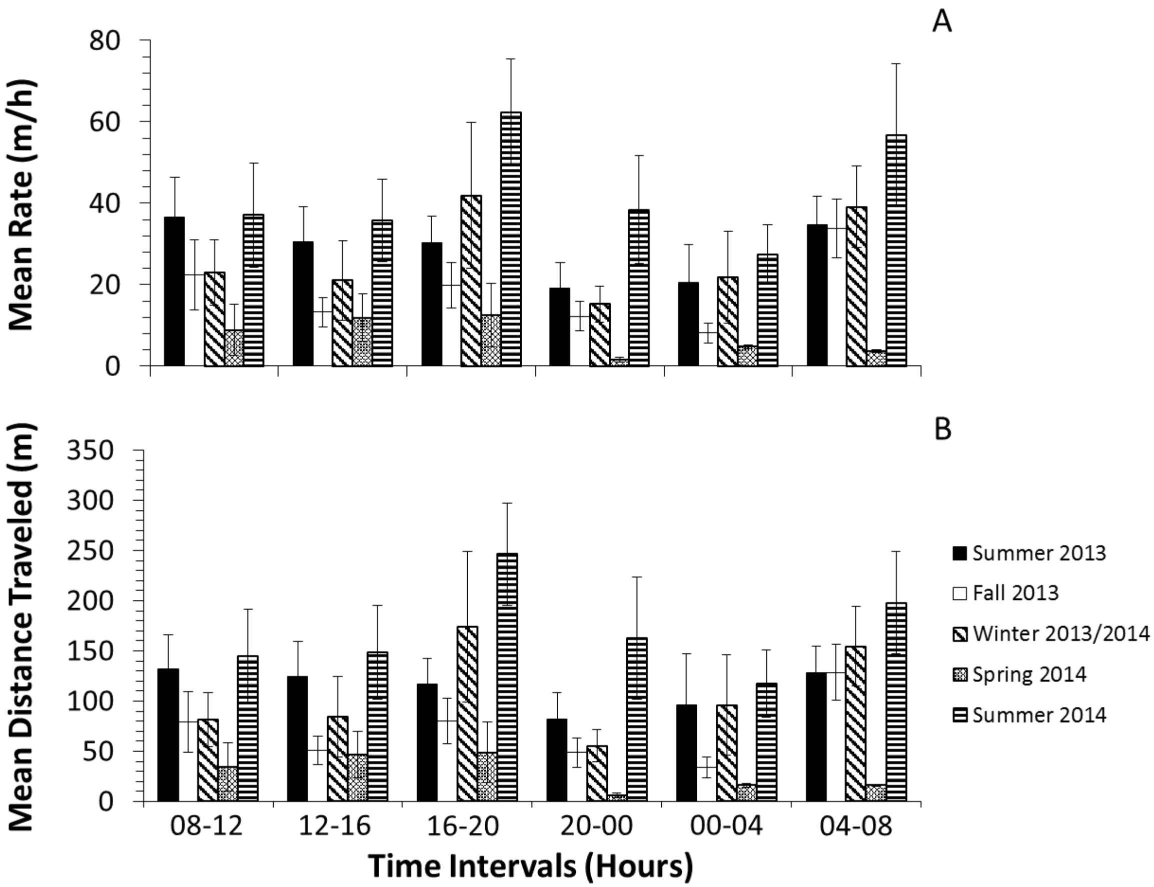

FIGURE 5.7. Mean movement rate (m/h) and mean distance traveled (m) across different seasons and times of day for Largemouth Bass sampled with 24-hour daily telemetry from summer, 2013 through summer, 2014 in Grand Lake, TX. Error Bars represent standard errors.

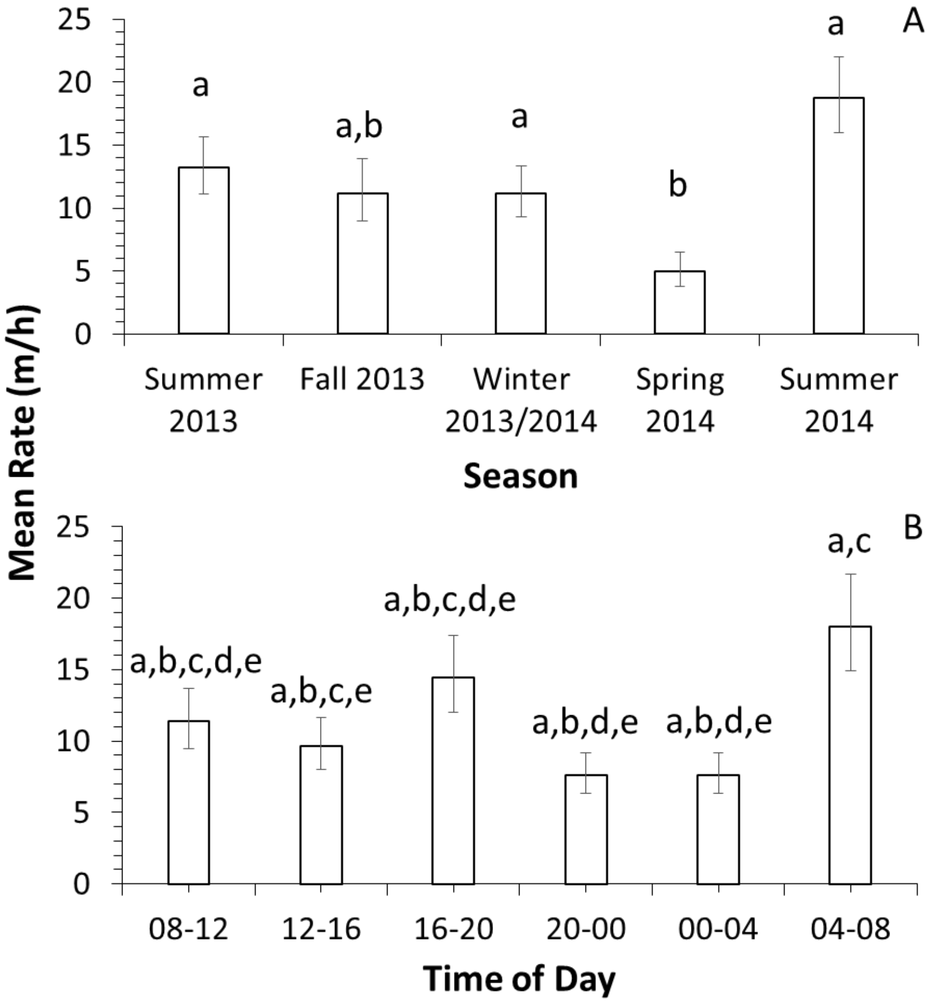

FIGURE 5.8. Significant differences in back-transformed movement rates (m/h) across seasons (A) and times of day (B) from 24-hour daily telemetry locations taken from Largemouth Bass sampled from Grand Lake, TX between summer, 2013 and summer, 2014. Error bars represent standard errors.

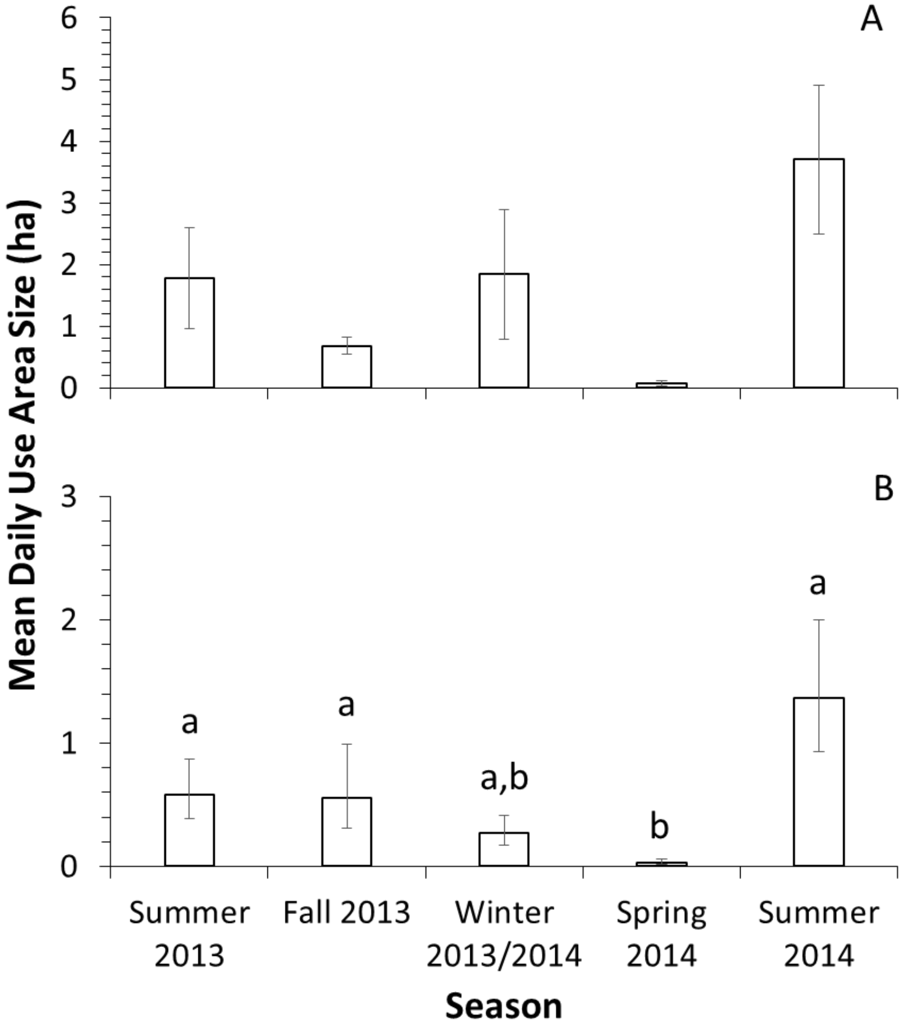

FIGURE 5.9. Mean observed daily use area (A) and back-transformed daily use areas (B) for Largemouth Bass sampled from Grand Lake, TX between June, 2013 and August, 2014. Back-transformed seasonal use areas are from the natural log transformed seasonal use areas used to analyze difference between seasonal use areas. Telemetry locations are from 24-hour daily telemetry. Error bars represent standard errors.

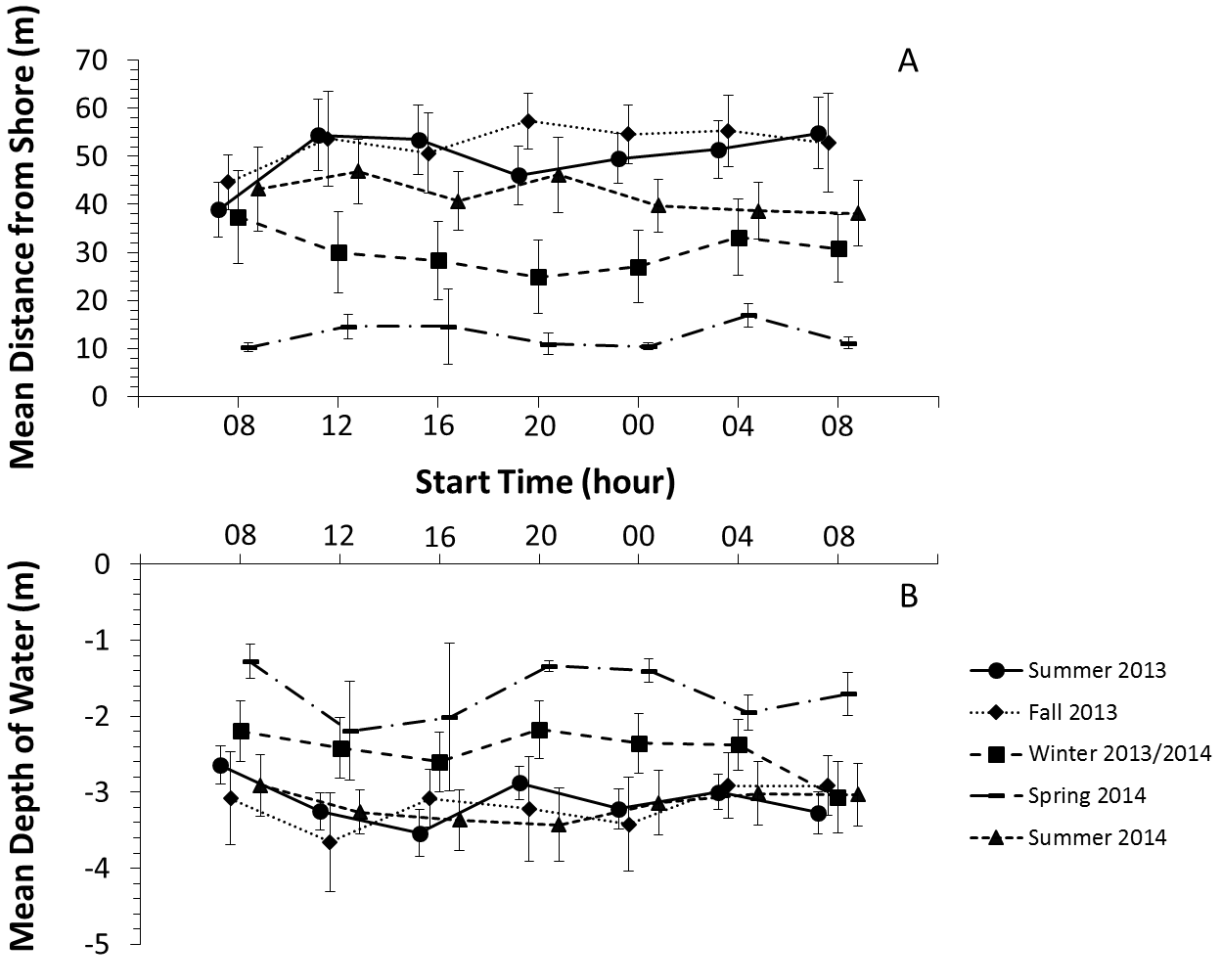

FIGURE 5.10. Mean distance from shore (A) and mean depth of water used (B) for Largemouth Bass sampled from Grand Lake, TX across different seasons and times of day. Telemetry locations are from 24-hour daily telemetry locations collected between summer, 2013 and summer, 2014. Error Bars represent standard errors.

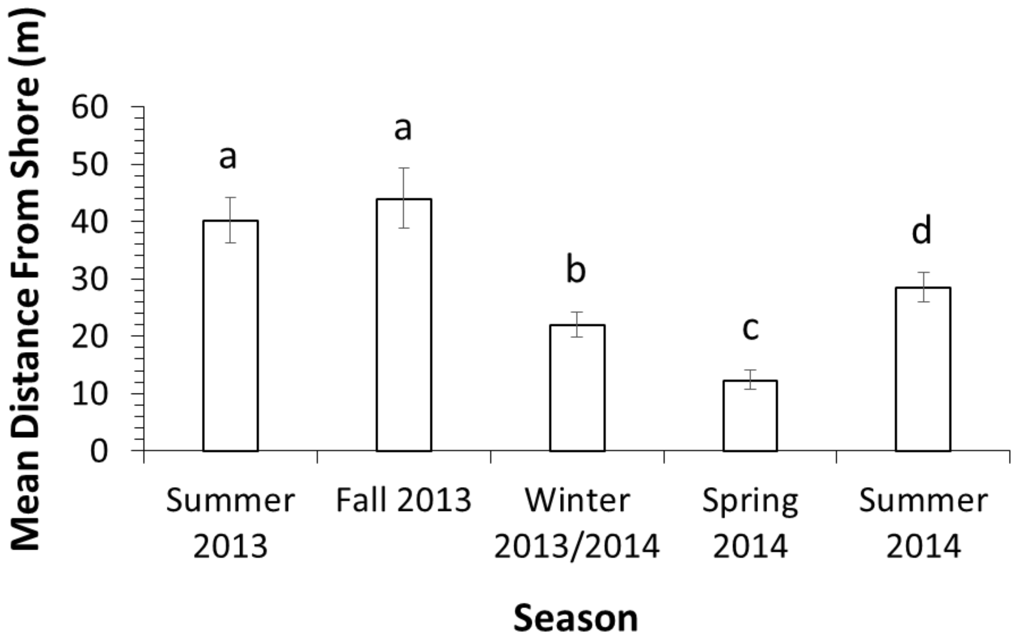

FIGURE 5.11. Mean back-transformed distances from shore across different seasons and years for Largemouth Bass sampled from Grand Lake, TX between summer, 2013 and summer, 2014. Significant differences are denoted by letters. Telemetry locations were taken from 24-hour daily telemetry. Error bars represent standard errors.

CHAPTER 6: CONCLUSIONS

All four factors that can affect the growth potential of Largemouth Bass (*Micropterus salmoides*) in Grand Lake, TX were successfully evaluated and information gleaned from these results can be used to tailor management to reach the goal of growing trophy Largemouth Bass. Surprisingly, prior to the major stocking event in late 2011/early 2012, the Largemouth Bass population in Grand Lake was already comprised of almost exclusively Bass that had some Florida genetics as all Largemouth Bass sampled were either pure Florida strain or F_1 or F_x hybrids. Although rare, Grand Lake must still have some pure northern strain Largemouth Bass as F_1 hybrids were captured. Therefore, the genetic makeup of the Largemouth Bass population in Grand Lake is optimal for growing trophy Bass as pure Florida strain Largemouth Bass and their hybrids have been shown to grow faster and attain larger sizes than northern strain Largemouth Bass (Rieger and Summerfelt 1976; Inman et al. 1977; Bottroff and Lembeck 1978; Pelzman 1980; Maceina et al. 1988).

However, despite having optimal genetics, growth of Largemouth Bass in Grand Lake was still slower than desired to create a trophy fishery, with mean back-calculated lengths at age of adult Largemouth Bass being similar to the 50th percentile for ecoregion 8 of North America taken from Brouder et al. (2009). Therefore, some factor other than genetics must be limiting the growth potential of Largemouth Bass in Grand Lake. Evaluations of the performance of the different stocked genetic groups revealed that feed trained hybrid Tiger Largemouth Bass consistently grew faster and maintained higher relative weights than any other stocked genetic strain or native Largemouth Bass. The fact that these feed trained Tiger Largemouth Bass have easy access to readily available, high energy pelleted food throughout the growing season or hybrid vigor (Shull 1948) could explain why this group performed better than any other stocked genetic strain or native Largemouth Bass. If available, stocking feed trained, Tiger Largemouth Bass along with a feeding program could increase the chances of growing trophy Largemouth Bass.

Overall, Largemouth Bass survival rates were high in Grand Lake compared to many other Bass populations throughout the country and were within the range of survival rates Crawford et al. (2002) deemed necessary to create a trophy Largemouth Bass fishery. Given the strictly catch-and-release nature of the Grand Lake fishery, it is not surprising that survival rates are high as exploitation can remove as many as 40% or more of the Largemouth Bass from heavily exploited fisheries, contributing to low population level survival. The stocked pure Florida strain Largemouth Bass from Florida had the lowest survival rates and their performance (i.e., growth and condition) was similar to native Grand Lake Largemouth Bass. The poor performance of these stocked pure Florida strain Largemouth Bass from Florida raises concerns for outbreeding depression following stocking (Hallerman 2003). Given their much lower survival rate, lack of performance benefit, and possibility of outbreeding depression, no future stockings of pure Florida strain Largemouth Bass.

The current prey fish management strategy is providing ample high energy fish for Largemouth Bass from early/mid-summer through the rest of the growing season. However, a prey bottleneck still exists in spring when Largemouth Bass are consuming large amounts of crayfish. Results of bioenergetics simulations showed that Largemouth Bass growth could improve if a higher proportion of fish were consumed and getting

Largemouth Bass to switch from crayfish to fish in the spring provides the largest area for increases in fish consumption. Perhaps stocking a high energy cool water fish species such as Rainbow Trout (*Oncorhynchus mykiss*) could allow for consumption of fish rather than crayfish during this time. Additionally, water temperatures in Grand Lake during May will be nearing the upper thermal limit of Rainbow Trout, making them an easy target for opportunistic Largemouth Bass. At the very least, future prey management should be aimed at ensuring crayfish do not become a larger portion of Largemouth Bass diets as crayfish have a low energy density and bioenergetics simulations showed that growth will slow even more if crayfish make up a larger proportion of diets.

Bioenergetics simulations also showed that water temperatures in Grand Lake are nearing the point in which they will limit growth of Largemouth Bass and climate change will exacerbate the effects of warmer temperatures. Under future predicted temperatures over the next 50-100 years, Largemouth Bass consumption will have to increase by 5-20% just to meet baseline energetic demands, depending on the model and future time scenario. Compounding this is the fact that current water temperatures are already above a Largemouth Bass' upper thermal optimum and total consumption is limited by water temperatures and will decrease under future climate scenarios. Therefore, climate change has the potential to dramatically limit the growth potential of Largemouth Bass in the southern US if attempts are not made to create a cool water refuge. Installing an aeration system that provides cooler water that contains ample oxygen or installing a system that directly injects oxygen into the thermocline now will limit the impacts of climate change beginning now.

Habitat appears to be the major limiting factor with regards to Largemouth Bass growth in Grand Lake. The fact that Grass Carp (Ctenopharyngodon idella) have removed all of the submersed aquatic vegetation along with the effects of reservoir aging on decomposition and loss of woody habitat means there is very little habitat for Largemouth Bass, a species that closely associates with cover and structure. This lack of habitat has resulted in daily, seasonal, and annual home ranges of Largemouth Bass that were all larger than expected and larger than those reported in other studies (e.g., Fish and Savitz 1983; Mesing and Wicker 1986; Rogers and Bergersen 1995). Furthermore, daily movement rates were also higher than expected. Other studies have shown that Largemouth Bass movement rates and activity increase as available habitat decreases (Sammons et al. 2003; Ahrenstorff et al. 2009). Similar to Ahrenstorff et al. (2009) it is hypothesized that increased metabolic expenditures associated with large daily, seasonal, and annual movement patterns are limiting the growth potential of Largemouth Bass in Grand Lake. If Largemouth Bass consumption remained the same, yet movement rates decreased dramatically as a result of increased habitat, growth should increase. The fact that reservoir aging and the loss of habitat is limiting growth of Largemouth Bass in Grand Lake could pose a management challenge to fisheries managers throughout the county as millions of reservoirs are >40 years old.

This research highlights the need to take an ecosystem based management approach to fisheries to ensure successful achievement of management objectives. Most often, the easiest and cheapest approach to management is taken without consideration for other factors. For example, Florida strain Largemouth Bass have been stocked throughout the southern United States where the northern strain Largemouth Bass is native to try to increase growth rates and create higher quality fishing opportunities. Genetics are very easy to evaluate as well as easy to manage through simple stockings, which is why manipulating genetics are often the first management strategy taken when managing for Largemouth Bass growth. However, stocking pure Florida strain Largemouth Bass into a lake in which habitat or prey are limiting does not ensure successful creation of a trophy fishery as shown in this study. Therefore, it is recommended that managers evaluate all factors that could affect growth of Largemouth Bass prior to selecting and implementing a best management strategy.

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APPENDIX

Plots of prey specific abundance versus frequency of occurrence for all Largemouth Bass diet samples collected from Grand Lake Texas during the 2012-2014 sampling seasons.

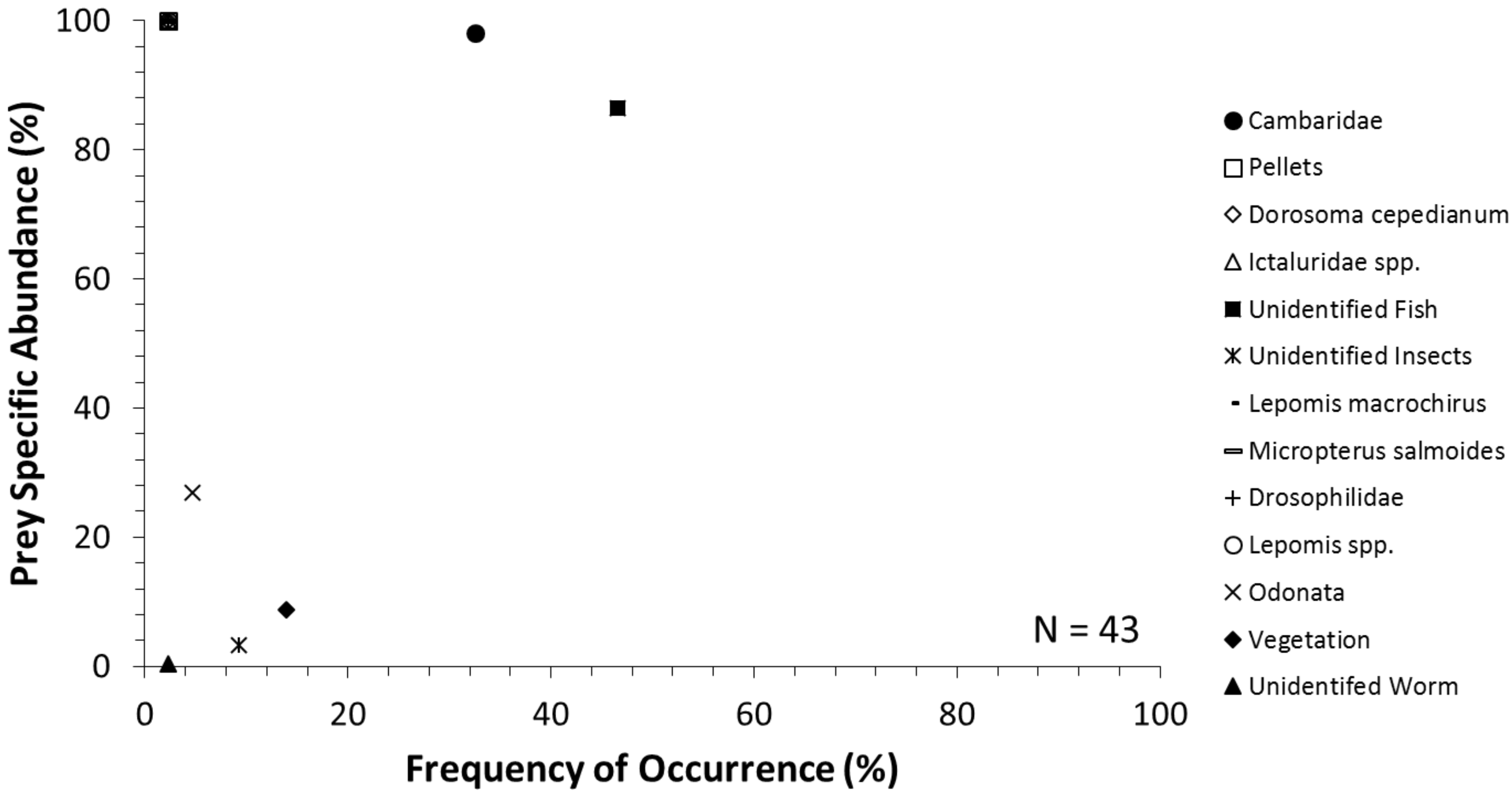

FIGURE A.1. Prey specific abundance (%) versus frequency of occurrence (%) for all diet items collected from all Largemouth Bass sampled from Grand Lake, TX in mid-May, 2012.

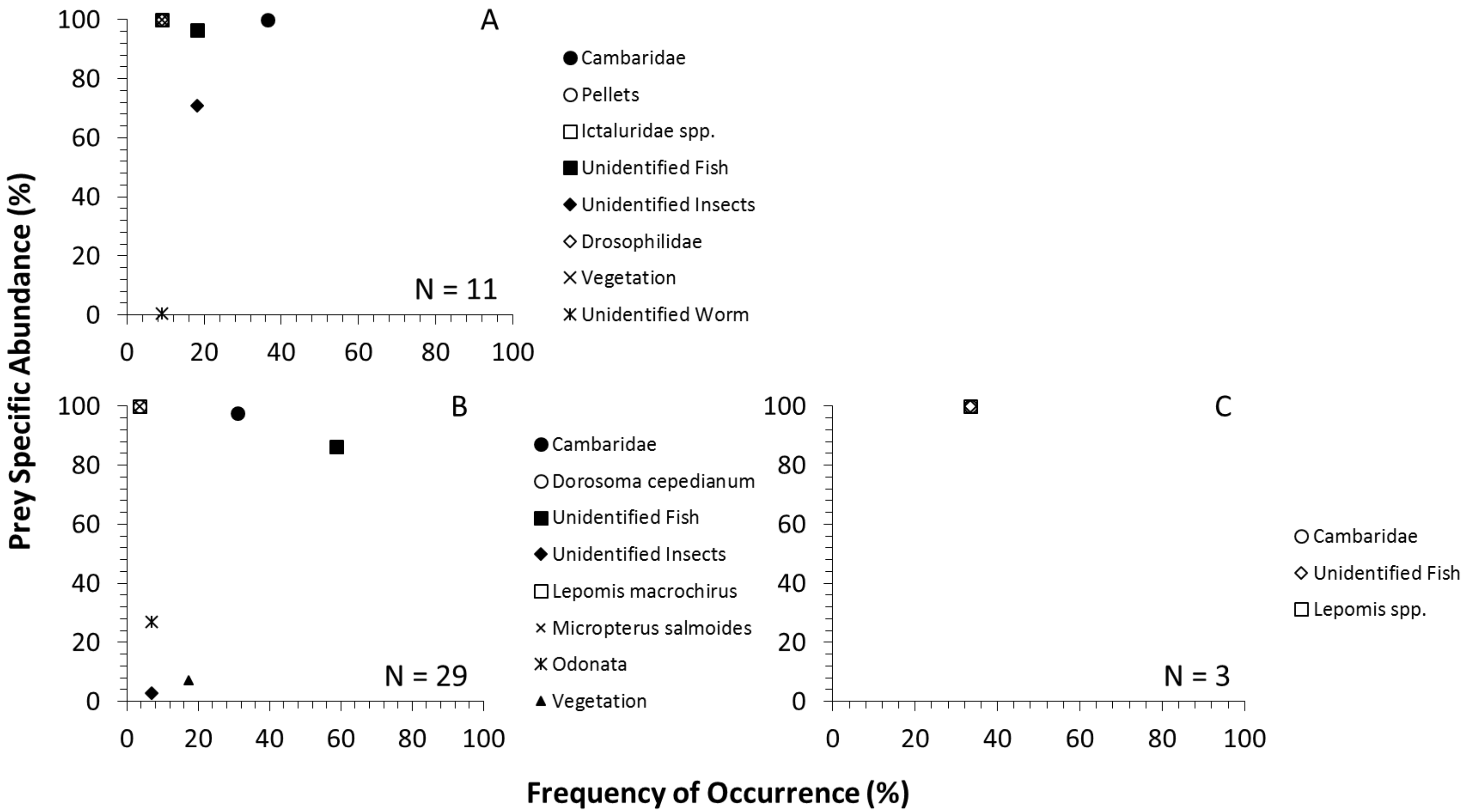

FIGURE A.2. Prey specific abundance (%) versus frequency of occurrence (%) for all diet items collected from Largemouth Bass 250-381 mm TL (A), 382-508 mm TL (B), and ≥ 509 mm TL (C) sampled from Grand Lake, TX in mid-May, 2012.

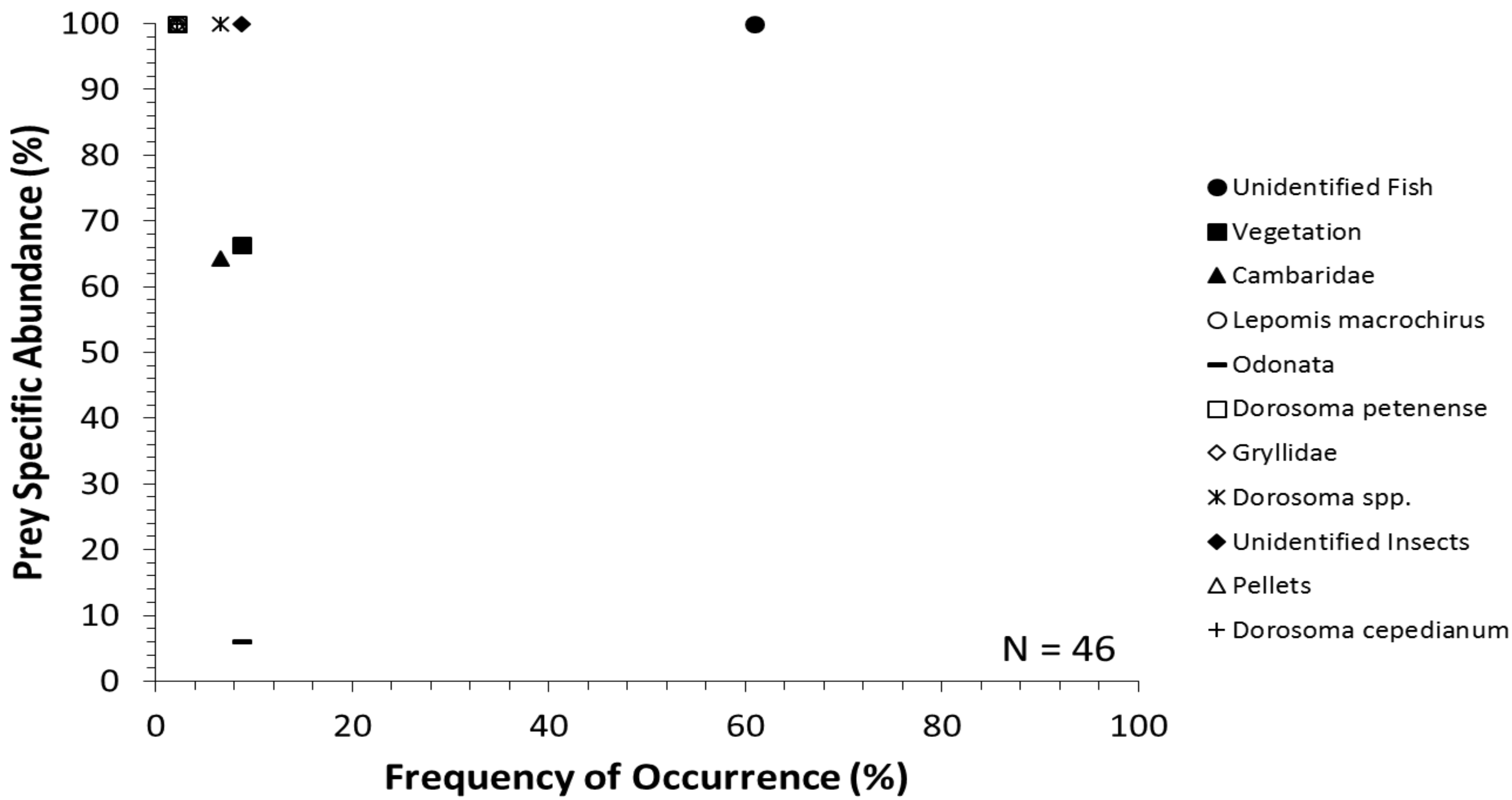

FIGURE A.3. Prey specific abundance (%) versus frequency of occurrence (%) for all diet items collected from all Largemouth Bass sampled from Grand Lake, TX in mid-August, 2012.

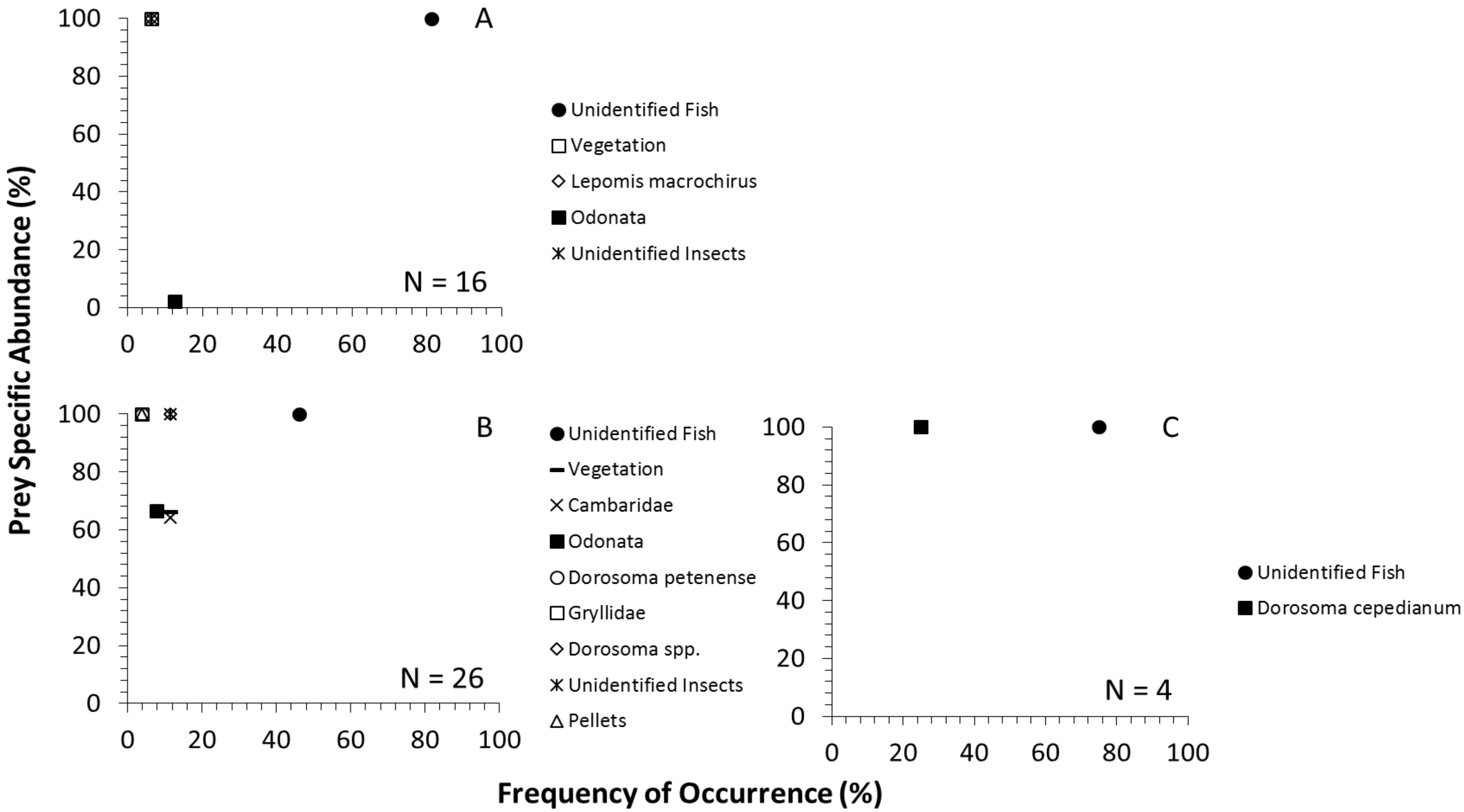

FIGURE A.4. Prey specific abundance (%) versus frequency of occurrence (%) for all diet items collected from Largemouth Bass 250-381 mm TL (A), 382-508 mm TL (B), and ≥ 509 mm TL (C) sampled from Grand Lake, TX in mid-August, 2012.

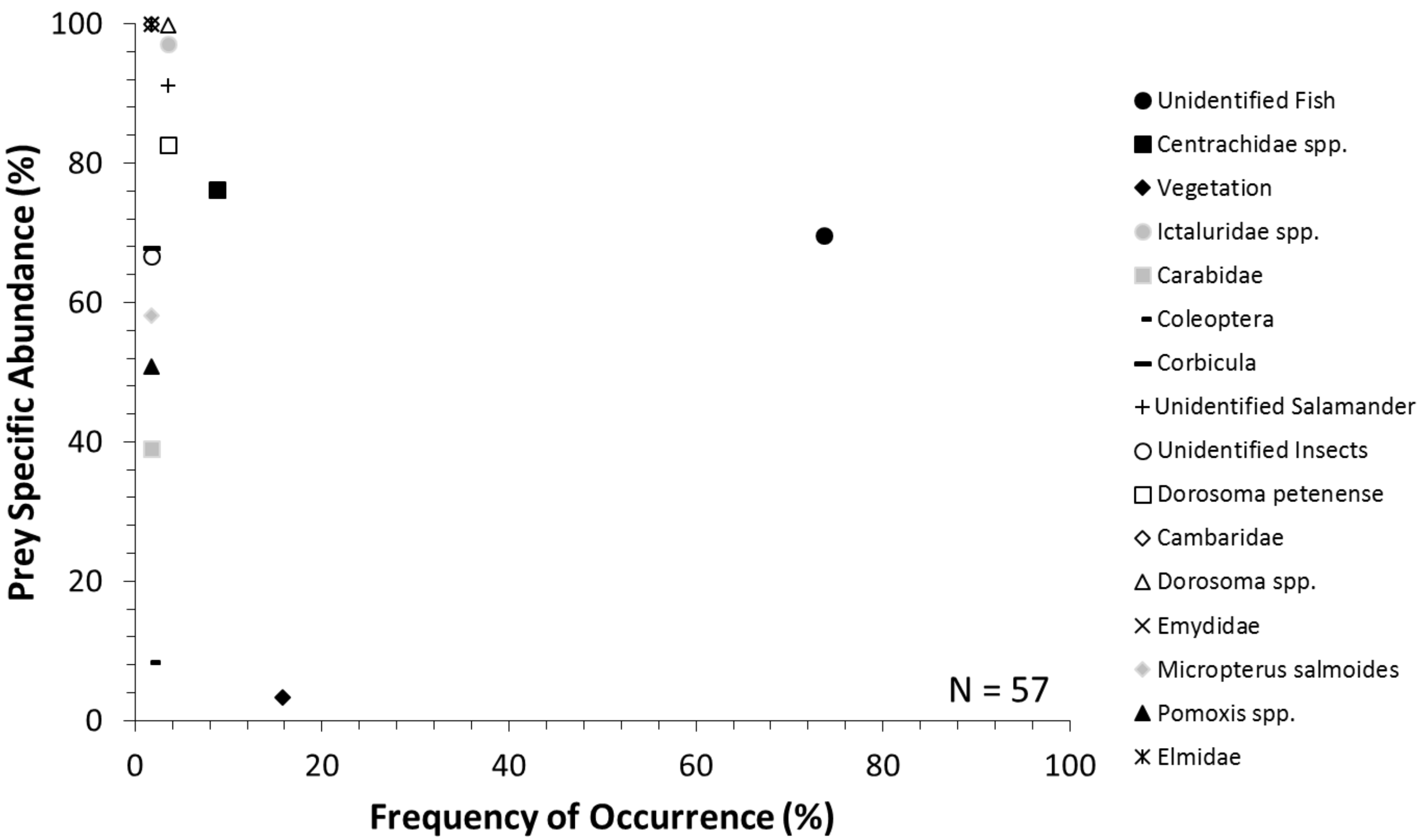

FIGURE A.5. Prey specific abundance (%) versus frequency of occurrence (%) for all diet items collected from all Largemouth Bass sampled from Grand Lake, TX in mid-November, 2012.

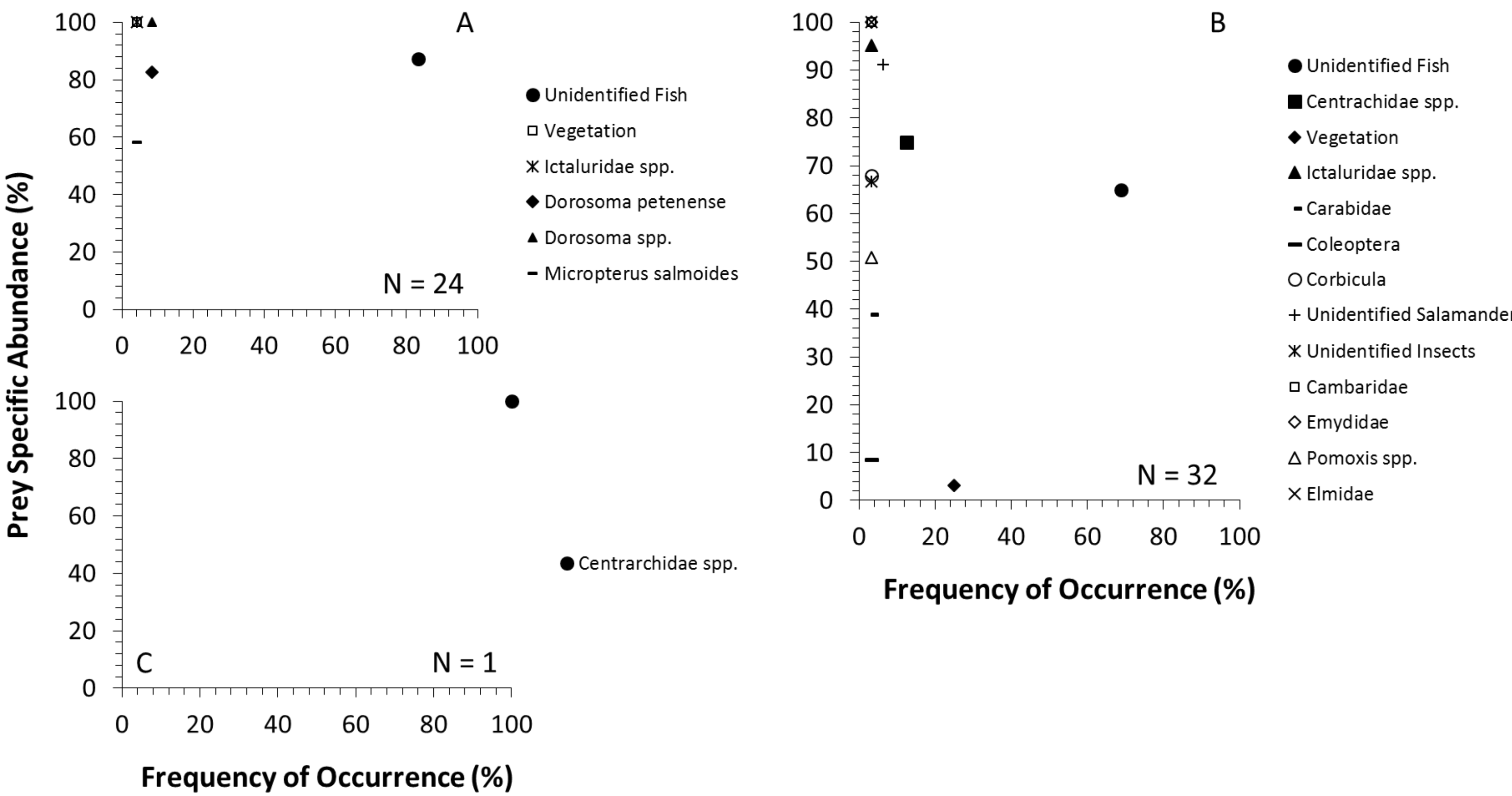

FIGURE A.6. Prey specific abundance (%) versus frequency of occurrence (%) for all diet items collected from Largemouth Bass 250-381 mm TL (A), 382-508 mm TL (B), and ≥ 509 mm TL (C) sampled from Grand Lake, TX in mid-November, 2012.

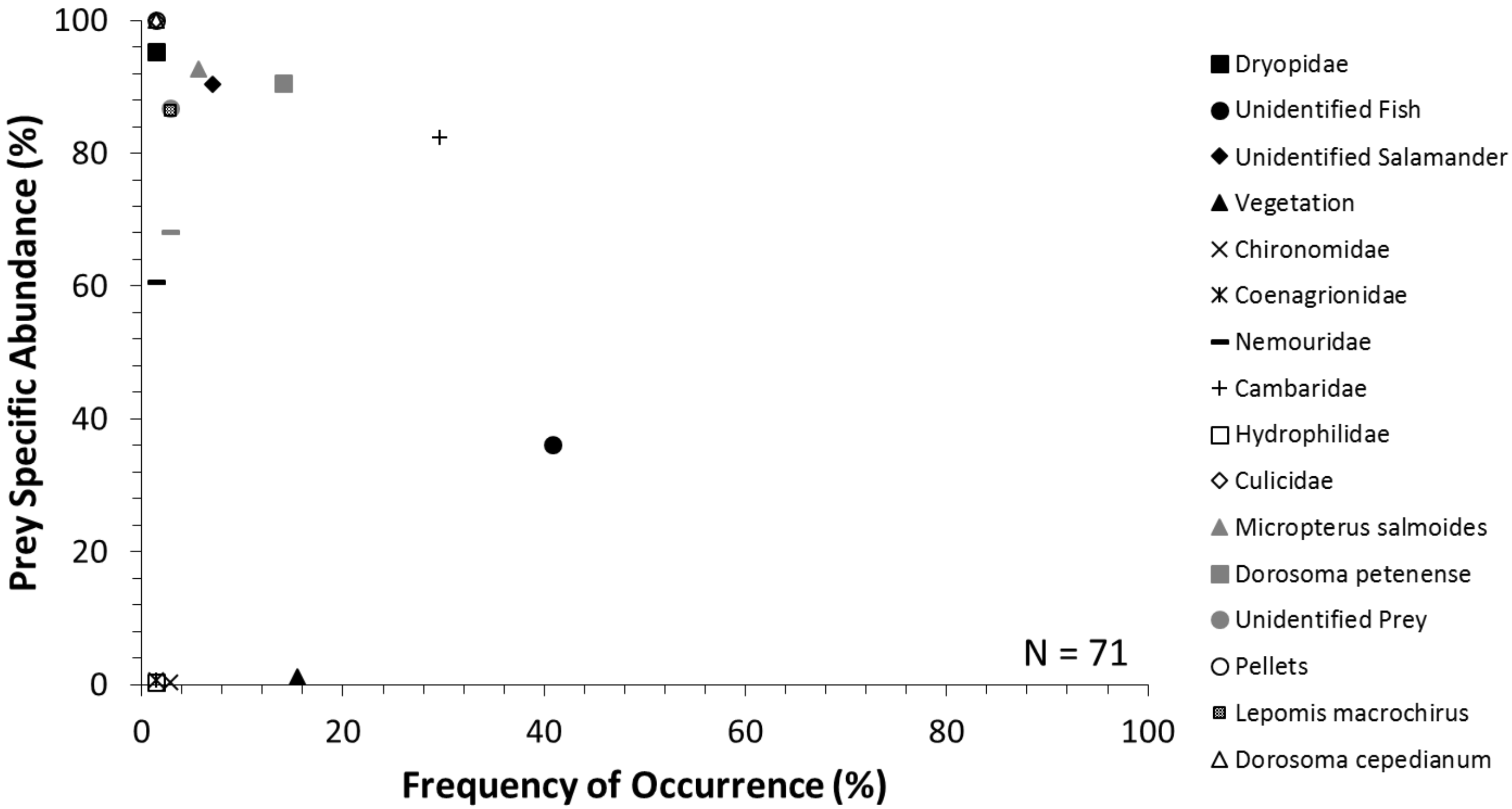

FIGURE A.7. Prey specific abundance (%) versus frequency of occurrence (%) for all diet items collected from all Largemouth Bass sampled from Grand Lake, TX in late-May/early-June, 2013.

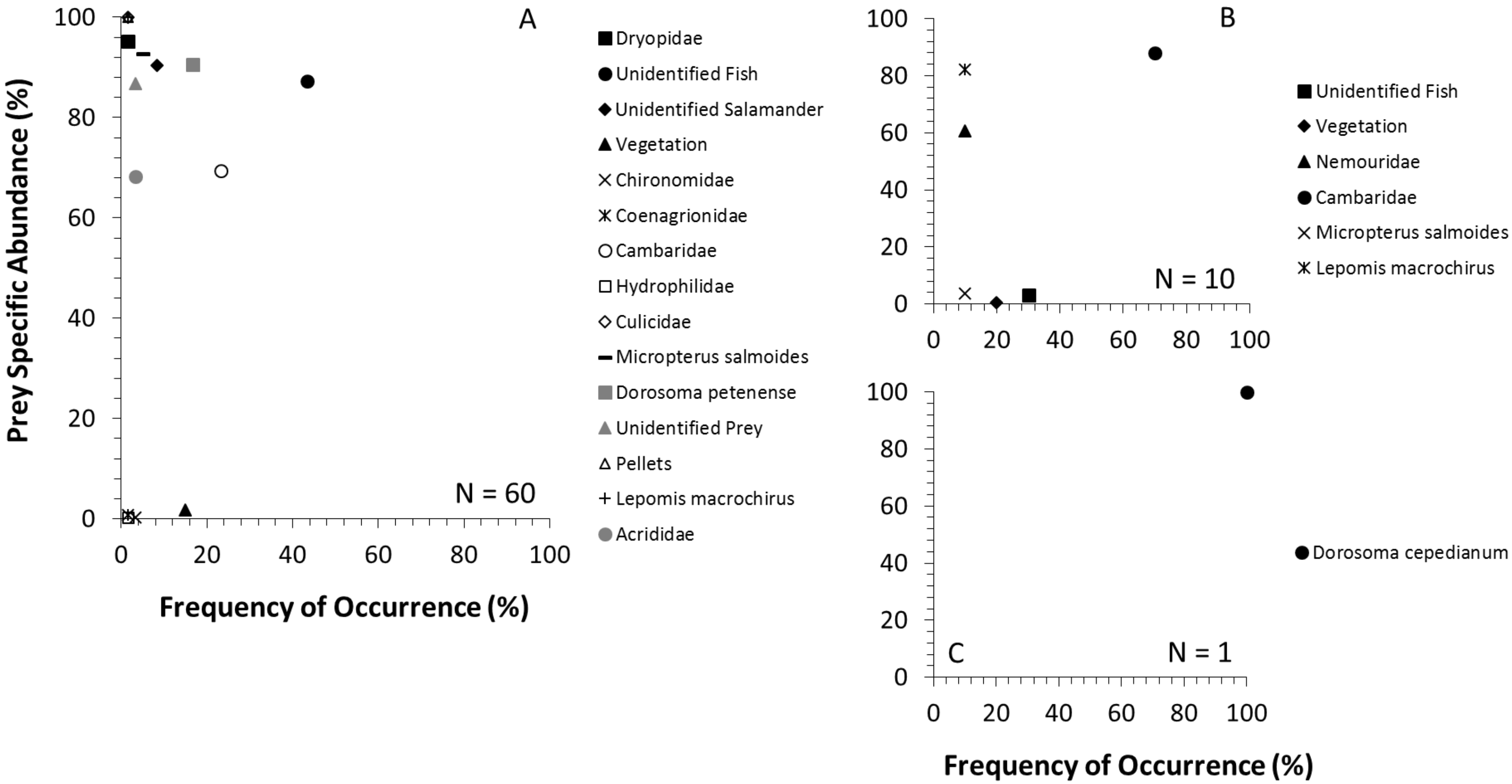

FIGURE A.8. Prey specific abundance (%) versus frequency of occurrence (%) for all diet items collected from Largemouth Bass 250-381 mm TL (A), 382-508 mm TL (B), and ≥ 509 mm TL (C) sampled from Grand Lake, TX in late-May/early-June, 2013.

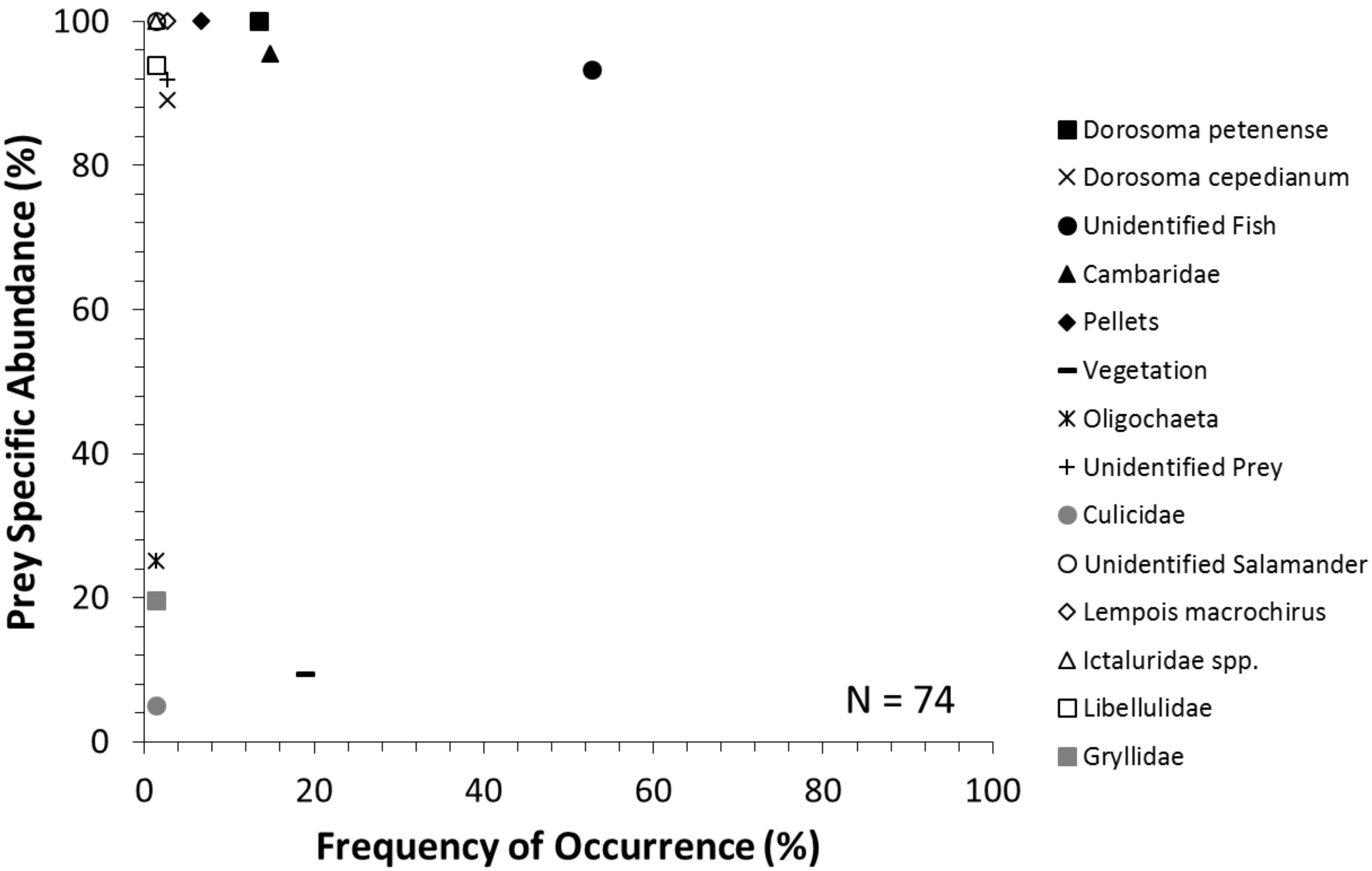

FIGURE A.9. Prey specific abundance (%) versus frequency of occurrence (%) for all diet items collected from all Largemouth Bass sampled from Grand Lake, TX in late-July/early-August, 2013.

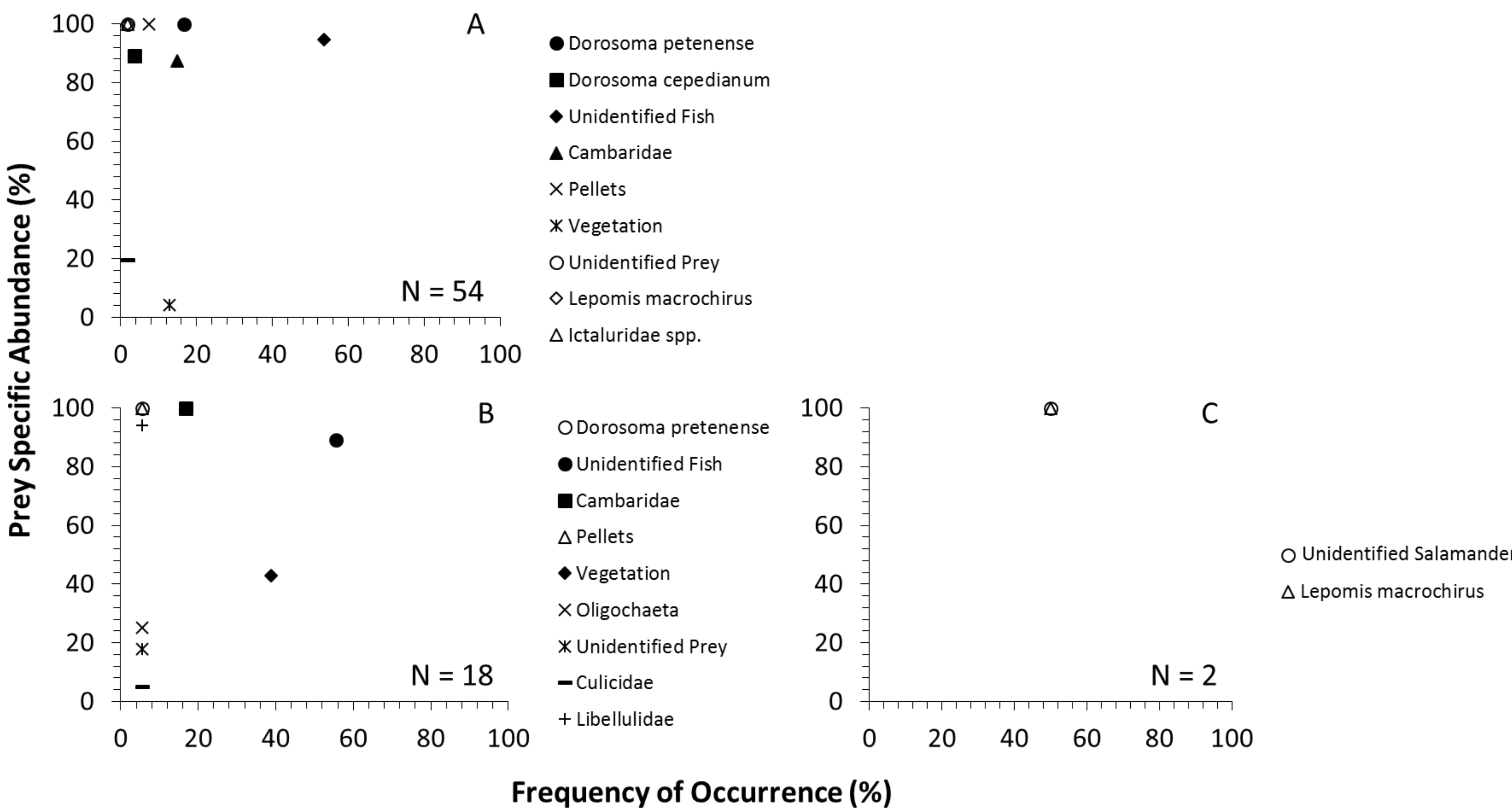

FIGURE A.10. Prey specific abundance (%) versus frequency of occurrence (%) for all diet items collected from Largemouth Bass 250-381 mm TL (A), 382-508 mm TL (B), and ≥ 509 mm TL (C) sampled from Grand Lake, TX in late-July/early-August, 2013.

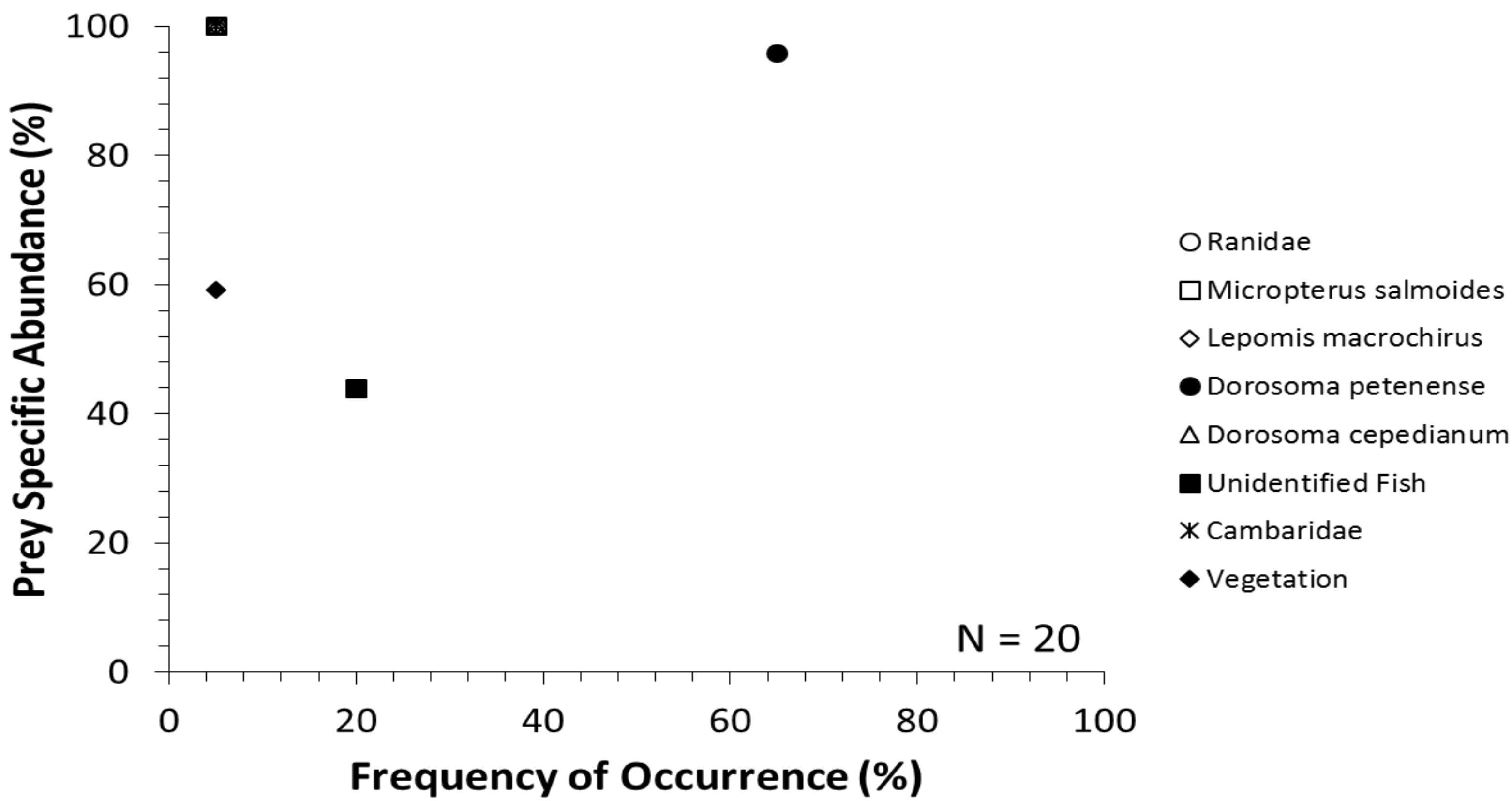

FIGURE A.11. Prey specific abundance (%) versus frequency of occurrence (%) for all diet items collected from all Largemouth Bass sampled from Grand Lake, TX in mid-September, 2013.

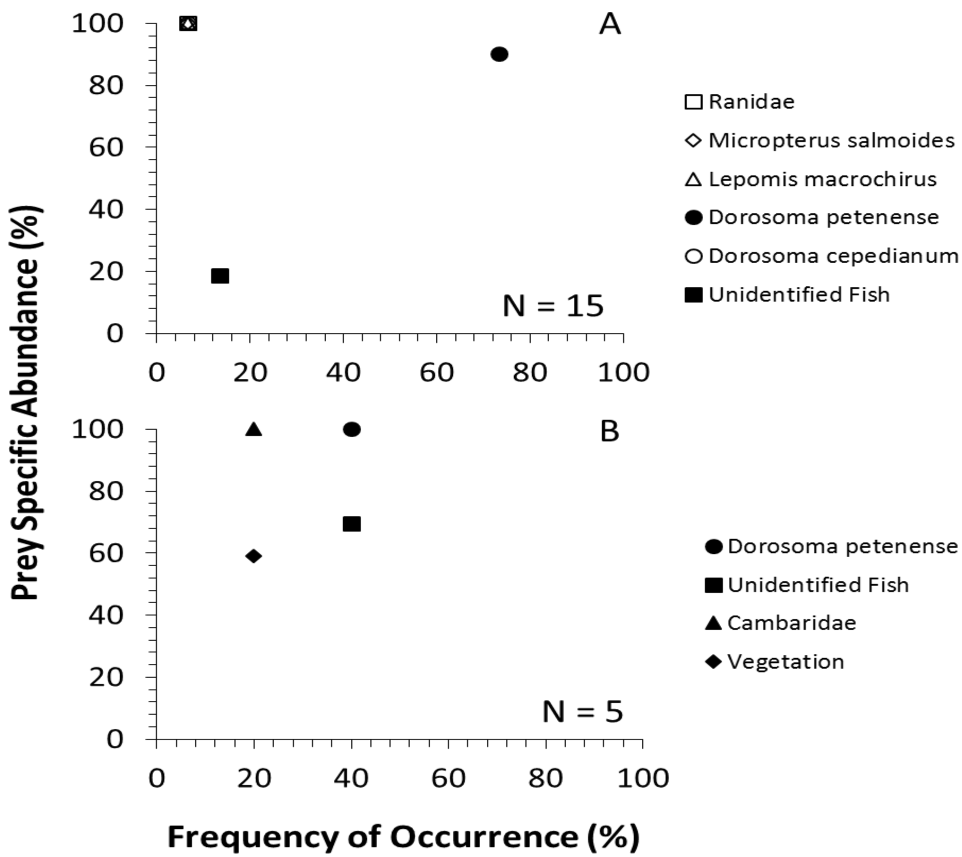

FIGURE A.12. Prey specific abundance (%) versus frequency of occurrence (%) for all diet items collected from Largemouth Bass 250-381 mm TL (A) and 382-508 mm TL (B) sampled from Grand Lake, TX in mid-September, 2013.

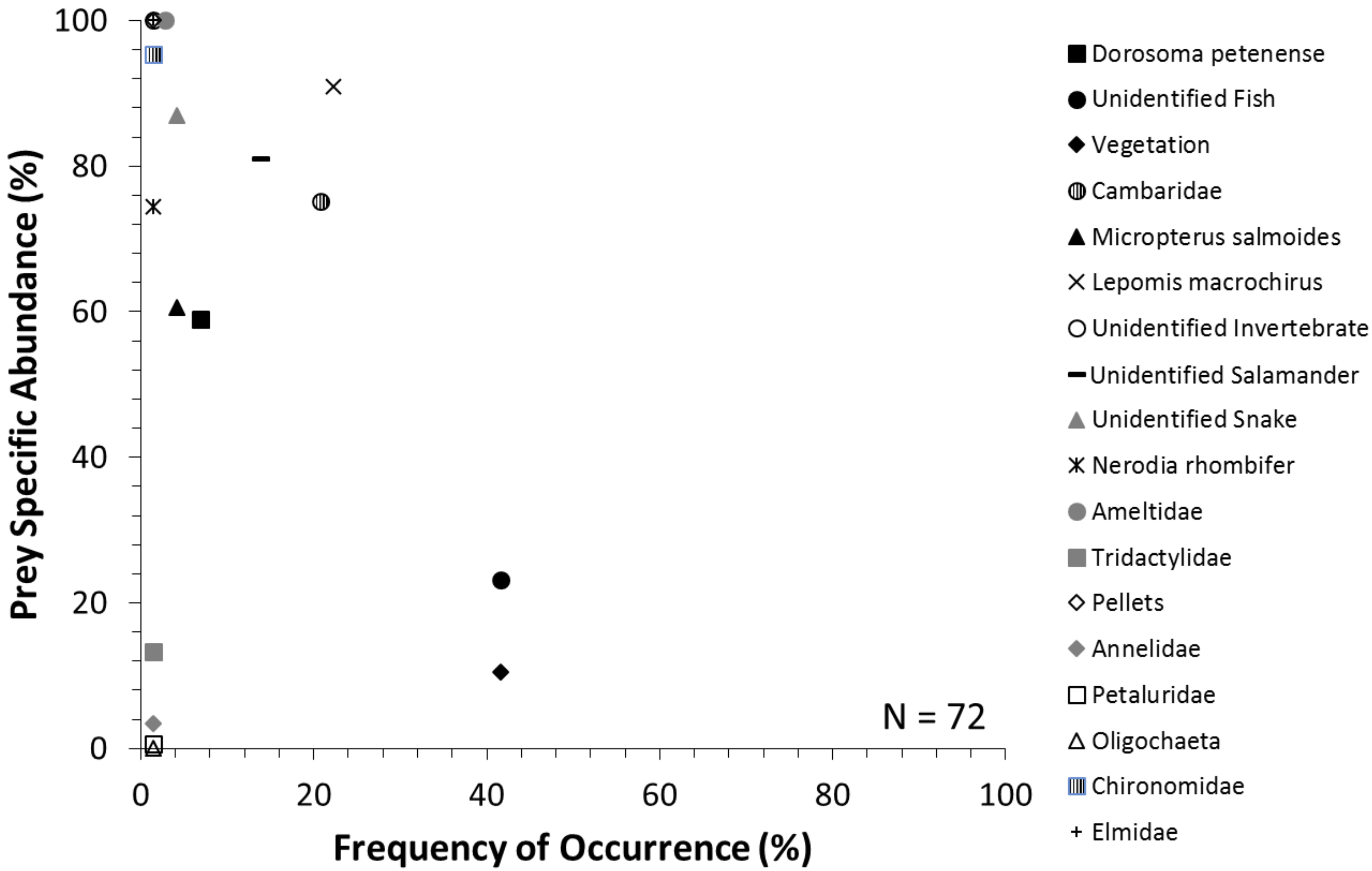

FIGURE A.13. Prey specific abundance (%) versus frequency of occurrence (%) for all diet items collected from all Largemouth Bass sampled from Grand Lake, TX in early-November, 2013.

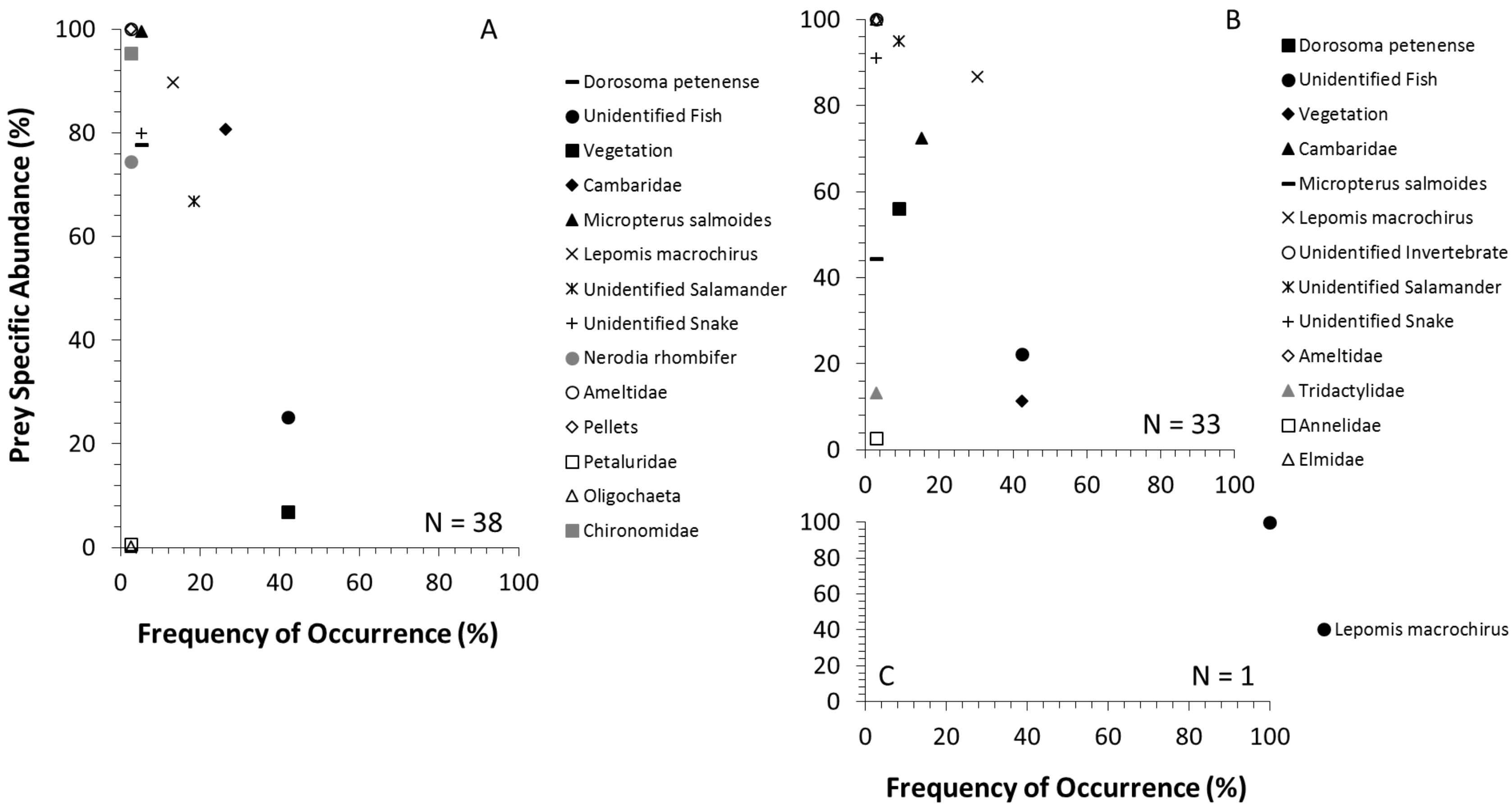

FIGURE A.14. Prey specific abundance (%) versus frequency of occurrence (%) for all diet items collected from Largemouth Bass 250-381 mm TL (A), 382-508 mm TL (B), and ≥ 509 mm TL (C) sampled from Grand Lake, TX in early-November, 2013.

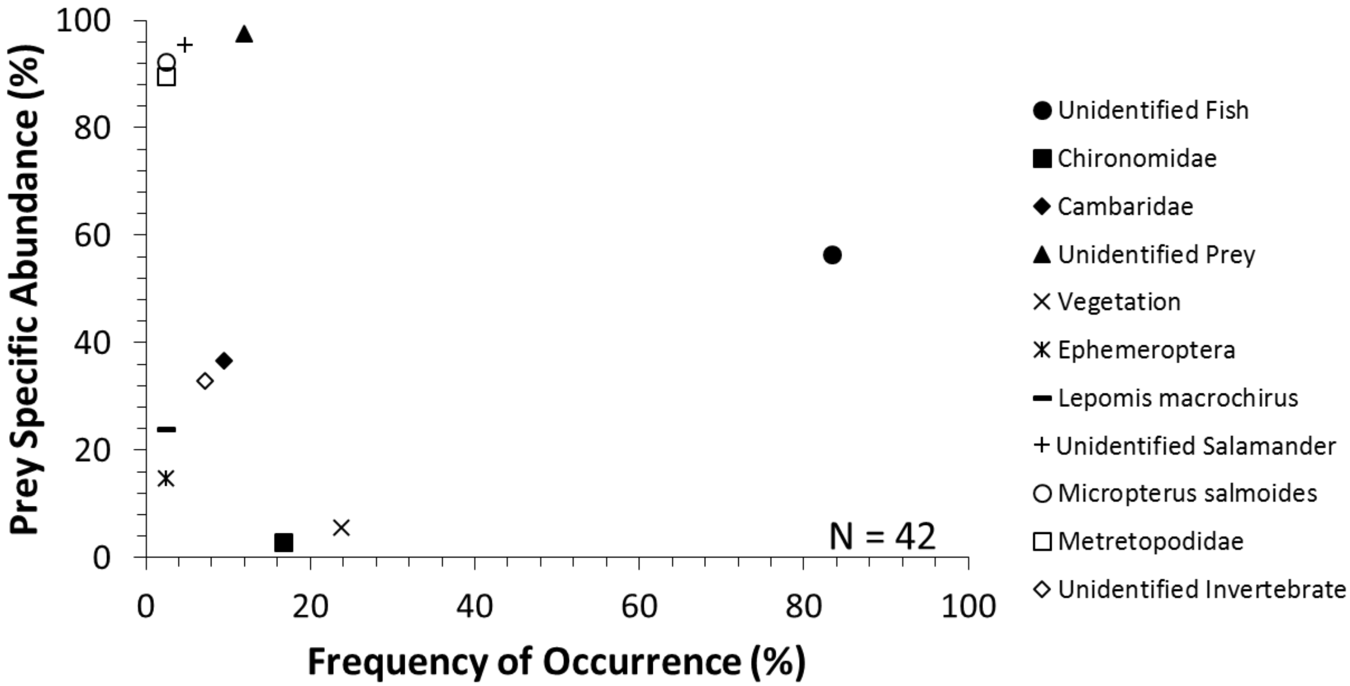

FIGURE A.15. Prey specific abundance (%) versus frequency of occurrence (%) for all diet items collected from all Largemouth Bass sampled from Grand Lake, TX in early-February, 2014.

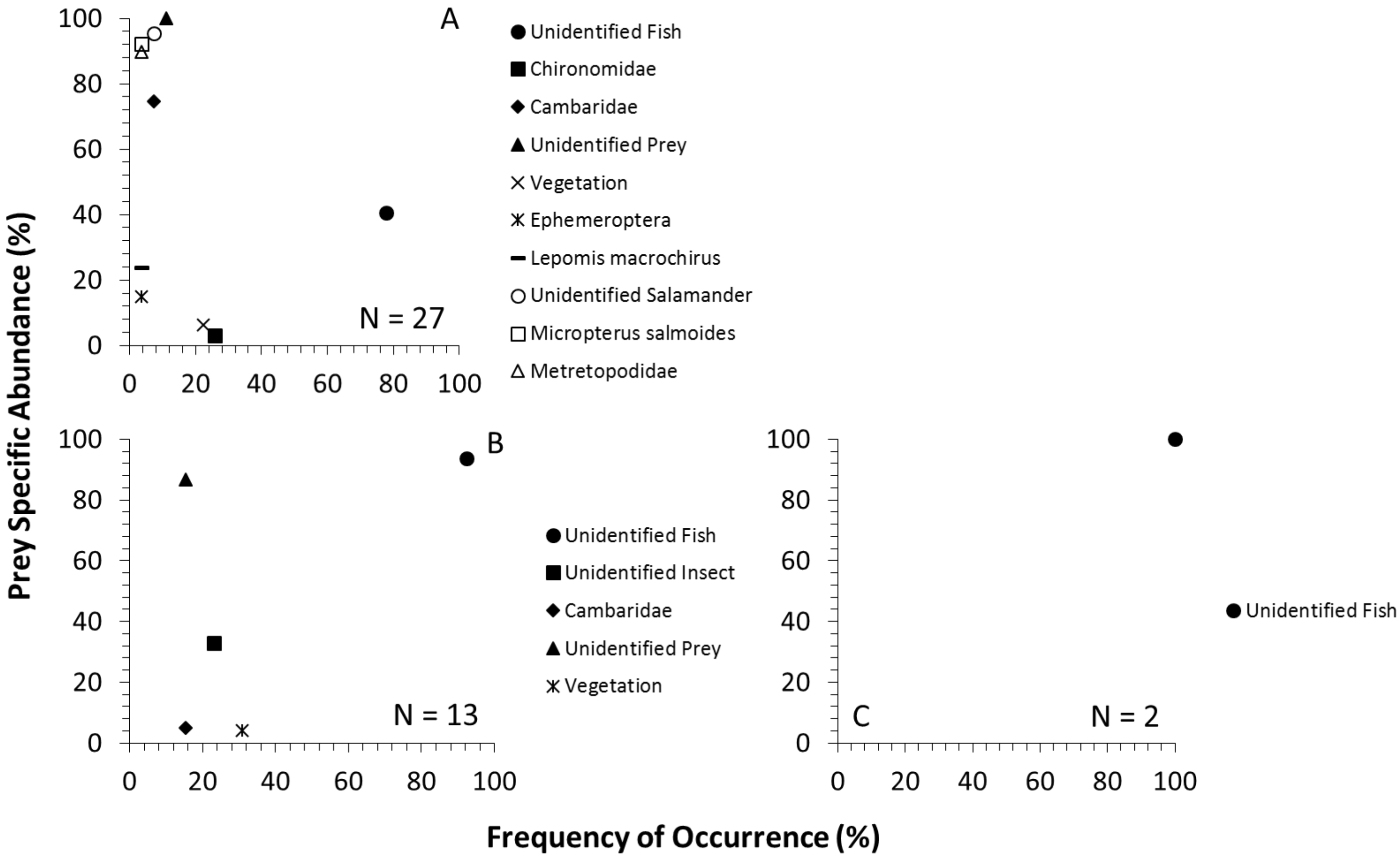

FIGURE A.16. Prey specific abundance (%) versus frequency of occurrence (%) for all diet items collected from Largemouth Bass 250-381 mm TL (A), 382-508 mm TL (B), and ≥ 509 mm TL (C) sampled from Grand Lake, TX in early-February, 2014.

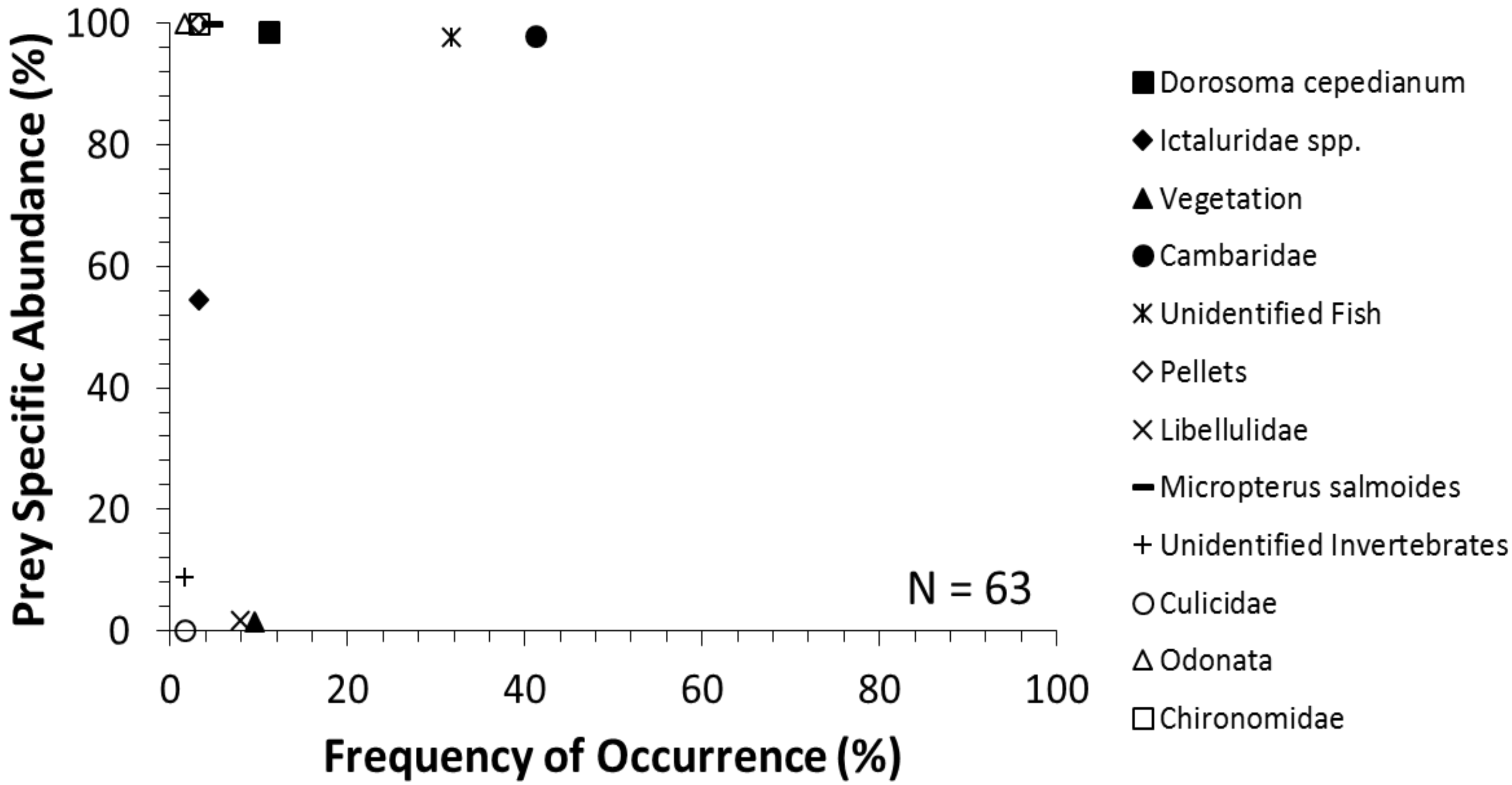

FIGURE A.17. Prey specific abundance (%) versus frequency of occurrence (%) for all diet items collected from all Largemouth Bass sampled from Grand Lake, TX in mid-May, 2014.

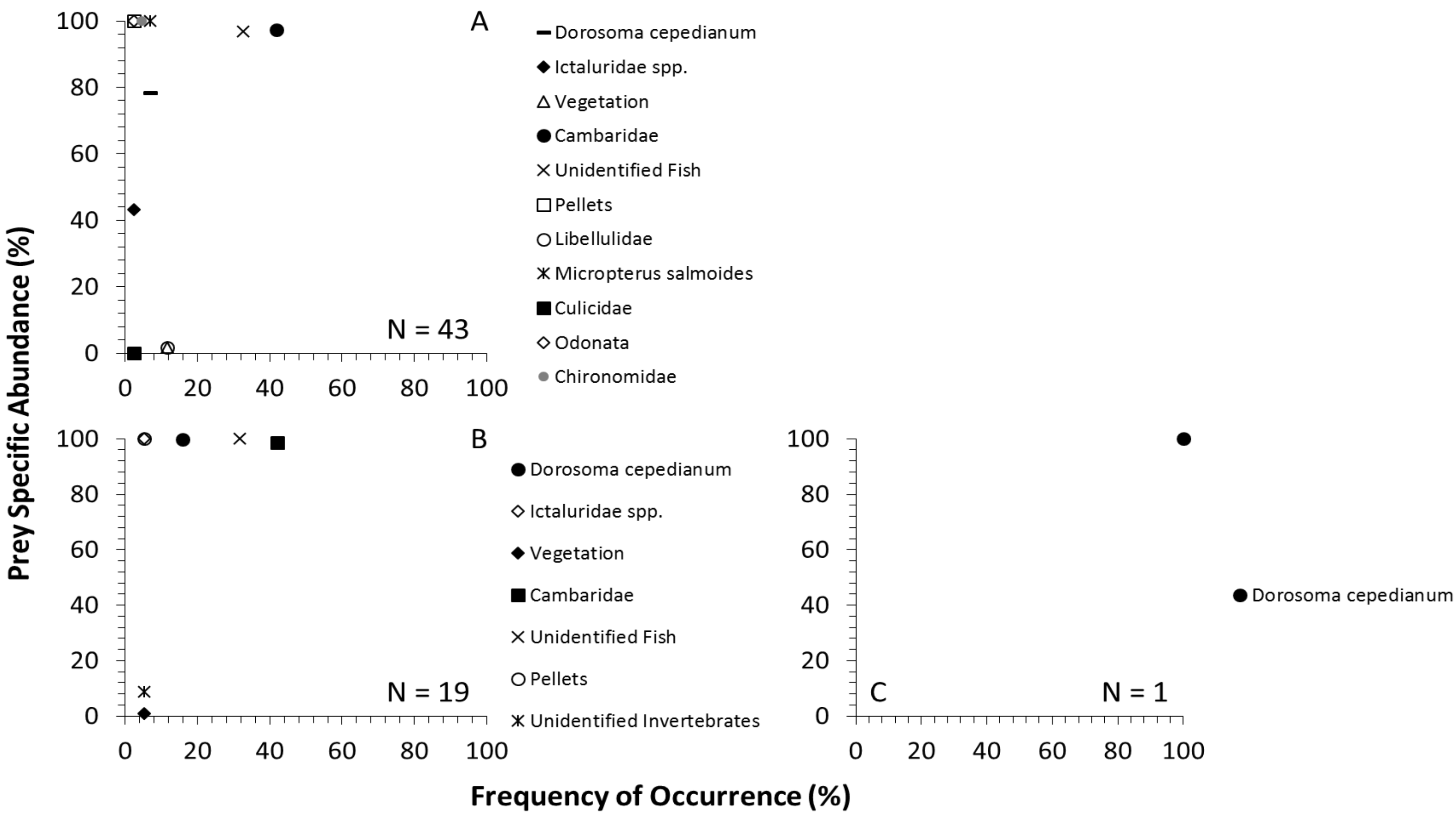

FIGURE A.8. Prey specific abundance (%) versus frequency of occurrence (%) for all diet items collected from Largemouth Bass 250-381 mm TL (A), 382-508 mm TL (B), and ≥ 509 mm TL (C) sampled from Grand Lake, TX in mid-May, 2014.

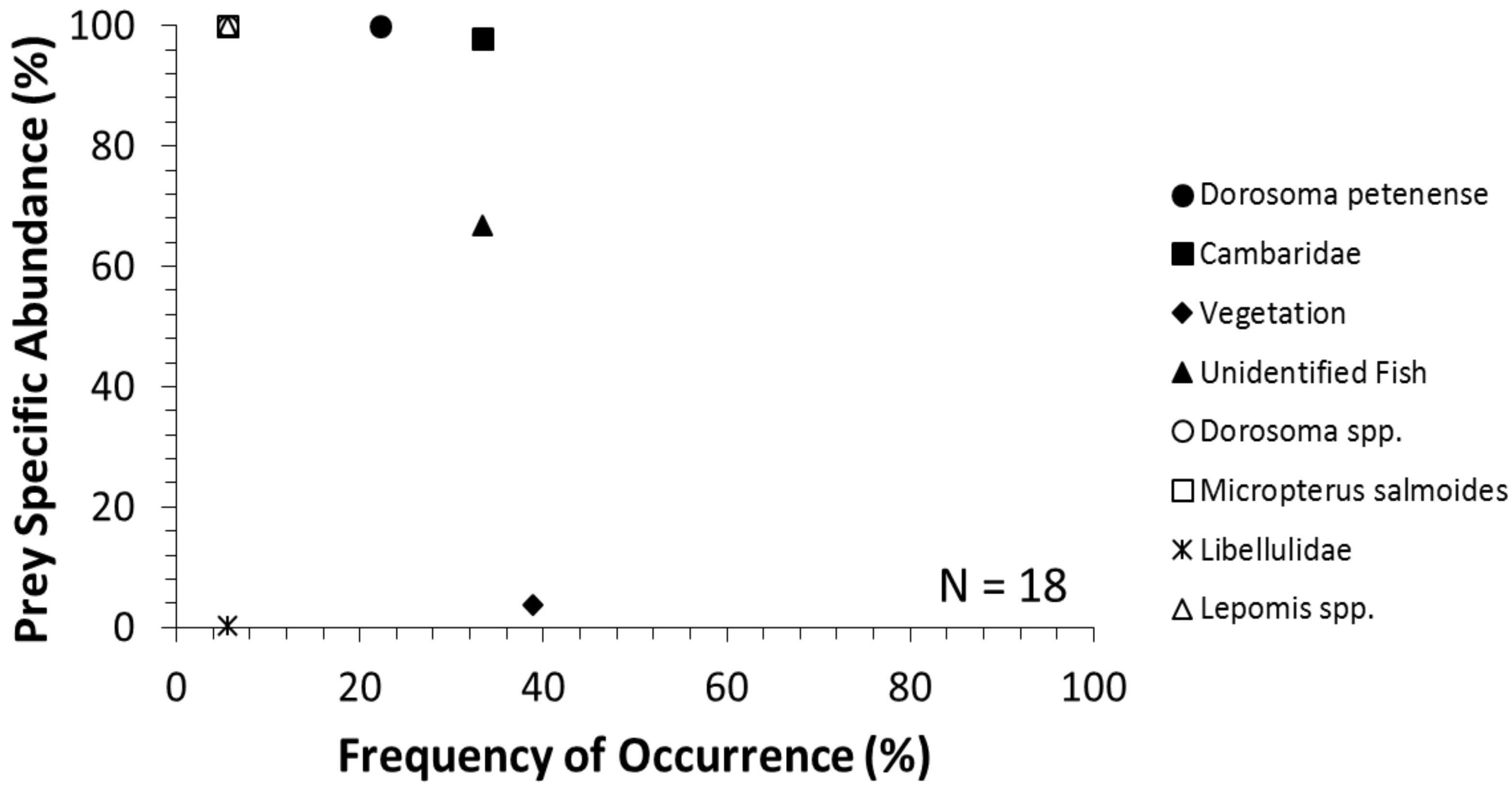

FIGURE A.19. Prey specific abundance (%) versus frequency of occurrence (%) for all diet items collected from all Largemouth Bass sampled from Grand Lake, TX in early-July, 2014.

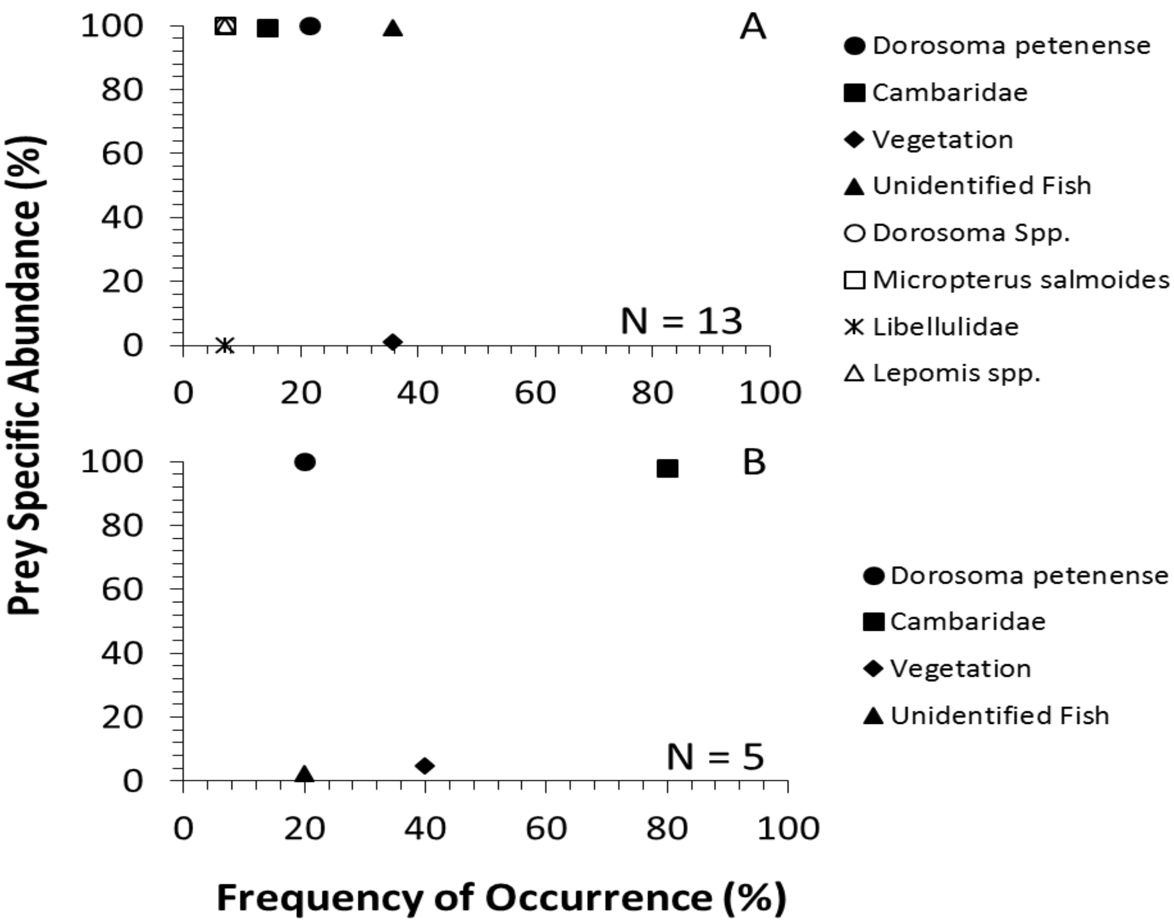

FIGURE A.20. Prey specific abundance (%) versus frequency of occurrence (%) for all diet items collected from Largemouth Bass 250-381 mm TL (A), 382-508 mm TL (B), and ≥ 509 mm TL (C) sampled from Grand Lake, TX in early-July, 2014.

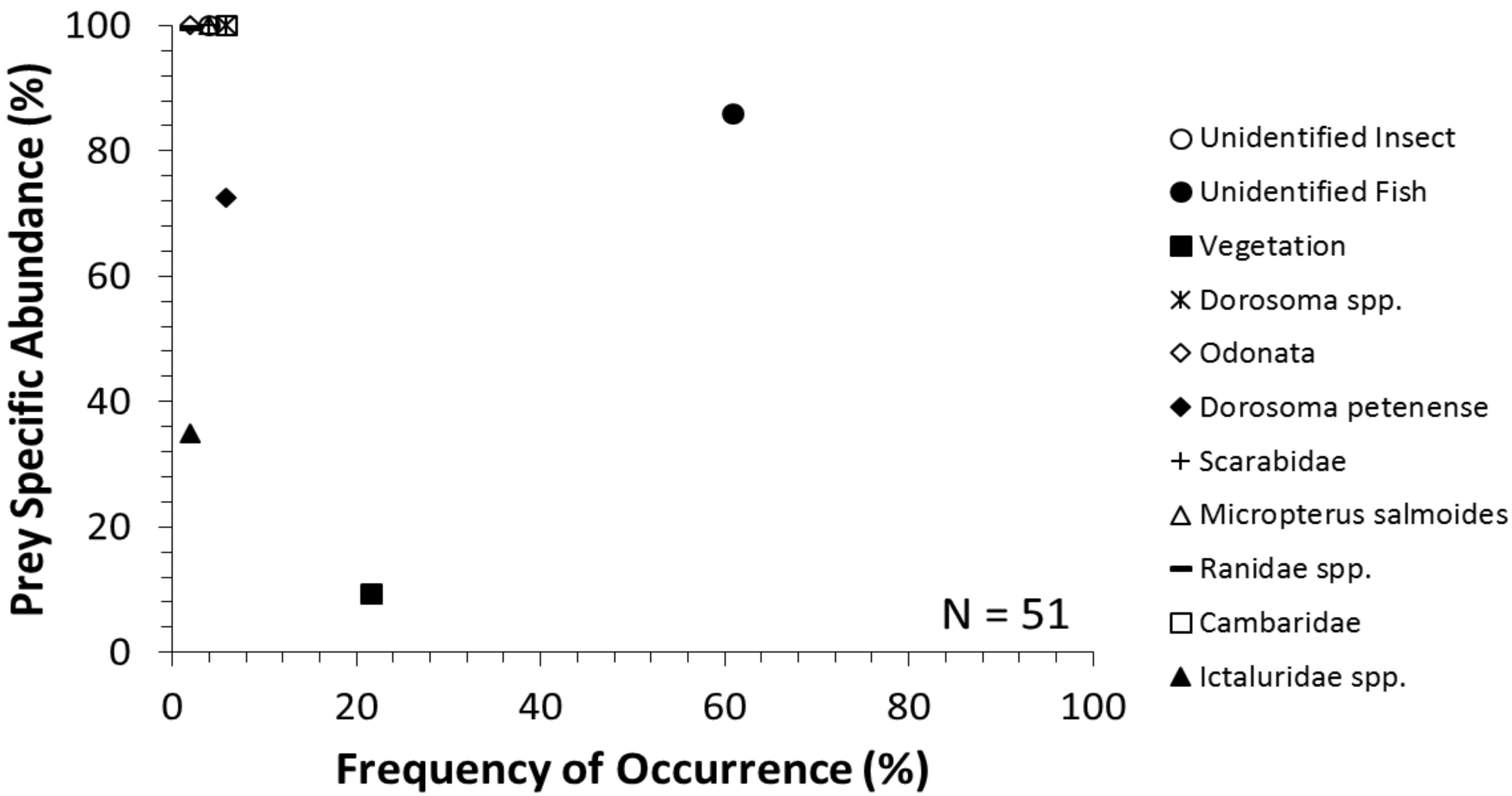

FIGURE A.21. Prey specific abundance (%) versus frequency of occurrence (%) for all diet items collected from all Largemouth Bass sampled from Grand Lake, TX in mid-September, 2014.

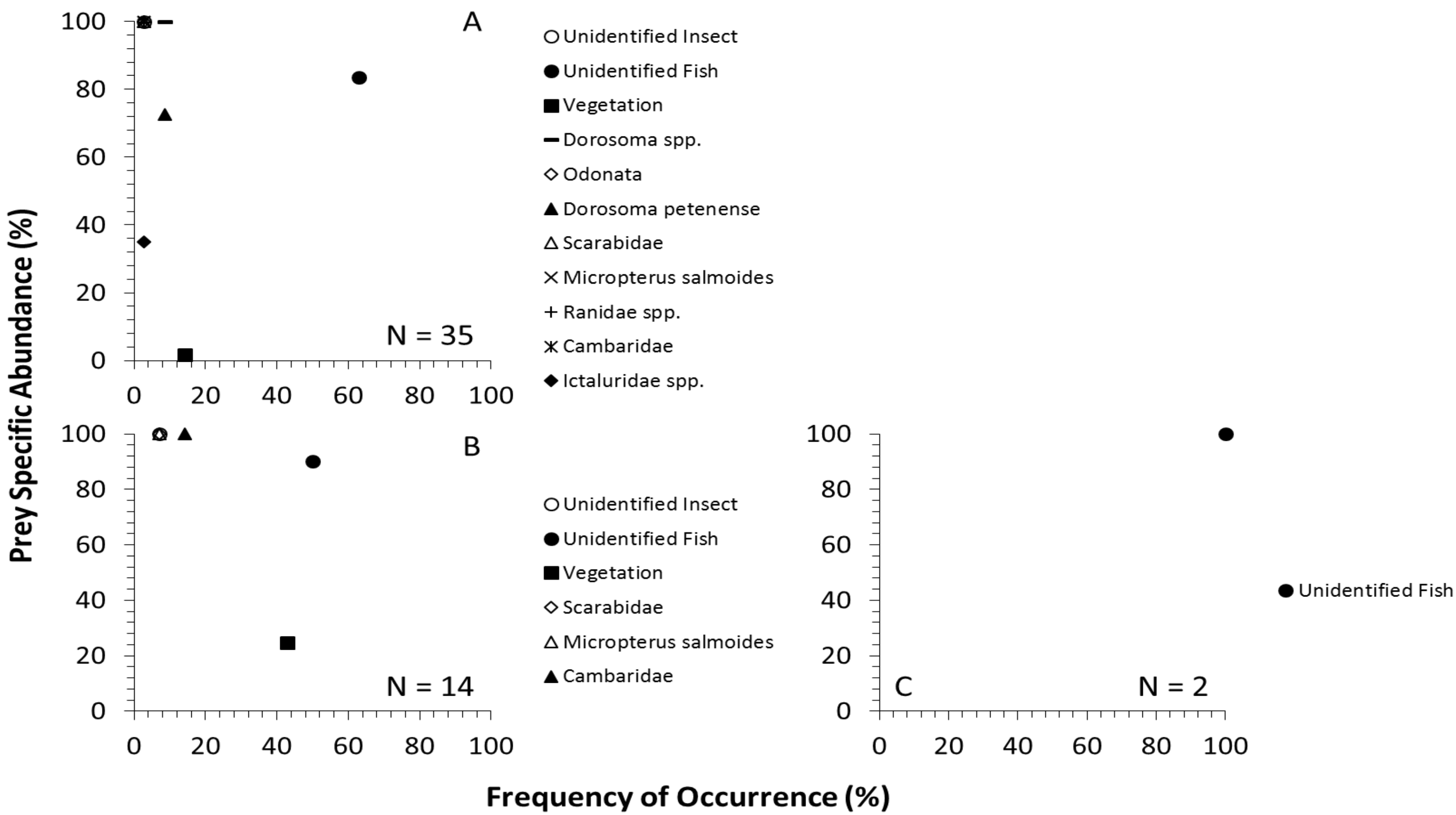

FIGURE A.22. Prey specific abundance (%) versus frequency of occurrence (%) for all diet items collected from Largemouth Bass 250-381 mm TL (A), 382-508 mm TL (B), and ≥ 509 mm TL (C) sampled from Grand Lake, TX in mid-September, 2014.

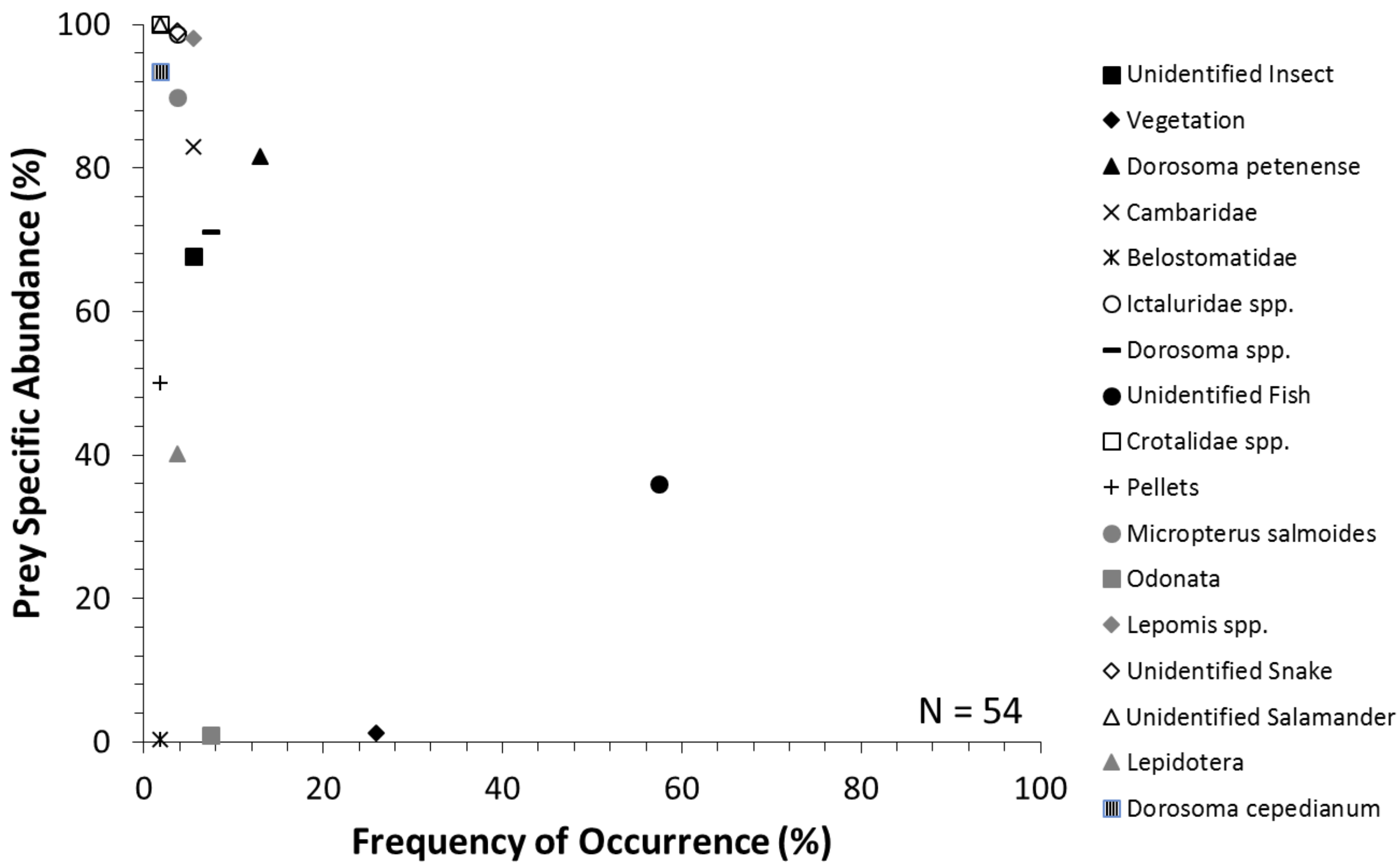

FIGURE A.23. Prey specific abundance (%) versus frequency of occurrence (%) for all diet items collected from all Largemouth Bass sampled from Grand Lake, TX in late-October, 2014.

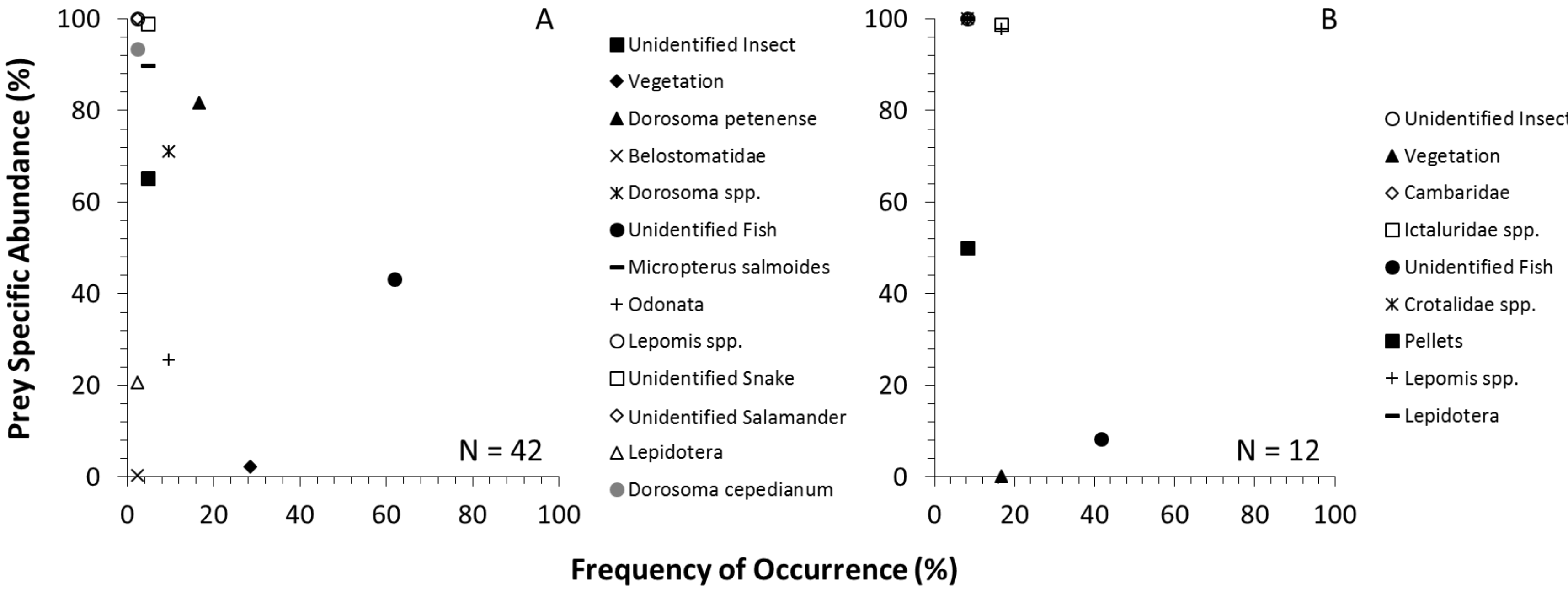

FIGURE A.20. Prey specific abundance (%) versus frequency of occurrence (%) for all diet items collected from Largemouth Bass 250-381 mm TL (A) and 382-508 mm TL (B) sampled from Grand Lake, TX in late-October, 2014. No diets were collected from Largemouth Bass ≥509mm TL from this sampling period.