**Introduced Yellow Perch in Lake Martin and Yates Lake, Alabama: Interactions with
Native Fishes**

by

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Abstract

Yellow perch has been introduced into Southeastern US drainages outside its native range. In Alabama, established populations now exist in Lake Martin and Yates Lake. Here, I determined how yellow perch might influence resident fishes in these reservoirs. I sampled all life stages of yellow perch and resident fishes with diverse sampling gears, conducted age-and-growth analyses, and quantified diets over two years. Yellow perch were more abundant and older in Yates Lake than in Lake Martin. Co-occurrence was limited between larval yellow perch and native fishes. Diet overlap was also generally low at older life stages. Juvenile yellow perch were consumed by *Micropterus* spp. in both lakes during spring, suggesting potential benefits. I suggest minimal negative effects of yellow perch on native fishes due to their generalist diet, early spawning period, and cool water temperature requirements. As prey, yellow perch may have positive influences on some native fishes.

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Introduction

Introduction of nonindigenous fishes has led to interactions between fish species that previously did not co-occur. The impacts from nonindigenous introductions are apparent in many regions of the United States. In the southeastern US, south Florida has 34 naturalized invasive fish species with potentially devastating impacts (Brooks and Jordan 2009). In the western US, the Colorado River basin has been flooded with at least 100 non-native fish species over the last century (Fuller et al. 1999). These introductions have led to freshwater fish taxa (species and subspecies) native to the Colorado River becoming extinct (n=2), endangered (n=16), or threatened (n=6) (Tyus and Saunders 2000). In the Great Lakes region, sea lamprey *Petromyzon marinus,* has been shown to increase fish mortality six fold by preying upon salmonids in Lake Michigan (Kitchell 1990). Another Great Lakes invasive, the round goby, *Neogobius melanostomus*, has been observed destroying native smallmouth bass, *Micropterus dolomieui,* nests (Steinhart et al. 2004) and their presence was associated with decreased abundances of the mottled sculpin, *Cottus bairdi*, and the johnny darter, *Etheostoma nigrum* (Lauer et al. 2004).

Nonnative introductions are not limited to fish from different continents, but can also include fish moved outside of their native range within North America. The spread of yellow perch *Perca flavescens* is an example of this type of non-native introduction within the United States. Yellow perch is native to North America east of the Rocky Mountains, with populations extending north to Quebec and south along the Atlantic slope to South Carolina (Etnier and Starnes 1993) and the Apalachicola River basin in Georgia, Florida, and Alabama (Hackney and Holbrook 1978). A native disjunct population is found in the Mobile-Tensaw Delta, Alabama (Boschung and Mayden 2004). The range of yellow perch has spread through the southeastern

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US, through both unintentional and intentional introductions (Timmons 1975; Clugston et al. 1978). Yellow perch has been introduced to the Tennessee and Chattahoochee rivers (Hackney and Holbrook 1978), and most recently into the Tallapoosa River in Alabama. This species has become well established in these systems, even though some appearances were only identified as recently as 2004 in the Tallapoosa River drainage (J. Hornsby, personal communication).

Yellow perch is an opportunistic feeder, preying upon almost any appropriately-sized organism (Knight et al. 2011). They begin feeding as prolarvae on small copepods, including copepod nauplii (Ney 1978). Pelham et al. (2001) found that age-0 yellow perch consumed 94% zooplankton, 23% to 100% of which were cladocerans. Similar diets were observed in West Point Reservoir on the Alabama/Georgia border, where cladocerans and copepods contributed 92% and 88% frequency of occurrence respectively (Timmons 1984). After reaching 35 mm in length, yellow perch diets shift from planktivory to insectivory, and at ~80 mm they again shift diets from insectivory to piscivory (Parker et al. 2009). However, adult yellow perch still have a wide diet breadth at larger sizes, continuing to feed on zooplankton and aquatic macroinvertebrates. When feeding on macroinvertebrates, adult yellow perch positively selected Diptera, Amphipoda, and Ephemeroptera (Nakashima and Leggett 1975). Once piscivorous, yellow perch in Lake Michigan fed on a variety of fishes, including alewife *Alosa pseudoharengus*, slimy sculpin *Cottus cognatus*, spottail shiners *Notropis hudsonius*, rainbow smelt *Osmerus mordax*, trout perch *Percopsis omiscomaycus*, johnny darters, and golden shiner *Notemigonus crysoleucas* (Tesar et al. 1979).

Yellow perch has been observed to both compete with and prey on fishes within its native range. Hayes et al. (1992) suggested that the presence of white sucker, *Catostomus commersoni*, caused yellow perch diet to shift from one composed of invertebrates to primarily zooplankton,

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suggesting that they were competing for invertebrate prey. Yellow perch have been observed to influence populations of bluegill, *Lepomis macrochirus*, with larger yellow perch preying on small bluegill (Fullhart et al. 2002). Brook trout, *Salvelinus fontinalis,* and yellow perch have been shown to compete for both spatial and prey resources (Browne and Rasmussen 2009). It is unknown what influence yellow perch is having on native fishes where it has been introduced in Alabama. In West Point Reservoir, Alabama-Georgia they were not found to have a strong negative impact on native largemouth bass populations (Timmons 1984). But given their demonstrated ability to compete with, prey on, and cause habitat/niche shifts with multiple species within their native range, they clearly could have negative effects on other species.

In contrast to the potential negative effects mentioned above, yellow perch can provide an important prey source for piscivores within their native range. Yellow perch dominated the diets of walleye *Sander vitreum* in a study of four lakes in Ontario where they were preferred over *Corregonus* sp., ninespine stickleback *Pungitius pungitius* and other prey species (Ryder and Kerr 1978). In another five-lake study of northern pike *Esox lucius* diets in Wisconsin, yellow perch were present in diets of fish from every lake (Margenau et al. 1998). While they may provide a prey resource to piscivores where they have been introduced, no data exist yet to support that. Anecdotal information suggests yellow perch may occur in diets of both Alabama bass, *Micropterus henshalli*, and striped bass, *Morone saxatilis*, in Lake Martin, Alabama (Jim Paramore and Nick Nichols personal communications). Therefore, they may provide additional prey resources for these or other piscivores.

In this study, I examined interactions among yellow perch and native fishes in two very different reservoirs in the Tallapoosa River system. The overall goal of this research was to evaluate the role of yellow perch in the Lake Martin/Yates Lake ecosystem, and to determine

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whether system productivity appeared to influence their eventual role. More specifically, my objectives were to:

1. Quantify the extent of prey overlap occurring between non-native yellow perch and native fishes (including largemouth bass *Micropterus salmoides*, Alabama bass, bluegill, redear sunfish, *Lepomis microplophus*, and crappie, *Pomoxis* spp.) based on diet composition, diet overlap, and prey selection at larval, juvenile, and adult life stages in Lake Martin and Yates Lake.

2. Assess the potential benefits of yellow perch as prey for Alabama bass, largemouth bass, and striped bass.

3. Quantify adult size structure, condition, growth rate, and estimate mortality of non-native yellow perch in Yates Lake.

4. Compare life history of yellow perch in the Tallapoosa River system with populations in its native range.

Methods

Sample Area and Locations

My research was conducted in two reservoirs in the Tallapoosa River system in Alabama, Lake Martin and Yates Lake, which is immediately downstream of Lake Martin. While these reservoirs are adjacent to one another, they differ in a number of characteristics. Lake Martin was impounded in 1926 as a tributary storage reservoir used primarily for hydroelectric purposes and water storage (Alabama Power 2011). It includes an area of 16,188 ha and is located in Tallapoosa, Coosa, and Elmore counties. I sampled three areas in Lake Martin - the Kowligia arm (Parker Creek Bay and Chapman Creek Bay), the Blue Creek arm (an undeveloped bay across from the Union Boat Ramp), and the main stem (Elkahatchee Creek Bay and Irwin Shoals) (Figure 1). Yates Dam was constructed in 1928 for hydroelectric generation, recreation, and navigation, impounding an area of 680 ha on the border of Elmore and Tallapoosa counties. I sampled three study sites in Yates Lake: the island near the Hwy 50 Bridge, Chanahatchee Creek, and Saugahatchee Creek (Figure 1). These two reservoirs were chosen because they both contained introduced yellow perch and differed in system productivity and yellow perch abundance. Sites within Lake Martin and Yates Lake were chosen based on survey information gathered from the Alabama Department of Conservation and Natural Resources and Alabama Power.

Sampling Methods

<u>Adult fishes</u>

Adult fish were sampled from February through April of both 2010 and 2011 using pulsed-DC night electrofishing (Smith Root 7.5 GPP) to ensure capture of prespawn, spawning, and postspawn adult yellow perch. Yellow perch begin spawning at water temperatures between

2-18 C in their native range (Carlander 1997). One transect (10-30 min/transect) was electrofished at each site once per week, and adult bluegill, redear sunfish, striped bass, Alabama bass, largemouth bass, crappie spp., and yellow perch were collected and placed on ice to be processed and analyzed in the lab. In 2011, a sample of yellow perch was also collected using hook and line sampling in Yates during the pre-spawn period (mid-February) to collect older yellow perch for age-and-growth analysis.

In 2011, I continued to sample from May to July with pulsed-DC night electrofishing. I increased sampling effort to 2-4 transects (10-30 min) at 4 sites biweekly, and collected adult yellow perch, largemouth bass, Alabama bass, and striped bass. During summer, yellow perch likely migrated to deeper water and therefore became unavailable to electrofishing, so I used gillnets to try to sample fish in deeper water. Once yellow perch were no longer collected in our electrofishing samples, I set gill nets (2.4 m deep, 38.1 m long, 38.1 mm-88.9 mm mesh size) overnight perpendicular to the shore. This sampling was conducted once per month at our standard sites as well as at some additional sites in both Yates and Martin from May until August. From late August through early December, I collected a sample of at least 100 yellow perch total per reservoir for age-and-growth purposes via night electrofishing.

Larval and Juvenile Fishes

Larval and early juvenile fish were sampled with two gears in 2010. The first was a push net (50 cm diameter, 150 cm long, 500 µm mesh) with an attached flow meter (General Oceanics, Inc., to allow calculation of sample speed and volume of water sampled). Two replicate 5 min pushes were collected at a speed of 1 – 1.5 m/sec. Once larval fish were estimated to have reached 10 to 13 mm, a neuston net (2m x 1m, 399 cm long, 1-mm mesh) with a flow meter was used. The neuston net was towed once per site for 8 -10 minutes at a speed of

1-1.5 m/sec. In 2011, I only used the push net due to the similar effectiveness of the two gears at sampling the same sizes of fish larvae. Larval sampling occurred once per week at each site from February through May. During May through August, I reduced this sampling to once per month.

In 2010, I experimented with a variety of sampling gears to collect juvenile yellow perch. These gears included minnow traps, light traps, a beam trawl, small mesh gill nets (~8 mm mesh) and prod pole electrofishing. I found pulsed-DC night electrofishing to be most effective for collecting juvenile yellow perch and juvenile *Micropterus* spp., therefore I limited my sampling to electrofishing in 2011. All juvenile yellow perch, bass, and crappie captured were held on ice and returned to the lab, where diets of up to 10 individuals per site per date were quantified.

Abiotic measures

I measured surface water temperature (ºC) and Secchi depth (nearest cm) at each site during every sampling trip. Surface water samples were collected in 500-ml dark polyethylene bottles, which were then placed directly on ice and returned to the lab. In the lab, I used these water samples to estimate turbidity with a nephelometer (NTU; HG Scientific, Inc.), and the remaining water sample was filtered and chlorophyll concentrations measured using standard fluorometry (Turner Designs Aquafluor). During May through August these measures were reduced from once per week to once per month, and water temperature and dissolved oxygen were measured at 1-m intervals from the surface to the bottom (based on minimal occurrence of adult yellow perch in electrofishing samples). During late August through early October, I again measured only surface water temperature during each sampling trip. In 2011, I set Hobo®temperature pendant data loggers (Model UA-002-64). In Yates Lake, I placed two loggers on the north end and one logger on the south end. Three loggers were placed in Lake Martin in the

main stem, Blue Creek arm and Kowligia arm. Temperature loggers were set to record water temperature at 2-hr intervals from January 2011 through December 2011.

Zooplankton

I sampled zooplankton at each site with a 50-µm mesh net (31cm diameter, 91cm long). Two replicate vertical tows were taken at each site every other week through the photic zone (approximately twice the secchi depth) or from the bottom, whichever was least. Samples were preserved in 70% ethanol and returned to the lab. In the lab, the first 10 zooplankton within each taxon were measured (body length). Subsamples were counted until at least 200 individuals of the most abundant taxa were counted or until the entire sample was counted (Dettmers and Stein 1992; Welker et al. 1994). Samples were taken at each site once per week during February through May, and once per month from May through August.

Laboratory Processing

All adult yellow perch collected from electrofishing were returned to the lab, weighed (nearest g), and measured (nearest mm TL). All yellow perch gonads were weighed and otoliths removed. A minimum of 25 yellow perch were taken from each sample to have their stomachs removed for diet analysis. All bluegill, redear sunfish, largemouth bass, Alabama bass, striped bass, and crappie were weighed and measured. For native fishes, I subsampled 10 stomachs per site per sample date per species.

Diets were analyzed under a dissecting microscope, where fish were identified to genus (species whenever possible), and invertebrates were identified to family. Prey items were measured, with the approach dependent on how digested that prey item was. Fish prey were measured as total length or standard length; if length was not obtainable, then otoliths were counted and measured. Using otoliths, digested fish were identified based on otolith structure

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and fish length estimated from the otolith size-fish size regression for that fish species. For invertebrates, the first ten head capsules were measured for each family and the rest were counted. For zooplankton in diets, all zooplankton were identified to genus. The first ten individuals from each taxon were measured (body length). The rest of zooplankton were counted.

Larval and juvenile fish were identified to genus, measured, and counted. I analyzed diets of larval yellow perch, larval *Pomoxis*, larval *Dorosoma*, and larval *Lepomis*. These species were chosen for analysis because of their potential co-occurrence with larval yellow perch and high abundance in the pelagic zone. I analyzed the diets of both juvenile yellow perch and juvenile black basses given their spatial and temporal overlap in the littoral zone. Diets of up to ten larval and ten juvenile fish were quantified for each species per site, and prey items (up to 10 per taxon per fish) were measured to the nearest 0.1 mm under a dissecting microscope with an ocular micrometer (Armstrong et al. 1998).

Fish age and growth

Yellow perch otoliths were removed, stored dry in vials, and aged under a dissecting microscope using immersion oil, by two independent readers. Otoliths that were difficult to read or were age 5 and older were cross-sectioned using a low speed diamond blade saw (South Bay Technology Model 650). Cross-sections were then mounted to a slide and immersion oil was used for clarity. Otoliths were measured from the focus to the posterior-most end of the annulus (nearest 0.001 mm) using an image analysis system.

Total length at the ith age (TL_i) was estimated using the direct proportion method (Le Cren 1947):

$$L_i = (S_i/S_c) \, L_c;$$

where L_i is the back calculated length of the fish at the formation of the ith increment, L_c is the length of fish at capture, S_c is the radius of the otolith at capture, and S_i is the radius of the otolith at the ith increment (DeVries and Frie 1996).

Individual and Population Metrics

Relative weight for yellow perch and native fishes was calculated as

$$Wr = (W/Ws) * 100,$$

where *Wr* represents relative weight, *W* is the weight of the fish (g), and *Ws* is a length-specific standard weight predicted by a weight-length regression for that individual species (Anderson and Neumann 1996). Relative weight was calculated for adults of yellow perch, largemouth bass, Alabama bass, bluegill, redear sunfish, and black crappie during the spring (February to May) in both 2010 and 2011. Condition of yellow perch was compared with that of native fishes using dummy-coded regression (PROC REG, SAS Institute Inc., Cary, North Carolina, USA) as described in Montgomery et al. (2006). I also tested the hypothesis that yellow perch collected from our uppermost site in Yates (i.e., near the tailrace of Martin Dam) would have a higher condition than other fish collected in Yates in both 2010 and 2011, given the assumption that yellow perch would have a better condition by living in cooler water released from Lake Martin.

For yellow perch mortality estimates, I used catch curve analysis for data from both 2010 and 2011 during both spring and fall using the following regression equation:

$$\ln(N_t) = \ln(N_o) - Z(t),$$

where $\ln(N_t)$ = the natural logarithm of the number of fish in a year class at time t, $\ln(N_o)$ represents the natural logarithm of the original number of fish in a year class, and $Z(t)$ equals the instantaneous rate of total annual mortality at time t. Using this equation, I calculated survival as

$$S = e^{-Z},$$

where S is survival and Z is the instantaneous rate of total annual mortality. These analyses were performed under the assumptions of constant recruitment, equal survival between year classes, equal survival between years, natural and fishing mortality being the same each year, and that the data are representative of true age structure (Van Den Avyle and Hayward 1999). Calculations were performed using Fishery Analysis and Simulation Tools (FAST version 3.0).

Length-weight regressions were calculated using combined length-weight data for yellow perch from both 2010 and 2011 sampling seasons. These length-weight relationships were estimated using log transformed data as:

$$\log_{10}(W) = a' + b * \log_{10}(L),$$

where a' is the y-axis intercept, b is the slope of the equation, W is the weight of the fish (g), and L is the length of the fish (mm) (Anderson and Neumann 1996).

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Growth was calculated using mean back-calculated length-at-age data collected from yellow perch otoliths. I used the von Bertalanffy (1938) growth equation to calculated growth rates for both 2010 and 2011. This analysis was done in FAST (version 3.0) with the following equation:

$$L_t = L_\infty(1 - e^{-k(t-to)}),$$

where L_t = length at time t, L_∞ = maximum theoretical length, k = growth parameter, t = time, and to = time when length would be zero.

I calculated the gonadosomatic index (GSI = gonad weight/body weight) for all yellow perch to characterize the spawning period for both males and females in both Yates Lake and Lake Martin through time in 2010 and 2011(Strange 1996).

Larval, Juvenile, and Adult Diet Analyses

Biomass estimates were calculated from prey length measurements using prey specific length-weight regressions. These biomass estimates were then used to calculate diet proportion for each prey item for each individual fish. For larval fish diet analysis, prey item proportions were compared by number, given the general similar size among prey items.

For evaluating the potential for competition between species, I calculated Schoener's overlap index,

$$\text{overlap} = 1 - 0.5\left(\sum_{i=0}^{n}|r_{xi} - r_{yi}|\right),$$

where r_{xi} and r_{yi} represent the proportion of prey type *i* in the diet of species *x* and *y* respectively, and *n* = number of prey types (Schoener 1970). I calculated diet overlap between yellow perch and the other sport fish species collected (i.e., crappie, black bass, bluegill) at larval, juvenile, and adult life stages.

If overlap between two species exceeded 0.5 at the larval life stage, prey selection by larval fish was estimated using Chesson's alpha, defined as

$$\alpha = (r_i/p_i)/\sum_i^m (r_i/p_i),$$

With p_i = proportion of prey type i in the zooplankton sample, r_i = the proportion of prey type in the predator's diet, m = number of available prey types, and α = the selectivity index. Neutral selection is defined as $\alpha = 1/m$ where a prey type is eaten in proportion to its occurrence in its environment (Chesson 1978, 1983). This analysis was run for each prey type for each individual fish, and means were calculated for each prey type across individuals within each fish species.

Fishing Mortality Modeling in Yates Lake

Because the yellow perch population is sizable enough in Yates Lake to sustain a fishery, I wanted to investigate the influence of varying amounts of fishing mortality in Yates Lake. To do this, I ran simulations using FAST (version 3.0) to investigate the influence of length limits on the population based on both exploitation and yield of the population.

I arbitrarily set an initial population size of 10,000 individuals and used combined 2010/2011 data for the length-weight regression, t_0 value (time in years when length would theoretically be zero), k (growth rate), and a conditional natural mortality of 48% (based on 2010/2011 combined catch-curves from Yates Lake). Recruit information was not included due to the lack of information concerning fecundity in Yates Lake yellow perch. Within FAST, I modeled populations to range from 0-30%, 0-60%, and 0-95% exploitation at 150 mm, 200 mm, and 250 mm length limits and investigated the effect on maximum yield of the fishery. When no growth overfishing seemed apparent from the simulations, I repeated the same simulations to looking at length limits from 0-250 mm for every 50 mm. These simulations were done to find a

critical length where growth overfishing might occur within the fishery (Slipke and Maceina 2006).

Results

Yellow Perch Population Analyses

Of the sampling approaches used, pulsed-DC night electrofishing was the most effective method for collecting adult yellow perch. Average spring electrofishing catch/hr of yellow perch was 17.40 in Lake Martin and 52.83 in Yates Lake in 2010. Catch rates were lower in 2011, being 2.59 per hour in Lake Martin and 29.50 per hr in Yates Lake. Relative to fish age, yellow perch in Yates Lake tended to include more older age classes than did fish in Lake Martin (c.f., Figures 2 and 3). Survival in spring 2010 was not calculated for Lake Martin due to insufficient year class representation, but in general, survival in Yates Lake (range = 52-59%) was higher than in Lake Martin (range = 30-56%) (Figures 2 and 3). Mean relative weight of yellow perch in Lake Martin (range = 68-70) and in Yates Lake (range = 70-74) were significantly lower than those of resident fishes ($F_{5, 499}$=23.56, P<.0001) (Figures 4-7). Within Yates Lake, there were no differences in condition of yellow perch at the Island site (site nearest Lake Martin dam) versus the Chanahatchee Creek and Saugahatchee Creek sites ($F_{2, 443}$=0.61, P>0.54) (Figure 8).

Yellow perch GSI was estimated for a portion of the 2010 sampling season starting in mid-March and for the entire 2011 sampling season. In 2010, Lake Martin yellow perch GSIs ranged from 0.25 - 22.0% for females and 0.27 – 5.0% for males. In Yates, GSIs ranged from 0.08 – 3.6% for females and 0.23 – 8.0% for males (Figure 9). In 2011, yellow perch GSI in Lake Martin ranged from 0.01 - 18% for females and 0.1 – 10% for males. In Yates Lake, GSI ranged 0.01 - 29% for females and 0.1 - 16% for males (Figure 10). Based on temporal changes in GSI, estimated spawning periods were during mid-March (~15 C) in Lake Martin and late March (~ 17 C) in Yates Lake (Figure 10). Lake Martin had a Von-bertalanffy growth parameter of 0.16 per year in 2010. I was unable to calculate a growth equation for Yates Lake in 2010, due

to the inability of the Von-bertalanffy growth function to converge. In 2011, Lake Martin and Yates Lake had approximately equal growth (K = 0.20 per year) (Figure 11). Yates Lake and Lake Martin yellow perch length-weight regressions (Figure 12) were most similar to regressions from three mountain reservoirs in Georgia (Table 1).

Larval Fishes

Larvae of seven fish taxa were collected with yellow perch, with *Pomoxis*, *Lepomis*, and *Dorosoma* being most abundant in both years. During 2010, larval yellow perch density in Lake Martin peaked at 0.0028 fish/m^3 in early April, while density in Yates Lake peaked at 0.28 fish/m^3 in mid-April (Figure 13). In 2011, larval yellow perch density in Lake Martin peaked at 0.07 fish/m^3 in late March, while reaching 0.61 fish/m^3 in Yates Lake in early April (Figure 14). There was little temporal overlap of larval yellow perch with larvae of other fish species in the limnetic zone in Lake Martin during 2010. Yellow perch larvae co-occurred with larval *Pomoxis* and *Dorosoma* on three sample dates in Yates Lake during late April through early May 2010. In 2011, yellow perch larvae co-occurred with *Pomoxis* larvae in Lake Martin on March 28th through April 18th. In Yates Lake 2011, temporal overlap between *Pomoxis* larvae and yellow perch larvae occurred from April 8th to April 20th, though *Pomoxis* densities were very low (range: 0.016 – 0.027 fish/m^3; n = 8 total individuals).

During 2010, larval yellow perch in Lake Martin consumed mostly calanoid copepods (approximately 90% of their diet); larval *Dorosoma* also consumed mostly calanoid copepods (84%), although these two taxa did not co-occur in samples. Larval *Pomoxis* and *Lepomis* consumed mostly *Bosmina* (59-62%) (Figure 15). In Yates Lake 2010, larval yellow perch similarly consumed mostly calanoid copepods (66%); larval *Pomoxis* also consumed primarily calanoid copepods (45%), while diets of larval *Pomoxis* and *Lepomis* were diverse (Figure 15).

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Diet overlap between larval yellow perch and *Pomoxis* based on Schoener's overlap index was variable in both reservoirs during 2010, ranging from 0.18-0.74 in Lake Martin and from 0.50-0.86 in Yates Lake (Table 2). During 2011 larval yellow perch in Lake Martin again consumed mostly calanoid copepods (76% of their diet by number); larval *Dorosoma* and larval *Pomoxis* also primarily consumed calanoid copepods (48% and 80%), while larval *Lepomis* consumed primarily *Bosmina* (90%) (Figure 16). In Lake Martin, diet overlap between larval yellow perch and larval *Pomoxis* was 0.86 on 28 March (Table 2). Though larval *Pomoxis* and larval yellow perch co-occurred until 18 April, I could not calculate overlap due to small sample size (<5 individuals for the entire reservoir). Larval yellow perch in Yates Lake consumed mostly calanoid copepods (37%); larval *Dorosoma*, larval *Pomoxis*, and larval *Lepomis* also fed primarily on calanoid copepods (55%, 40%, and 100%, respectively) (Figure 16). Due to small sample sizes of *Pomoxis* in Yates Lake, I did not calculate diet overlap between larval *Pomoxis* and larval yellow perch. No other species co-occurred with larval yellow perch in our samples in Yates Lake during 2011.

Yellow perch larvae generally positively selected for calanoid copepods (range: 0.68 – 0.94), while larval *Pomoxis* positively selected for *Bosmina* (0.48-0.73), and larval *Dorosoma* positively selected for calanoid copepods (0.68) during both years. Larval *Lepomis* only co-occurred with larval yellow perch on one sample date (5/6/2010) and neutrally or negatively selected all zooplankton taxa. *Bosmina* was neutrally or negatively selected for by larval yellow perch, *Dorosoma*, and *Lepomis*. Positive selection for the same prey, calanoid copepods, occurred on only one date (4/30/2010) by both larval yellow perch and *Dorosoma* in Yates Lake (Table 3).

Juvenile Fishes

Too few juvenile yellow perch were collected in 2010, to allow for diet analyses. In 2011, I quantified diets of juvenile yellow perch, largemouth bass, and Alabama bass given that these were the only species present in sufficient numbers. Juvenile yellow perch first appeared in electrofishing samples in early May in both lakes and were regularly collected through early June in Lake Martin and late June in Yates Lake. Over this time, juvenile yellow perch averaged 58 mm TL (± 2.30 SE) in Lake Martin and 59 mm (± 0.04 SE) in Yates Lake. In Lake Martin, juvenile yellow perch diets (biomass) included diverse zooplankton taxa (36%), while juvenile largemouth bass diets mostly contained calanoid copepods (36%) (Figure 17). In Yates Lake, juvenile yellow perch diets were diverse with the greatest contribution coming from *Daphnia* (29%). Largemouth bass in Yates consumed various zooplankton taxa (38%) and Alabama bass mostly consumed native fishes (83%) (Figure 17). I calculated diet overlap (Schoener's index, range=0-1) for yellow perch versus both largemouth bass and Alabama bass. In Martin, diet overlap between juvenile yellow perch and juvenile largemouth bass was 0.48. In Yates, overlap between juvenile yellow perch and juvenile largemouth bass was 0.55, and was 0.17 between juvenile yellow perch and Alabama bass (Table 4).

Adult Fish Diet Analysis

In Lake Martin during 2010, adult yellow perch diets were diverse, with zooplankton being most prevalent (49%). Bluegill diets also included zooplankton (38%), while black bass diets contained primarily native fishes (78%), and redear sunfish diets consisted mostly of invertebrates (81%) (Figure 18). Diet overlap between yellow perch and black basses (0.17) and redear sunfish (0.45) was low, but was high with bluegill (0.80) (Table 5). In Yates Lake during 2010, yellow perch fed mostly on Chaoborus (45%), while bluegill and redear sunfish fed

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primarily on mayflies (31% and 74%). Largemouth bass also fed mostly on native fishes (43%) (Figure 18). Diet overlap in Yates was moderate between yellow perch and bluegill (0.57) and low with redear sunfish (0.30) and largemouth bass (0.45) (Table 5).

In Lake Martin during 2011, adult yellow perch diets were diverse with native fishes contributing the largest portion of the biomass (30%). Chironomids were the primary prey of bluegill (47%), black crappie (55%), and redear sunfish (68%). Native fish prey contributed most of the largemouth bass (78%) and Alabama bass diets (61%) (Figure 19). However, yellow perch were consumed in large numbers by both largemouth bass and Alabama bass in a 3-week period during May in Lake Martin (Figure 20). Overall yellow perch contributed an average of 15% of largemouth bass diets and 20% of Alabama bass diets. In Lake Martin, diet overlap between yellow perch and native fishes was less than 0.60 for all species (Table 6). In Yates Lake, yellow perch diets were diverse, but contained a large number of chironomids (40%). Chironomids also contributed a large part of bluegill (60%) and black crappie (37%) diets. Redear sunfish diets were dominated by a variety of invertebrates (62%). Largemouth bass fed primarily on native fishes (48%), while Alabama bass fed primarily on juvenile yellow perch (43%) (Figure 20). Largemouth bass also consumed yellow perch (39%). Again, yellow perch were consumed in a focused period from early May until early July in Yates Lake (Figure 20). In Yates, diet overlap between yellow perch and native fishes was less than 0.50 except for bluegill (0.67) and black crappie (0.75) (Table 6).

During the two sampling seasons, 16 adult striped bass were sampled and their diets taken in both Lake Martin and Yates Lake. Of those fish sampled, diet biomass consisted of crayfish (31%), mayfly larvae (29%), shad (26%), and sunfish (14%) (Figure 21). No yellow perch were found in diets of striped bass collected. Anecdotal information from a local striped

bass guide also indicated that yellow perch were not found in striped bass diets in Martin and Yates (Jim Parramore, personal communication).

Modeled Fishing Mortality

Based on modeling the impacts that fishing mortality would have when added to natural mortality, I estimated that a 150-mm length limit would produce maximum yield for yellow perch harvest in Yates Lake at an additional 30, 60, and 95% fishing mortality (Figure 22). This size limit was compared with 200 mm and 250 mm for Yates Lake. When 95% fishing mortality was modeled for 50 – 250 mm length limits, the critical length of the yellow perch population in Yates was between a 100 – 150 mm length limit (Figure 23). Below a 150- mm length limit, the yellow perch population is likely to be harvested at low numbers, due to growth overfishing. But setting the length limit above 150 mm did not improve yield of catchable yellow perch in Yates Lake.

Discussion

Yellow perch has been introduced widely across North America, including areas in the Southeastern US (Timmons 1975; Clugston et al. 1978). I studied two introduced yellow perch populations in Southern US reservoirs, with particular emphasis on their interactions with native fishes. My results suggest that the cool water nature of yellow perch limited their interaction with native fishes in these southern systems. In both systems, abundant juvenile yellow perch provided prey for some resident piscivores, and in one of the systems adult yellow perch appeared to have generated a sustainable fishery. Therefore these southern yellow perch populations appear to have minimal negative effects on native fishes within these systems, while providing some benefits.

Potential Negative Impacts

Yellow perch and native fishes potentially compete for prey resources and territory (as seen in Hayes et al. [1992]). Because yellow perch are generally mobile and capable of traveling great distances (Weber and Les 1982), including diel migrations to and from the littoral zone (Brown et al. 2009), they likely do not compete for territory with native species. However, competition for common prey resources was possible, especially at the larval and juvenile life-stages. Of the species we studied, yellow perch hatched and their larvae were in the pelagic zone earlier in the spring than were larvae of native *Pomoxis*, *Dorosoma*, or *Lepomis* (see also Kaemingk et al. 2012). This timing generated minimal temporal overlap and, therefore, little opportunity at the larval life stage for diet overlap and competition between yellow perch larvae and larvae of native fishes in these two reservoirs. A similar trend occurred with yellow perch larvae in lakes of the upper Midwest (Schael et al. 1991; Jolley et al. 2010; Kaemingk et al. 2012). In my study, co-occurrence occurred primarily between larval yellow perch and *Pomoxis*

during April of both years in these systems. Analysis of prey selection showed that larval yellow

perch primarily selected copepods (also seen in Jolley et al. 2010), while larval crappie had a

more diverse diet. Therefore, all evidence suggested that the potential for competition between

larval yellow perch and larvae of native fishes was minimal.

At the juvenile stage, yellow perch diets overlapped very little with those of largemouth

bass and spotted bass. Yellow perch juveniles in the study reservoirs (as well as in their native

range) primarily fed on zooplankton (Galbraith 1967; Mills and Forney 1983; Hansen and Wahl

1981; Wallus 2006), with macroinvertebrates found in diets of juveniles >50 mm (Fisher and

Willis 1997). When co-occurring with yellow perch juveniles, black bass juveniles (<70 mm)

had already transitioned to feed on fishes and various macroinvertebrates, as has been

documented in several studies (Wicker and Johnson 1987; Hirst and DeVries 1994; Phillips et al.

1995). This difference in diet between species limits the amount of diet overlap occurring at the

juvenile stage between yellow perch and black basses, and so reduces the potential for

competitive interactions.

High diet overlap was found among adult bluegill, black crappie, and yellow perch in

spring 2011 (similar high diet overlap occurred between adult bluegill and yellow perch in 2010,

though small sample size biased that sample). With yellow perch in both lakes consuming a

large proportion of chironomids in 2011, it is likely that the presence of abundant chironomids

resulted in a readily available prey resource for three species that all tend to be opportunist

invertebrate feeders (Etnier 1971; Tuten et al. 2008). Therefore, despite the potential for

competition between yellow perch, black crappie, and bluegill, it is unlikely because they are all

opportunistic feeders that take advantage of abundant macroinvertebrate prey sources (as seen

with mayflies and Mississippi River fishes; Hoopes 1960). In contrast, diet overlap was low

between adult yellow perch and redear sunfish, largemouth bass, and Alabama bass. The possibility of yellow perch adults consuming native fishes was another potential negative interaction; however, I did not observe significant numbers of native fishes in adult yellow perch diets. Based on diet comparisons, the data suggest competitive interactions between that of yellow perch and native fishes may be minimal.

Potential Positive Impacts

The diet shift by largemouth bass and Alabama bass from native fishes to feed on juvenile yellow perch in 2011 was significant finding, suggesting that yellow perch can be an important source of forage for these piscivores. Juvenile yellow perch were first observed in electrofishing samples during mid-May of 2011 (weekly inshore sampling during 2010 focused on adults, and thus ceased in April when adults left the littoral zone), peaking in abundance at 412 fish/hr in Yates Lake and 36 fish/hr in Lake Martin. These seasonal peaks in abundance occur as juvenile yellow perch recruit to the littoral zone upon metamorphosis from the pelagic larval stage to the juvenile life-stage in late spring. Yellow perch first appeared in black bass diets in late April 2011 and continued to occur in diets through July. A previous study of Lake Martin fish communities relative to shoreline development also found this trend, with Alabama bass having a relatively high proportion of yellow perch in diets despite their low occurrence in fish collections (Purcell 2011). Therefore, age-0 yellow perch appear to have become a seasonally important prey resource for black basses in both lakes. Previous studies have shown that juvenile yellow perch occupy the littoral zone (especially at night) making them more vulnerable to predators (Kelso and Ward 1977; Ryder and Kerr 1978; Helfman 1981; Lyons 1987; Post et al. 1988). Black basses tend to be active in the littoral zone (as in Demers et al. 1996), increasing the chances of a predator- prey interaction with juvenile yellow perch.

Striped bass is another piscivore present in both reservoirs that could benefit from yellow perch as prey. Anecdotal information suggested that striped bass primarily consumed threadfin and gizzard shad at capture (Jim Parramore, fishing guide for striped bass anglers, personal communication). Ruderhausen et al. (2005) found age-1 striped bass in North Carolina primarily preyed on yellow perch during the late spring; however they did not constitute a high proportion of the diets of all age-classes throughout the year. As in this study, the striped bass tended to favor clupeids as prey (Ruderhausen et al. 2005). The thermal stratification of Lake Martin may create the greatest potential for spatial overlap between yellow perch and striped bass and, therefore, more opportunity for striped bass to consume yellow perch. However, due to a small sample size (n=16 individuals) collected over the two-year study period, I was unable to conclude whether yellow perch was an important prey item for striped bass.

Population Characteristics, Habitat, and Seasonal Movement

Yellow perch in both Yates Lake and Lake Martin had very low relative weights. Because these fish did not appear to be thin or in poor condition, it is more likely that these southern populations differ morphologically from populations in their native range and require the development of an alternate standard weight equation for this region. Alternatively, these southern yellow perch populations may be stressed due to living outside of their native range at the edge of their thermal tolerance. Willis et al. (1991) found that yellow perch sampled from four Georgia reservoirs also expressed poor condition, with mean relative weights between 56 and 71. This poor condition was attributed to low productivity of lakes in that region. My two study reservoirs are also low productivity systems, relative to other reservoirs in Alabama. However, in my study I also observed a higher peak GSI for yellow perch than in their native range. The low relative weight may indicate an alternate energy allocation for yellow perch from

southern systems whereby they devote more energy to gonad development versus somatic development. My observed GSIs for yellow perch from peaked at 29% for females and 16% for males, compared to yellow perch in southern Lake Michigan where GSIs ranged from 12-25% for females and 3-6.2% for males (Hayes and Taylor 1994; Walters and Lauer 2010). A study in South Carolina also found higher peak GSIs with females peaking at 27.4% (Clugston et al. 1978). Northern yellow perch gonad development is likely constrained due to harsher winters (Post and Evans 1989; Henderson et al. 2000), whereas southern yellow perch can devote more energy to gonad development. Likewise, warmer southern temperatures may increase yellow perch metabolism where they are not able to build fat reserves in the summer as do yellow perch in colder climates (as seen in Glover [2010]) with the effect of salinity as a stressor for largemouth bass).

Survival has been estimated 46-61% for unexploited native adult yellow perch populations (Thomas and Haas 2000; Paukert and Willis 2001; Scholten et al. 2001). Within my two study systems, I found differences in survival between Yates Lake (52-59%) and Lake Martin (30-56%). These differences may be due to differences in temperature regimes and prey resources. Lake Martin is primarily a storage impoundment (mean depth = 12 m) with a high water retention time, resulting in stratification (Alabama Power 2011). Yates Lake is a shallower run-of-the-river impoundment (mean depth = 8.3 m) used for hydroelectric generation with a short water retention period and less stratification (Alabama Power 2011). The longer period of stratification that occurs in Lake Martin may force yellow perch to occupy unfavorable habitats with extreme temperatures and low dissolved oxygen (DO). The lethal limits of temperature above 25 C and DO below 2 ppm (Wallus 2006) may constrain yellow perch in Lake Martin during summer to live in stressful conditions. These constraints have been shown to affect

yellow perch populations within their native range. In Lake Erie, yellow perch actively avoid the anoxic zone, altering their movements vertically and horizontally (Roberts et al. 2009; Arend et al. 2011). Suthers and Gee (1986) found that hypoxia can influence juvenile yellow perch by forcing them away from preferred littoral habitat and making them more susceptible to predation. This habitat reduction, which is potentially more severe in Lake Martin than in Yates Lake, may explain the higher mortality of yellow perch there. Yellow perch in Yates Lake may benefit from cool-water hypolimnetic releases near the Lake Martin Dam, which alter temperature in the upper part of Yates Lake (as seen in Figure 24 and Figure 25).

Yates Lake and Lake Martin also have different prey resources with the presence of higher densities of *Daphnia* in 2011 in Yates Lake. *Daphnia* have been shown to be an important prey source for yellow perch at all life-stages (Galbraith 1967; Prout et al. 1990; Lathrop et al. 2002), especially in age-0 yellow perch (Prout et al. 1990; Lerclerc et al. 2011). *Daphnia* represented nearly 40% of juvenile diets by biomass in 2011 in Yates Lake. This prey type is less abundant in Lake Martin (average *Daphnia* density = 117/m^3) compared to Yates Lake (328/m^3). A similar trend was observed in Oneida Lake, New York with age-0 yellow perch becoming dependent on *Daphnia pulex* as their main prey source (Hansen and Wahl 1981) and *Daphnia* biomass directly influencing age-0 perch growth and vulnerability to predation (Mills and Forney 1983; Confer and Lake 1987). Therefore the differences in *Daphnia* resources between study lakes may affect recruitment in Lake Martin.

Seasonal movements of yellow perch were similar in Lake Martin and Yates Lake. Yellow perch adults occupied the littoral zone of both lakes from October to June. Adult yellow perch catch rates were highest during February and March in both lakes (due to spawning), followed by a dramatic reduction in April. After spawning, adult yellow perch left the littoral

zone but it remains unclear where they went. They likely moved into deeper water adjacent to the littoral spawning areas for a cool water refuge (as in Radabaugh et al. 2010) but sampling in these deeper areas is difficult, making this hypothesis hard to test with our sampling data. During summer, few adult yellow perch were sampled in either reservoir. In the fall of both years, once the water cooled below 20 C in Yates and at 17 C in Martin, adult yellow perch were once again collected. Here they occupied areas around 1-2 m of depth through the winter before moving into shallow spawning areas the following spring (as seen in Radabaugh 2006).

Management Implications and FAST modeling

Yellow perch populations in both reservoirs do not appear to be having a negative impact on native fishes. This conclusion is based on evidence that diet overlap and hence the potential for competition at the larval and juvenile life stages is limited. For adults shared prey sources (zooplankton, chironomids) do not appear to be limiting. In addition to minimal evidence for negative/competitive impacts, juvenile yellow perch also provided a seasonally abundant prey resource for resident black basses in late spring when many native prey fishes are still in the larval stages and unavailable to adult basses. Given that anglers actively target this fish in Yates Lake, I investigated whether this population could be managed as a sport fishery. Based on models created from Yates Lake yellow perch population data, it is quickly apparent that management will not benefit the fishery. When modeling the effects of length limits, the apparent optimum length limit is between 100 -150 mm when there is high fishing pressure (95%). However, it is unlikely that anglers would harvest fish that small.

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Table 1. Sample size, intercept, and slope values for four populations from Georgia and Lake

Martin and Yates Lake of my study.

Location	Water body	Sample size	Intercept	Slope
Georgia	Lake Burton	49	-4.685	2.808
	Lake Rabun	16	-6.248	3.518
	Lake Seed	75	-5.113	3.035
	Lake Tugaloo	19	-6.093	3.445
Alabama	Lake Martin	262	-5.607	3.26
	Yates Lake	672	-5.661	3.29

Table 2. Schoener's diet overlap index values for larval yellow perch with larval *Pomoxis,*

Lepomis, and *Dorosoma* collected from Lake Martin and Yates Lake. Yates Lake = Yates and

Lake Martin = Martin.

Date	System	Pomoxis	Lepomis	Dorosoma
4/9/2010	Martin	0.74	n/a	n/a
4/15/2010	Martin	0.18	n/a	n/a
4/22/2010	Yates	0.73	0.26	0.73
4/30/2010	Yates	0.50	n/a	n/a
5/6/2010	Yates	0.86	n/a	0.93
3/28/2011	Martin	0.86	n/a	n/a

Table 3. Prey selection quantified using Chesson's alpha for 2010 -2011 sampling season in Lake Martin and Yates Lake on those dates when yellow perch co-occurred with larvae of other native fishes. Numbers in parentheses denote ± 95% CL. + = positive selection. - = negative selection. YP = yellow perch, CP = *Pomoxis*, SH = *Dorosoma*, SF = *Lepomis*. Spp. = species.

Date & Lake	Spp.	Neutral Selection	Cyclopoid	Calanoid	Nauplii	Bosmina	Diaphanosoma	Daphnia	Ceriodaphnia
4/9/2010	YP	0.11	$0.01(0.03)^-$	$0.94(0.08)^+$	0^-	$0.05(0.08)^-$	0^-	0^-	0^-
Martin	CP		0^-	$0.27(0.39)$	0^-	$0.73(0.38)^+$	0^-	0^-	0^-
4/15/2010	YP	0.08	0^-	$0.95(0.10)^+$	0^-	0^-	0^-	0^-	0^-
Martin	CP		0^-	$0.19(0.14)$	$0.08(0.08)$	$0.57(0.17)^+$	$0.05(0.09)$	$0.01(0.02)^-$	$0.04(0.08)$
4/20/2010	YP	0.08	0^-	$0.68(0.30)^+$	0^-	$0.02(0.04)^-$	$0.10(0.19)$	0^-	$0.10(0.20)$
Yates	CP		$0.24(0.21)$	$0.11(0.08)$	0^-	$0.48(0.23)^+$	0^-	$0.01(0.01)^-$	$0.06(0.11)$
4/30/2010	YP	0.08	0^-	$0.94(0.11)^+$	0^-	$0.0008(0.001)^-$	$0.06(0.11)^-$	0^-	0^-
Yates	SH		$0.15(0.20)$	$0.68(0.24)^+$	$0.17(0.18)$	0^-	0^-	0^-	0^-
5/6/2010	YP	0.06	$0.03(0.04)^-$	$0.02(0.02)^-$	$0.0006(0.001)^-$	$0.02(0.02)^-$	$0.32(0.28)$	$0.06(0.05)^-$	0^-
Yates	SH		0^-	$0.26(0.32)$	$0.14(0.25)$	$0.13(0.25)$	0^-	$0.10(0.20)$	$0.25(0.33)$
	SF		$0.27(0.35)$	$0.18(0.33)$	0^-	$0.01(0.01)^-$	$0.17(0.33)$	$0.22(0.30)$	$0.15(0.31)$
	CP		$0.04(.04)^-$	$0.03(0.01)$	0^-	$0.08(0.18)$	0^-	$0.05(0.15)^-$	$0.03(0.24)^-$
3/28/2011	YP	0.06	0^-	$0.93(0.11)^+$	0^-	0^-	$0.07(0.11)$	0^-	0^-
Martin	CP		$0.03(0.06)^-$	$0.31(0.18)^+$	$0.33(0.21)^+$	0^-	$0.15(0.12)$	$0.12(0.14)$	0^-

Table 4. Schoener's diet overlap index values for juvenile yellow perch and juvenile black basses in Lake Martin and Yates Lake 2011 during spring and summer sampling dates.

Reservoir	Alabama Bass	Largemouth Bass
Lake Martin	n/a	0.48
Yates Lake	0.17	0.55

Table 5. Schoener's diet overlap index values for adult yellow perch and adult bluegill, redear sunfish, black crappie, and black basses in Lake Martin and Yates Lake 2010 during spring sampling dates.

Reservoir	Bluegill	Redear Sunfish	Black Crappie	Black Basses
Lake Martin	0.80	0.45	n/a	0.17
Yates Lake	0.57	0.30	n/a	0.45

Table 6. Schoener's diet overlap index values for adult yellow perch and adult bluegill, redear sunfish, black crappie, and black basses in Lake Martin and Yates Lake 2011 across all sampling dates. R. Sunfish = redear sunfish, B. Crappie = black crappie, A. Bass = Alabama bass, L. Bass = largemouth bass

Reservoir	Bluegill	R. Sunfish	B. Crappie	A. Bass	L. Bass
Lake Martin	0.58	0.41	0.60	0.47	0.38
Yates Lake	0.67	0.47	0.76	0.25	0.13
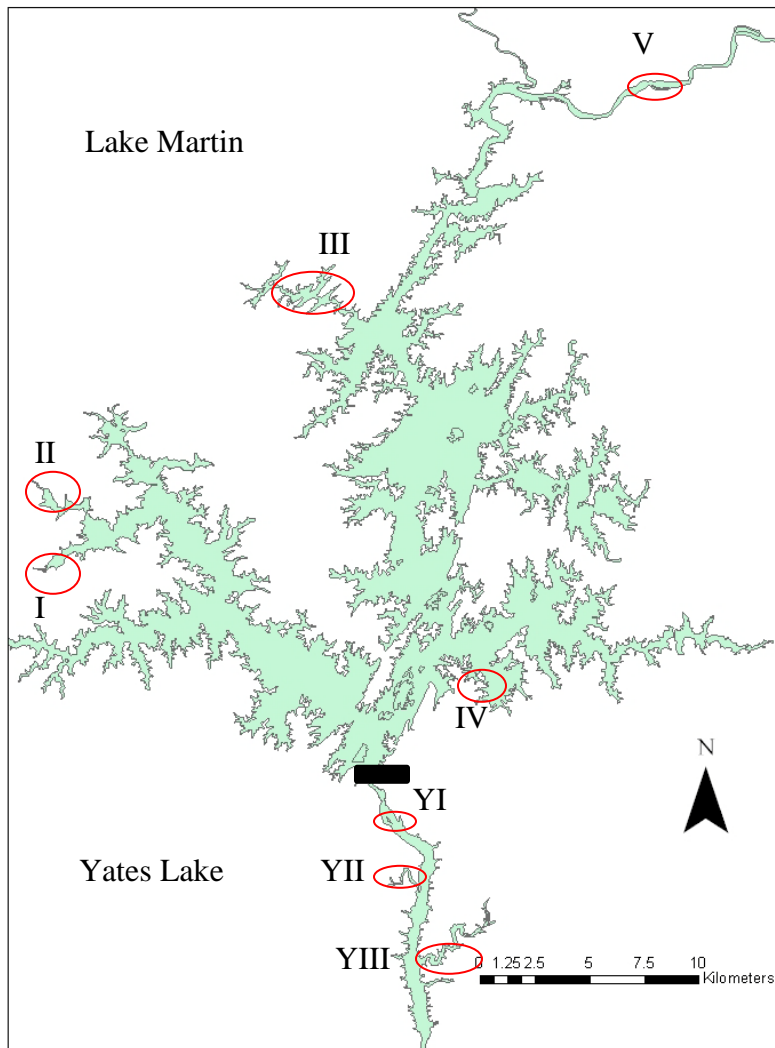
Figure 1. representative sites on Lake Martin (I = Parker, II = Chapman, III = Elkahatchee,

IV = Blue Creek, V = Irwin Shoals) and Yates Lake (YI = Island near Hwy 50 bridge,

YII = Chanahatchee, YIII = Saugahatchee)
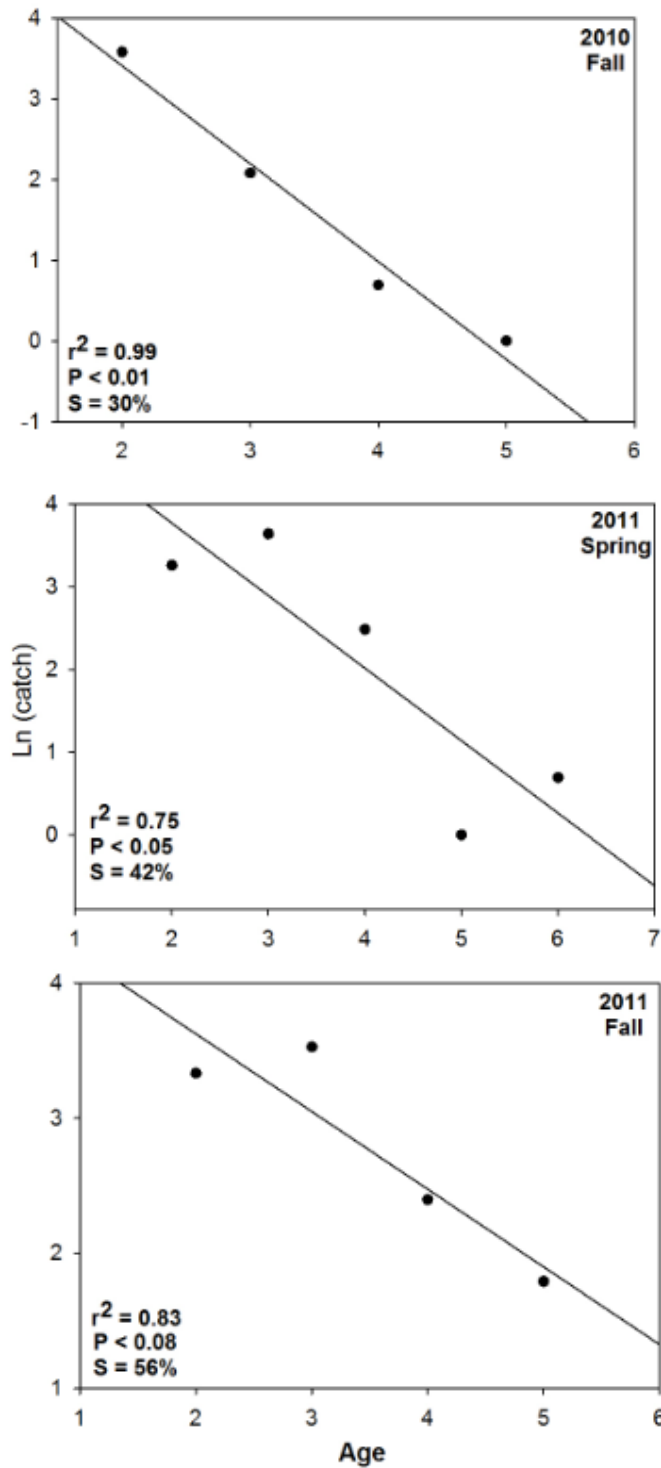
Figure 2. Catch curve regressions and the annual survival rates (*S*) calculated for yellow perch of age 2 to age 5 and 6 from Lake Martin in 2010 and 2011. Survival was not calculated for spring 2010 due to a lack of sufficient age classes.
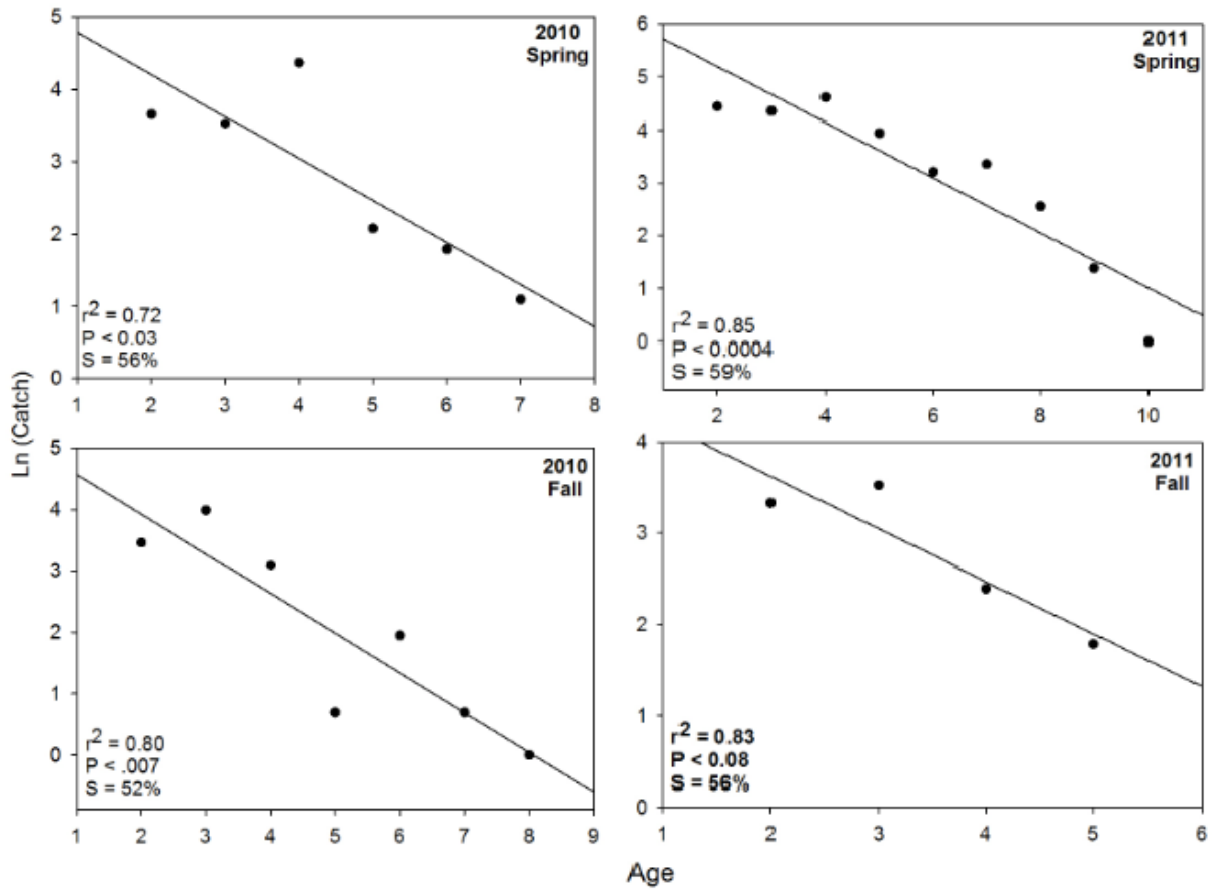
Figure 3. Catch curve regressions and the annual survival rates (*S*) calculated for yellow perch of age 2 to age 5, 7, 8, and 10 from Yates Lake in 2010 and 2011.
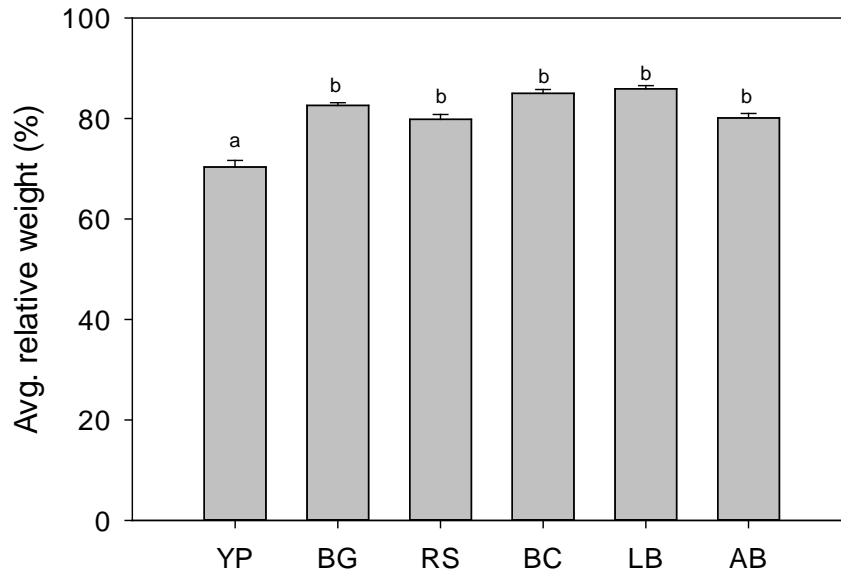
Figure 4. Average relative weight of yellow perch and native fishes collected in spring 2010 in

Lake Martin. YP = yellow perch, BG = bluegill, RS = redear sunfish, BC = black crappie,

LB = largemouth bass, AB = Alabama bass. Different letters denote significant difference

between each other. (i.e. a and b)
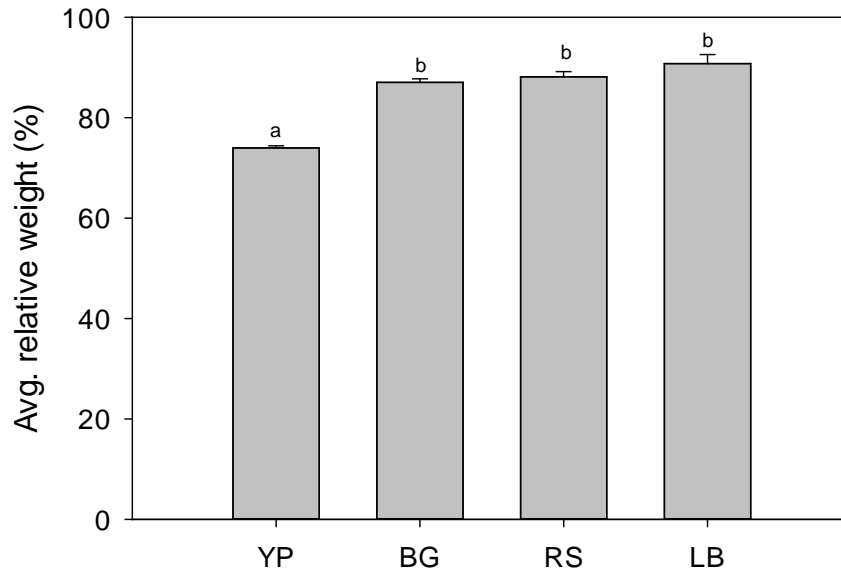
Figure 5. Average relative weight of yellow perch and native fishes collected in spring 2010 in

Yates Lake. Species abbreviations and significance letters are as presented in Figure 4.
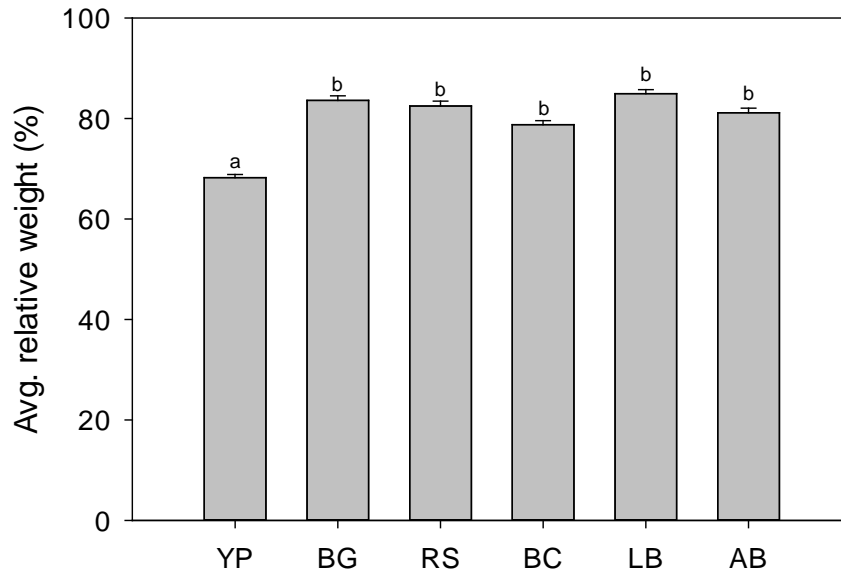
Figure 6.   Average relative weight of yellow perch and native fishes collected in spring 2011 in

Lake Martin. Species abbreviations and significance letters are as presented in Figure 4.
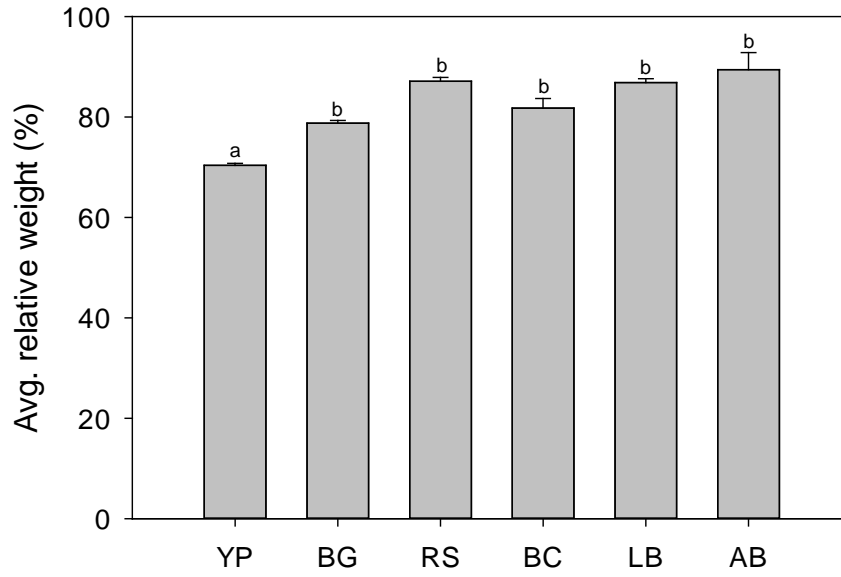
Figure 7. Average relative weight of yellow perch and native fishes collected in spring

2011 in Yates Lake. Species abbreviations and significance letters are as presented in Figure 4.
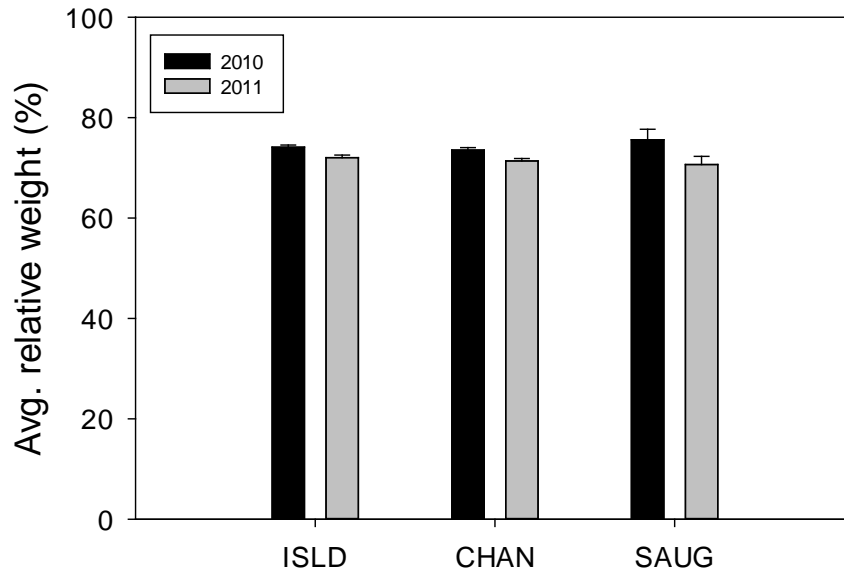
Figure 8. Average relative weight between sites at Yates Lake. ISLD = Island near Hwy 50

bridge, CHAN= Chanahatchee Cr., SAUG = Saugahatchee Cr.
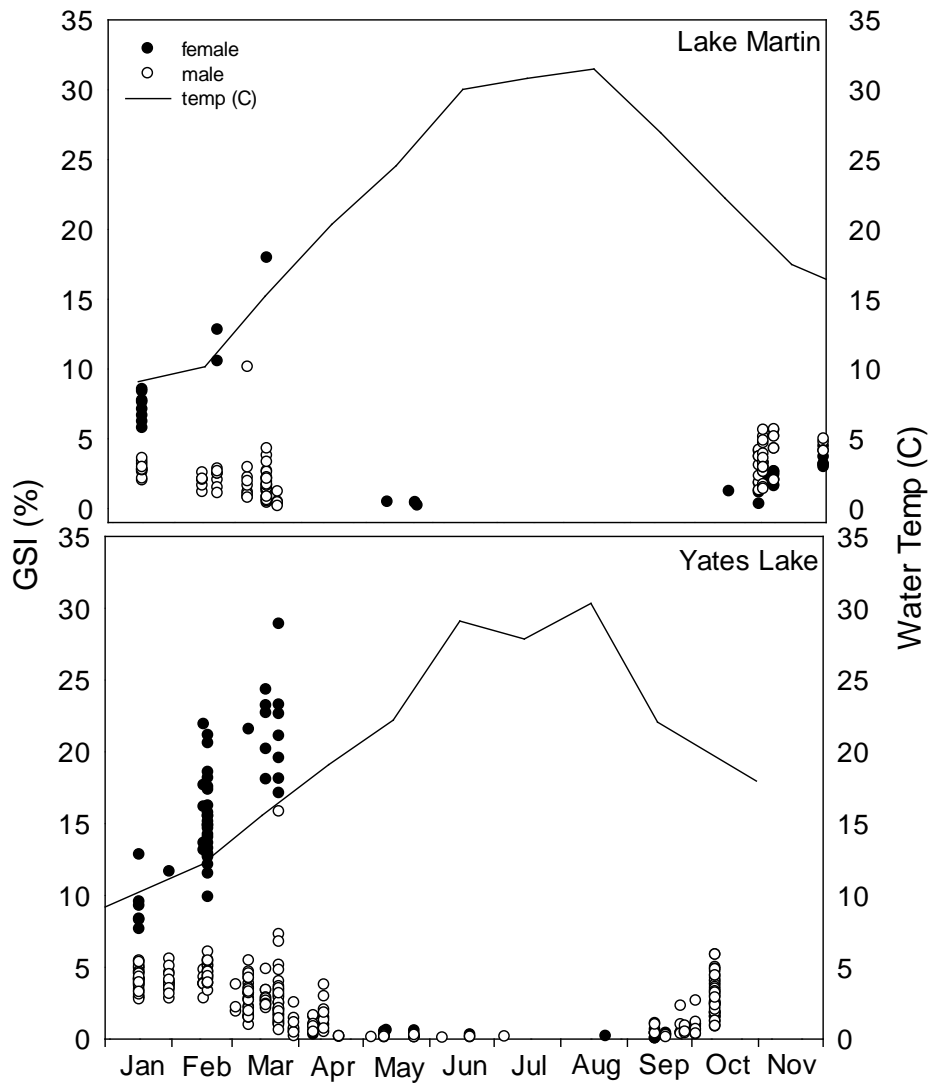
Figure 9. Relationship of GSI and surface water temperature (C) through time during 2010 in
Lake Martin (top) and Yates Lake (bottom).
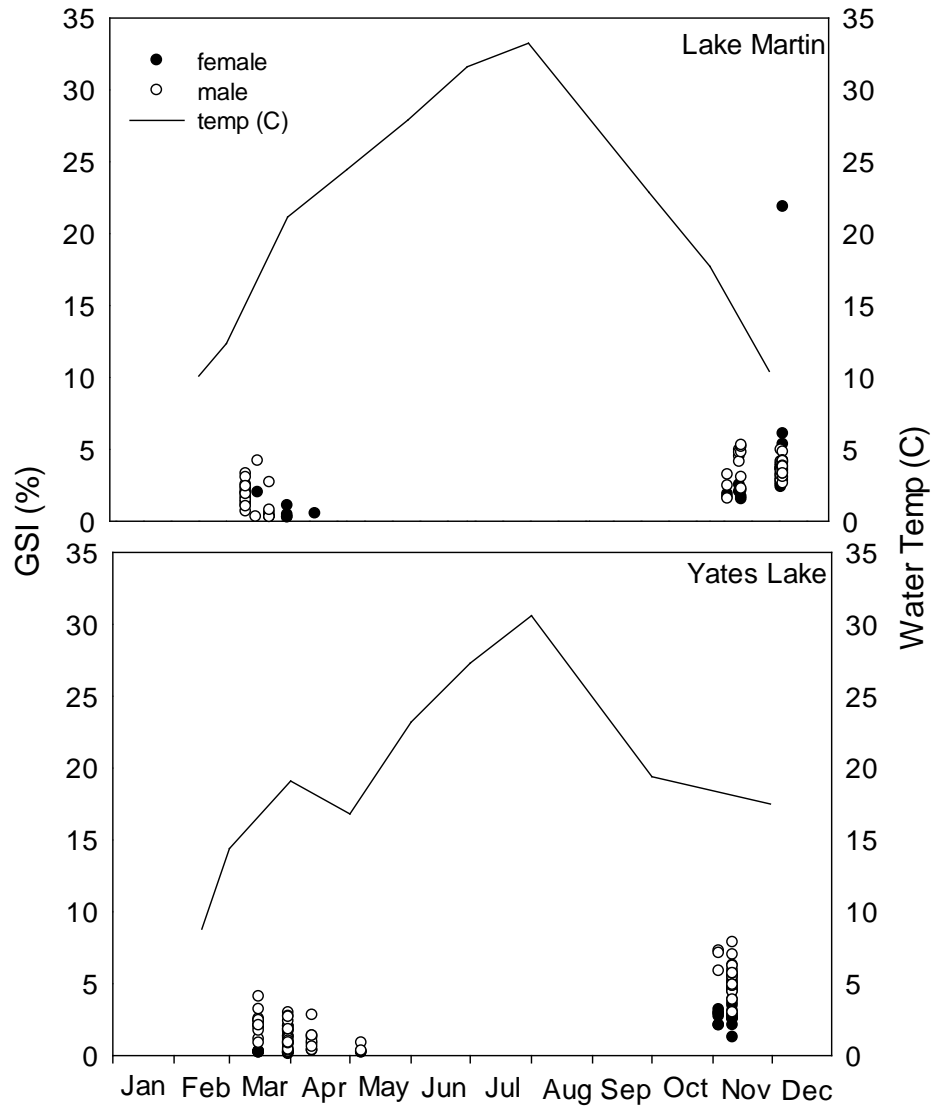
Figure 10. Relationship of GSI and surface water temperature (C) through time during 2011 in Lake Martin (top) and Yates Lake (bottom).
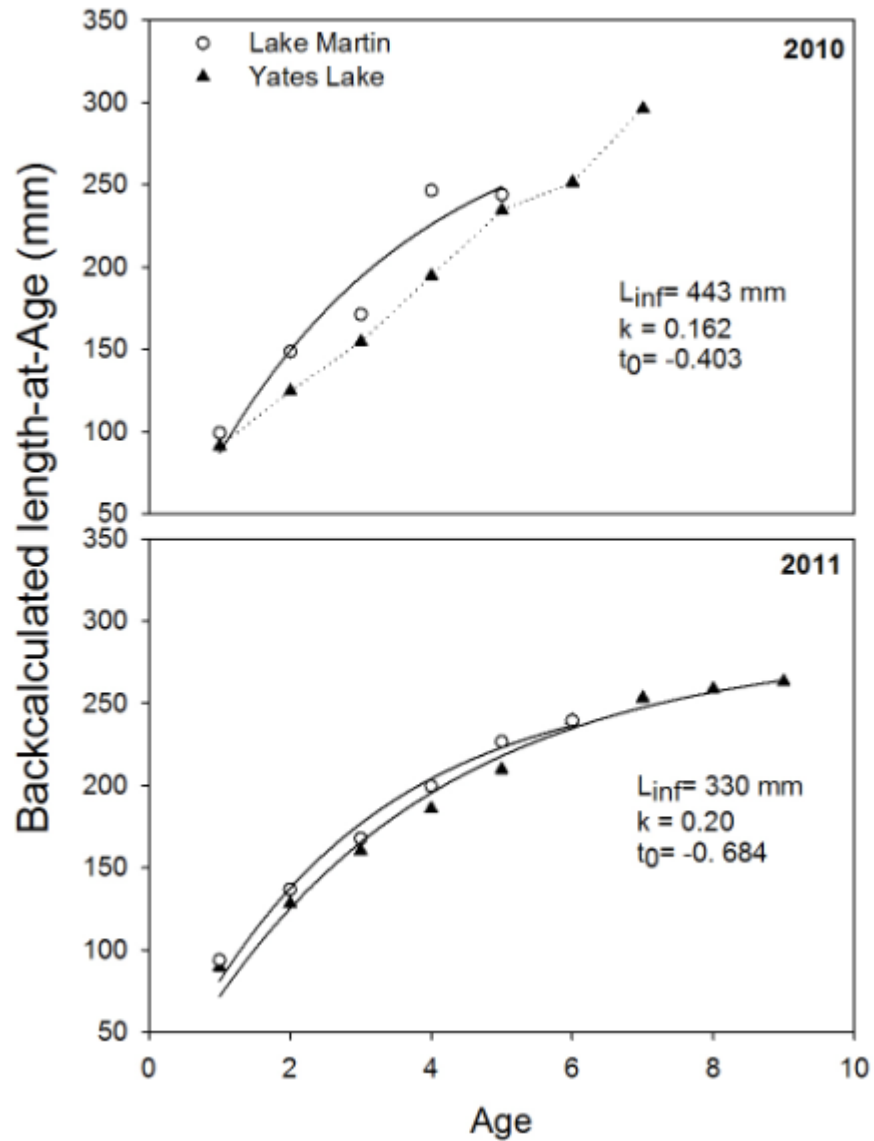
Figure 11. Mean backcalculated length-at-age of yellow perch collected (circles = Lake Martin, triangles = Yates Lake) and the growth predicted by the von Bertalanffy growth equation (L_{inf} is the theoretical maximum length, k the growth coefficient, and t_o the time at which length would theoretically be zero) in 2010 (upper panel) and 2011 (lower panel). For Yates Lake in 2010, the von Bertalanffy growth function would not converge and was therefore not included. In 2011, Yates Lake and Lake Martin had the same growth equation.
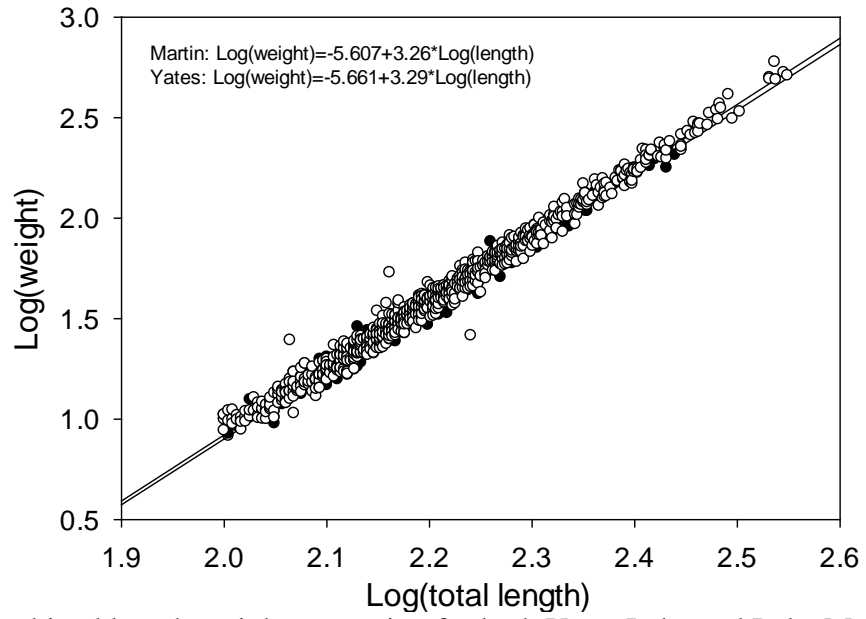
Figure 12. Combined length-weight regression for both Yates Lake and Lake Martin 2010-2011.

Martin: N= 262, Yates: N= 672.
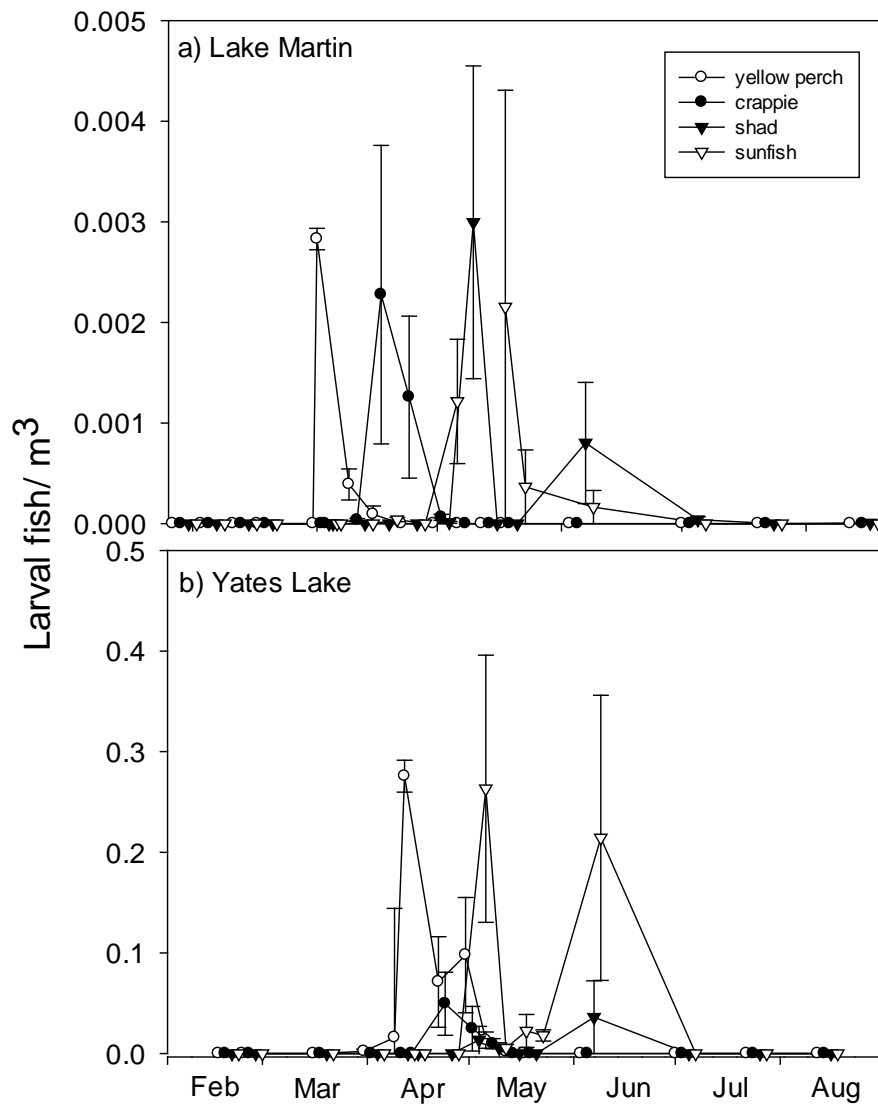
Figure 13 . Average (± 1 SE) larval fish density (individuals/m³) from push net samples plotted

through time during a) Lake Martin and b) Yates Lake during the 2010 sampling season.

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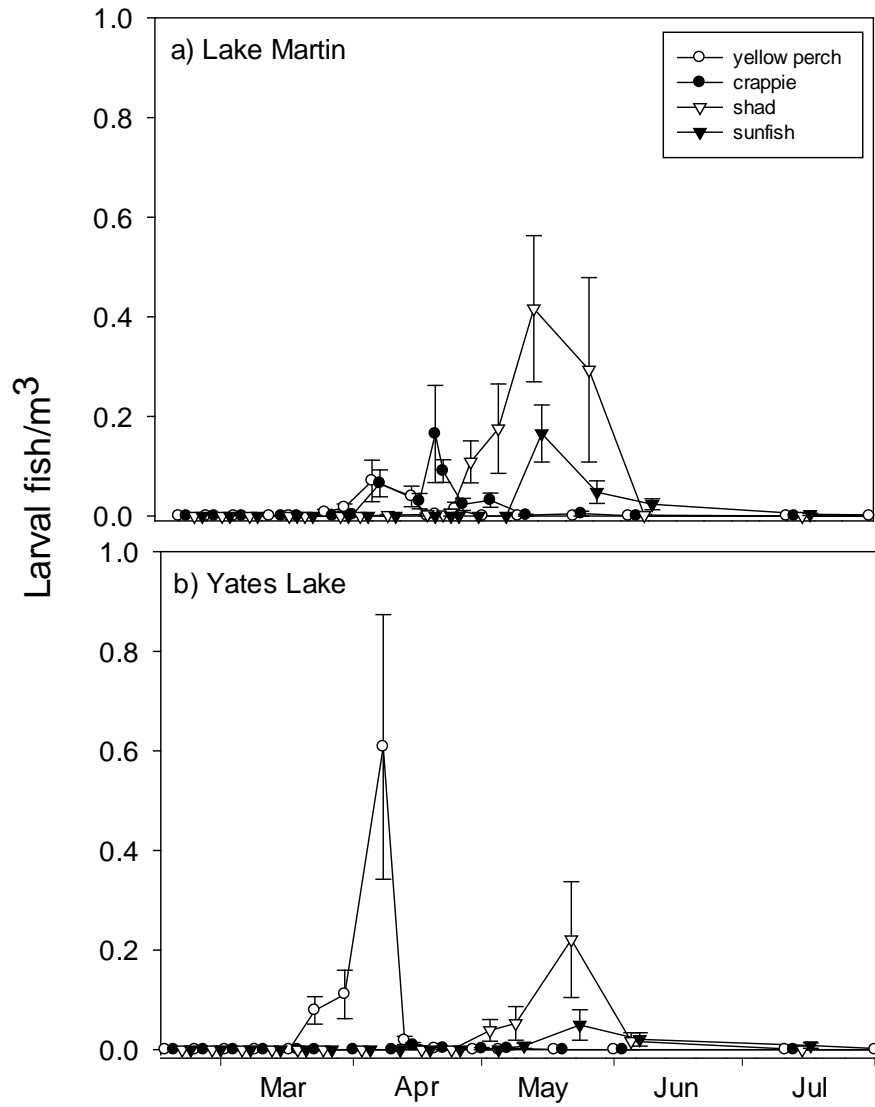
Figure 14. Average ($\pm$ 1 SE) larval fish density (individuals/m^3) from push net samples plotted

through time during a) Lake Martin and b) Yates Lake during the 2011 sampling season.
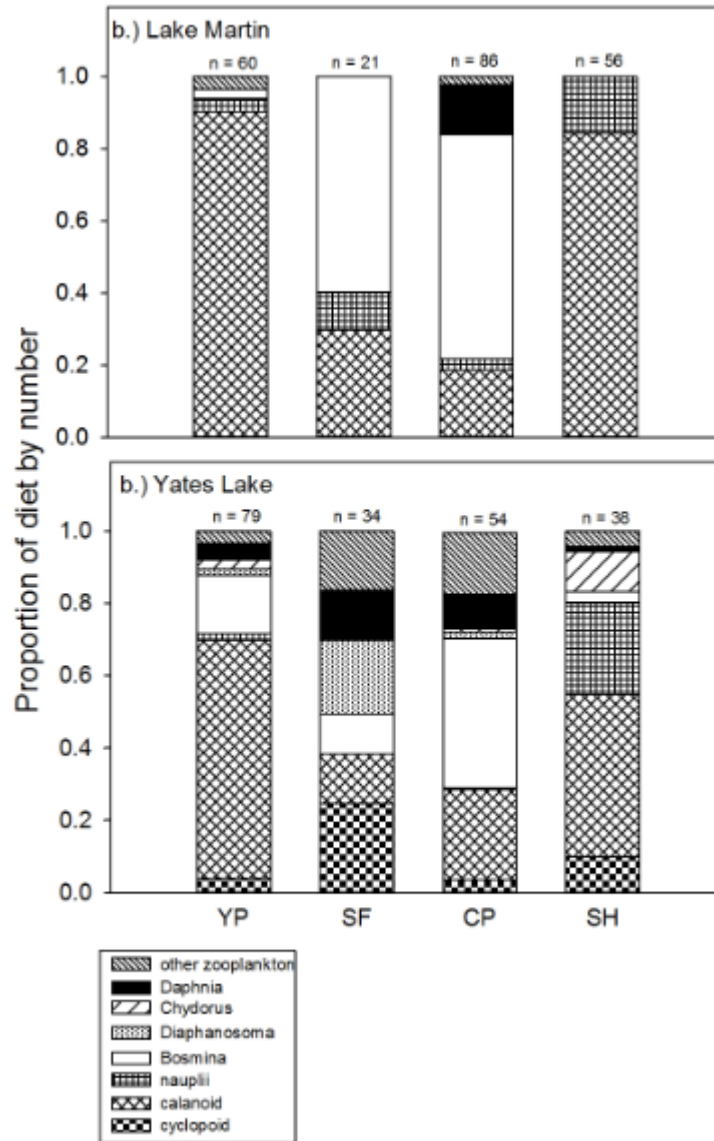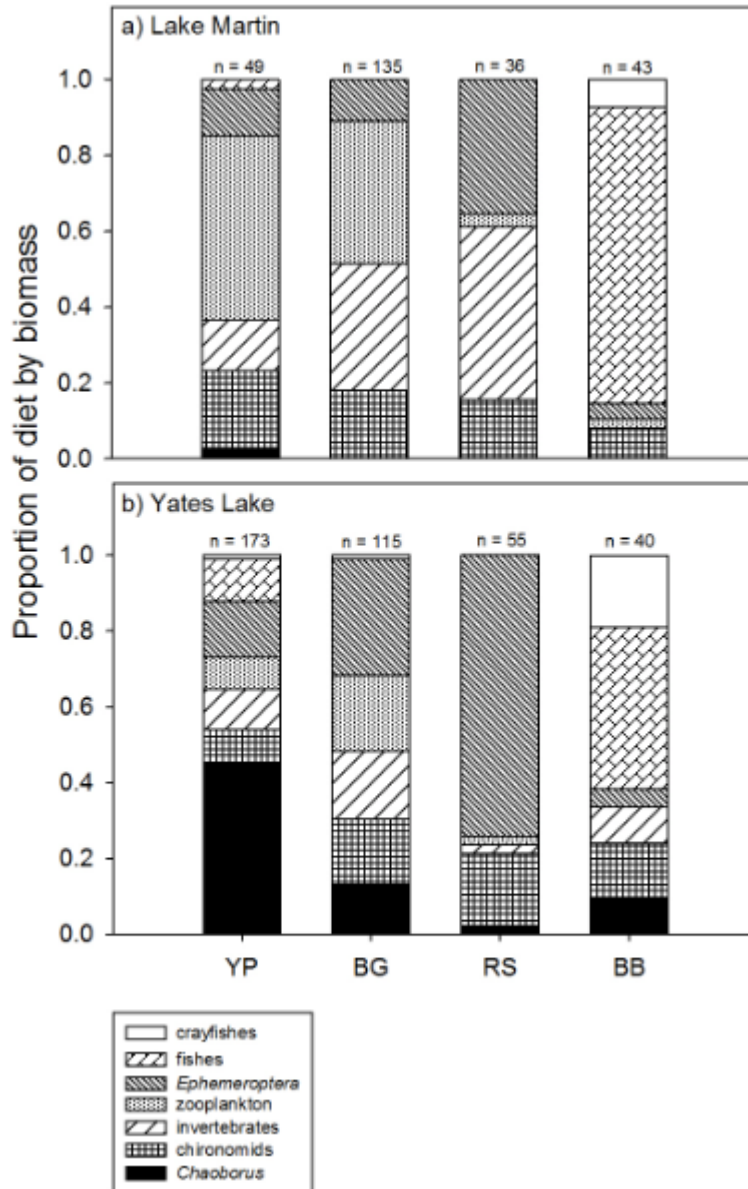
Figure 15. Proportion of diet by number for larval fishes collected during 2010 at a) Lake Martin and b) Yates Lake. The number on top of each bar indicates the number of fish analyzed. YP = yellow perch, SF = *Lepomis* sp., CP = *Pomoxis* sp., SH = *Dorosoma* sp.
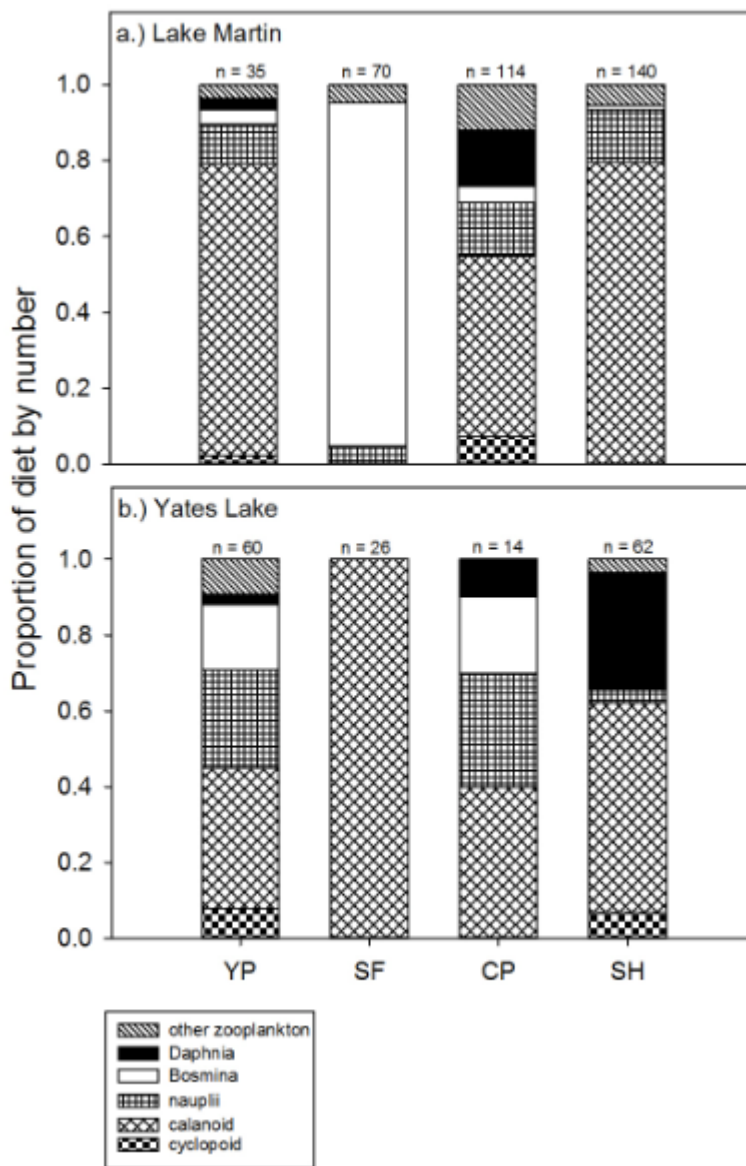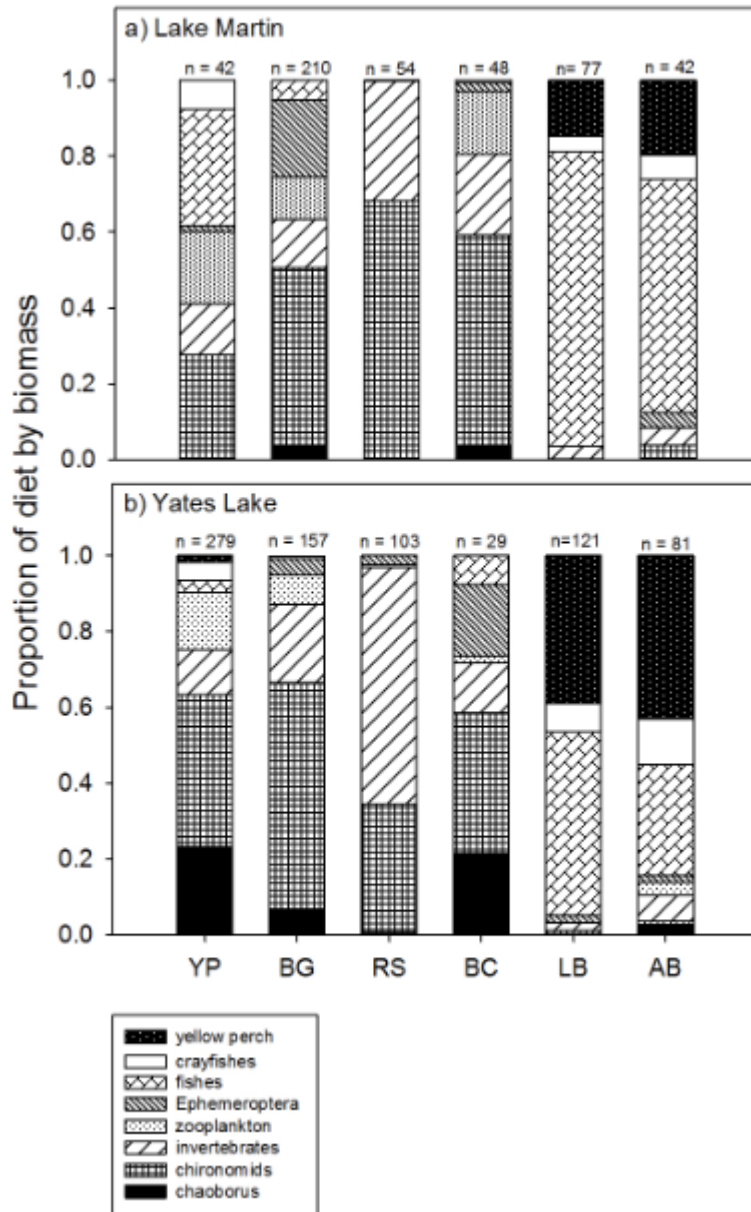
Figure 16. Proportion of diet by number for larval fishes collected during 2011 at a) Lake Martin and b) Yates Lake. The number on top of each bar indicates the number of fish analyzed. Species abbreviations are as presented in Figure 15.
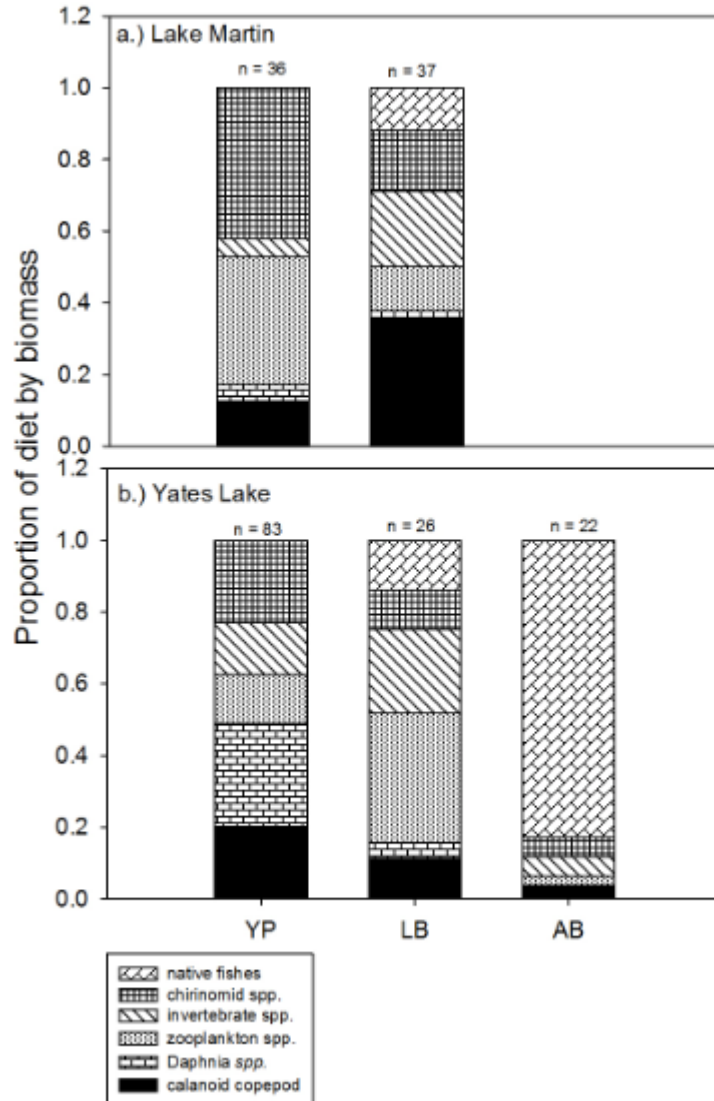
Figure 17. Proportion of diet by biomass (g) for juvenile black basses and yellow perch

collected during 2011 at Lake Martin and Yates Lake. The number on top of each bar indicates

the number of fish that had food items in the stomach. YP = yellow perch,

LB = largemouth bass, AB = Alabama bass.

Figure 18. Proportion of diet by biomass for adult fishes and yellow perch collected during 2010 in a) Lake Martin and b) Yates Lake. The number on top of each bar indicates the number of fish that had food items in their stomach. BB = black basses, other species abbreviations are as in Figure 4.

Figure 19. Proportion of diet by biomass for adult fishes and yellow perch collected during 2011 at a) Lake Martin and b) Yates Lake. The number on top of each bar indicates the number of fish that had food items in the stomach. Species abbreviations are as in Figure 4.
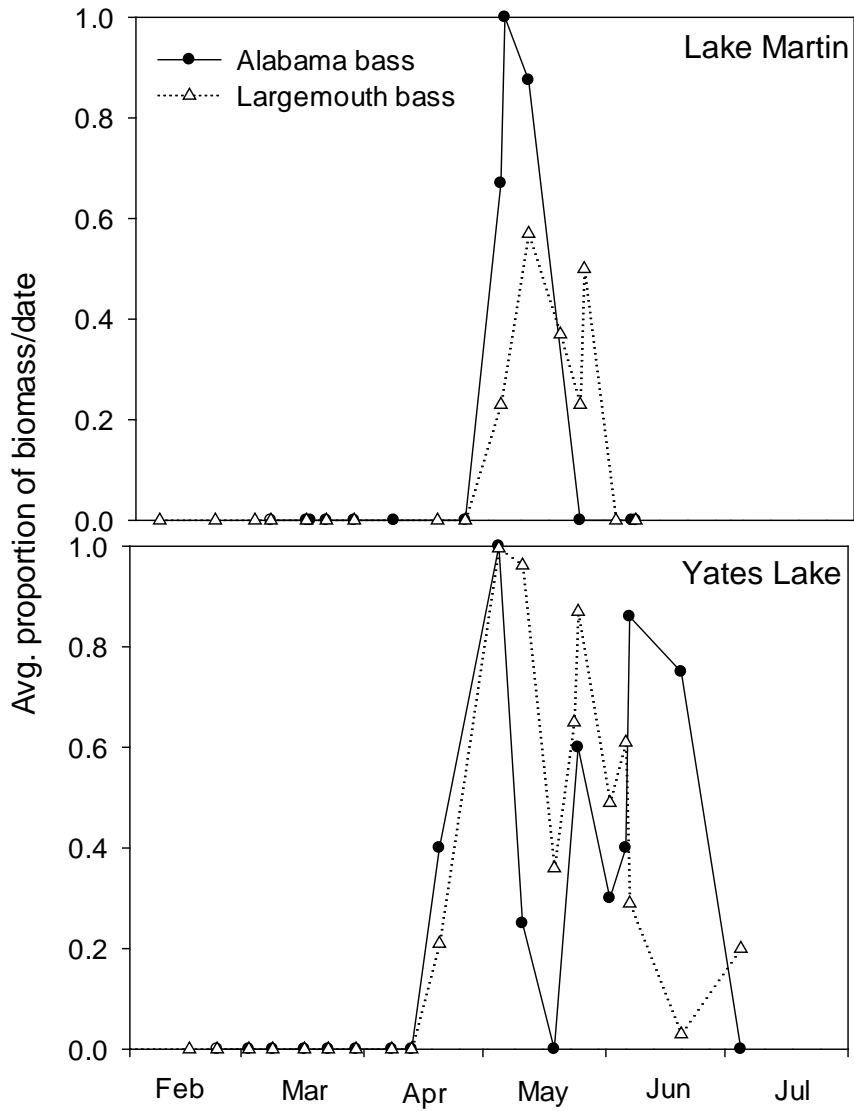
Figure 20. The proportion of diet biomass contributed by yellow perch in diets of Alabama bass

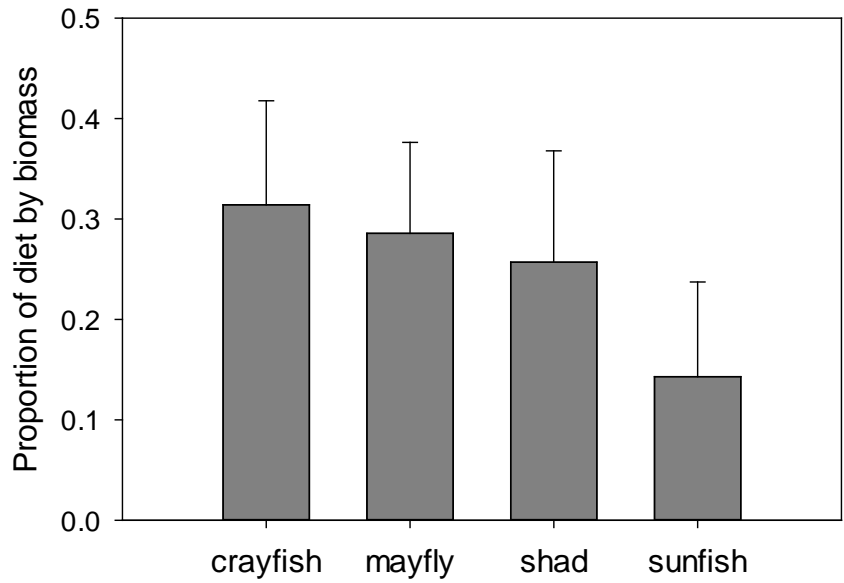and largemouth bass in both Lake Martin and Yates Lake during 2011.

Figure 21. Proportion of diet by biomass for adult striped bass (n = 16) in Lake Martin and

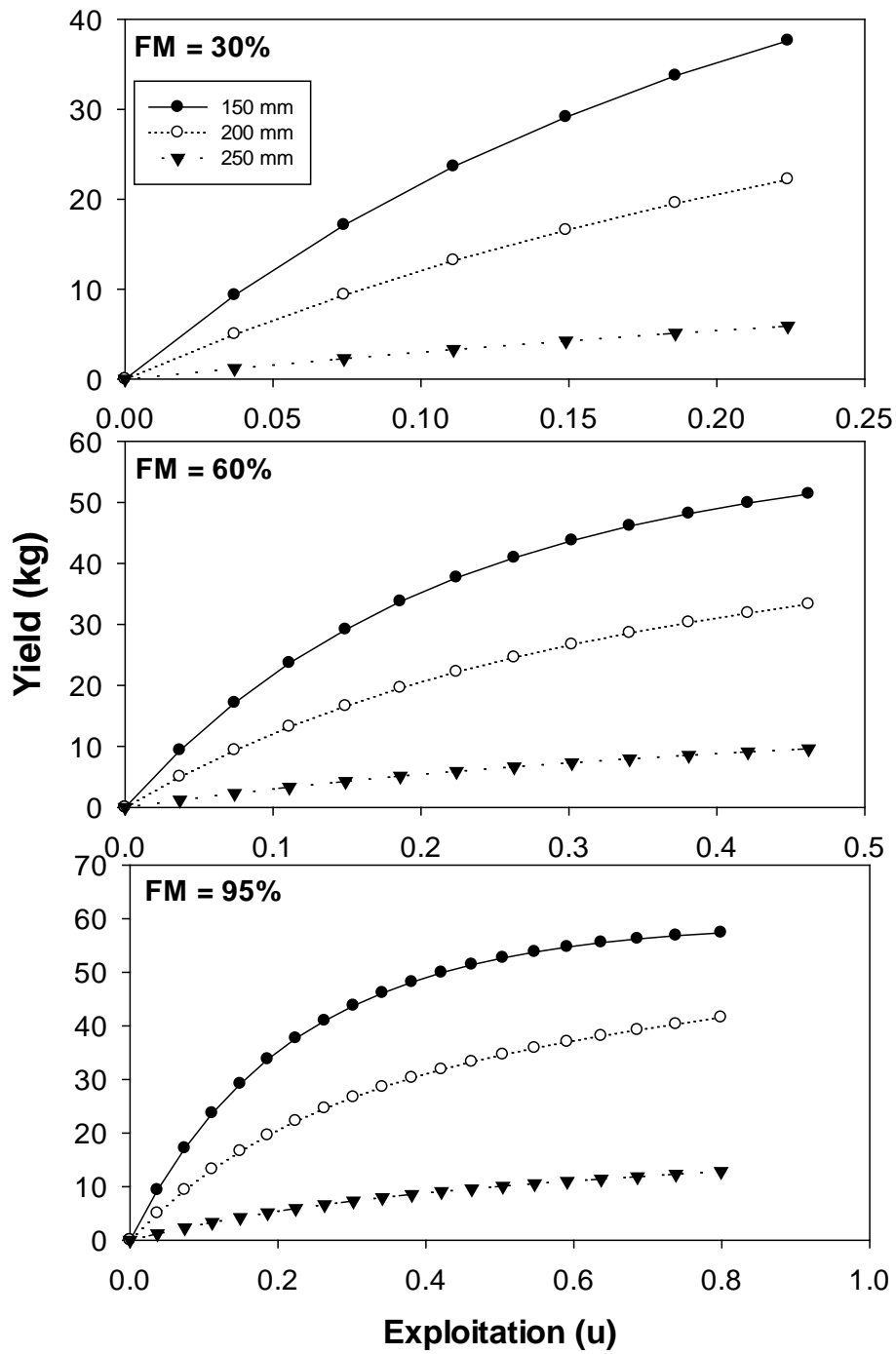Yates Lake 2010-2011. Size range: 264 – 925 mm. Yates Lake: n = 14, Lake Martin: n = 2.

Figure 22. Predicted yield plotted against exploitation as derived from models for 30, 60, and 95% fishing mortality (FM).
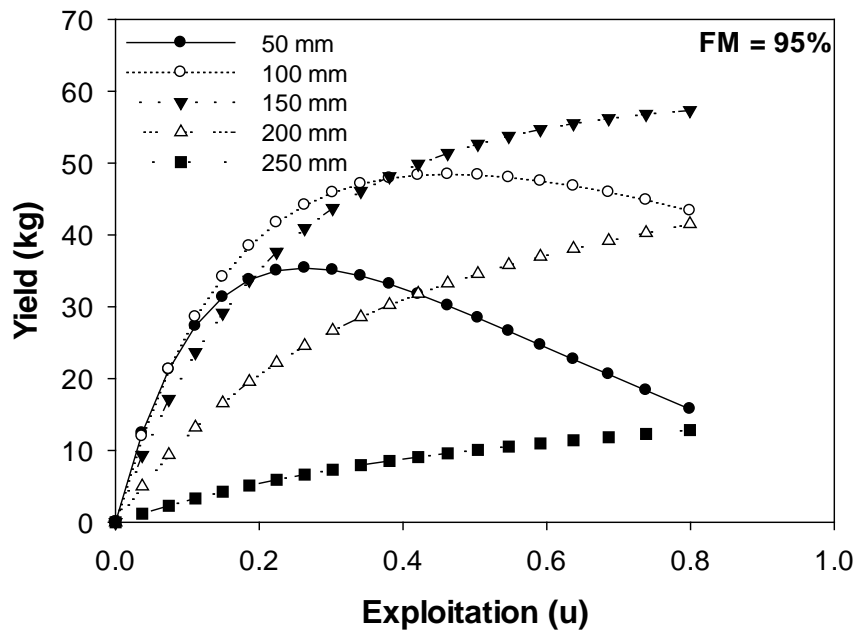
Figure 23. Predicted yield plotted against exploitation as derived from models for 50 – 250 mm

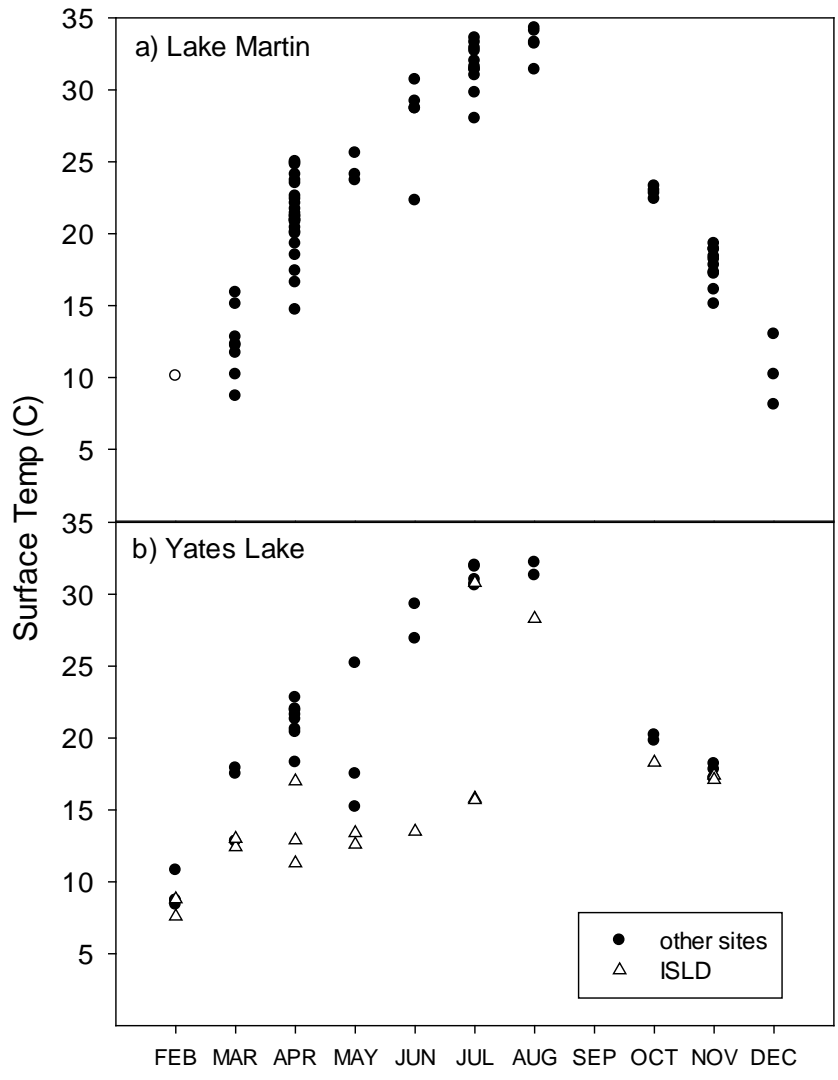length limits at 95% fishing mortality (FM).

Figure 24. Surface temperature by month for a) Lake Martin and b) Yates Lake in 2010.

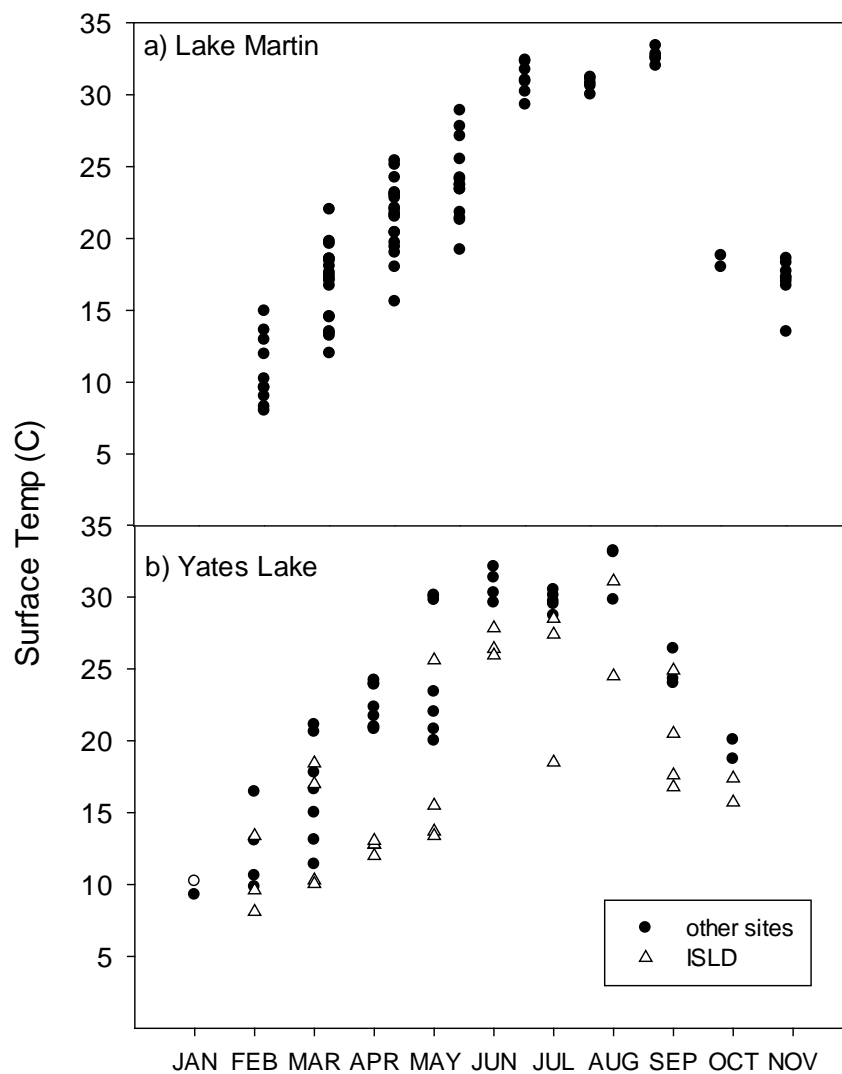ISLD = island site near upper end of Yates Lake.

Figure 25. Surface temperature by month for a) Lake Martin and b) Yates Lake in 2011.

ISLD = island site near upper end of Yates Lake.