Capture and Mortality Rates of Largemouth Bass at Guntersville and Wheeler Reservoirs, Alabama

by

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Abstract

Catch-and-release angling for Largemouth Bass *Micropterus salmoides* has substantially increased since the 1980s, yet few studies have assessed the population-level consequences of these activities. Guntersville and Wheeler Reservoirs, Alabama, are nationally known Largemouth Bass fishing destinations with high levels of angling effort and high rates of voluntary release (>85%). I used a variable reward tagging study to estimate rates of capture, release, mortality, and angler reporting of tagged Largemouth Bass at these reservoirs. Separate estimates were obtained for non-tournament release, tournament release, and harvest fishery sectors to evaluate the relative magnitude of potential population impacts among these fishery sectors. An estimated 56.1% of Largemouth Bass were captured annually in year 1 of the study at Lake Guntersville and 49.5% in year 2 and 45.8% (year 1) and 30.8% (year 2) at Lake Wheeler. Harvest rates were 4.7% and 5.9% at Lake Guntersville and 2.3% and 2.9% at Lake Wheeler. After accounting for literature-based estimates of post-release mortality, an estimated 8.5% and 10.6% of the Largemouth Bass died due to angling at Lake Guntersville versus 5.4% and 7.8% at Lake Wheeler. Although total capture rates were high, harvest and catch-and-release mortality are likely low enough that the total population impact of recreational angling is low. Tag reporting rates were lower for fish caught in competitive tournaments than that for non-tournament captures. The annual instantaneous tag loss rate of dart tags was 0.037. The tagging induced mortality rate was 0.015 after one month. My results could improve management strategies at heavily fished reservoirs with high rates of voluntary release.

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Chapter I. Introduction

Largemouth Bass *Micropterus salmoides* is the most highly sought freshwater fish species by recreational anglers in the United States and Alabama (USFWS 2011). There are 10.6 million anglers that pursue black bass (*Micropterus* spp.) nationwide for a total of 171 million angler days (USFWS 2011). Voluntary catch-and-release angling is a popular practice with Largemouth Bass anglers. There has been a significant increase in the catch-and-release angling rate since the 1980s. On some bodies of water, voluntary release of legal-sized Largemouth Bass may be more than 95% (Myers et al. 2008). Since 1990, the average harvest rate has decreased by 50% even though angling effort has remained relatively constant (Allen et al. 2008).

The population level effects of catch-and-release angling are of great interest to fishery managers and stakeholders. Population effects are a function of capture/release rates and post-release mortality rates (CR). Many studies have estimated CR (Wilde 1998) but relatively few have estimated the population level effects of catch-and-release angling (Kwak and Henry 1995). Also, tournament angling has become an increasingly important component of catch-and-release angling for black bass since the 1980s (Schramm et al. 1991, Wilde 1998, Kerr and Kamke 2003), which has raised concerns among stakeholders and fishery managers regarding potential negative fishery effects.

Few studies have assessed population level effects of black bass tournament fishing, but those that have been conducted have generally found that these effects are modest. Driscoll et al. (2007) estimated exploitation, tournament mortality, and catch-and-release mortality rates of Largemouth Bass for Sam Rayburn Reservoir, Texas using a tagging study. They found tournament mortality contributed 1–16% of total annual mortality, compared with 2–17% for non-tournament catch-and-release mortality. Allen et al. (2004) also found that tournament associated mortality may not significantly influence most Largemouth Bass fisheries except in fisheries where the tournament catch was substantially greater than that of harvest. Edwards et al. (2004) predicted that tournaments in Connecticut would have a low impact on black bass populations when mortality rates were less than 10%. More studies of population level effects of tournaments, and more broadly catch-and-release fishing, are needed particularly in systems known to experience very high fishing effort.

It is important for fisheries managers to understand how different components of mortality (i.e., tournament release, non-tournament release, harvest, natural mortality) effect black bass fisheries. Assessing the population level effects of catch-and-release mortality will provide fisheries managers with a better understanding of the effectiveness and the downfalls of regulations aimed at providing quality catch-and-release angling opportunities. Estimating the components of mortality can be used in simulations to evaluate the performance of potential management options. For example, high voluntary release rates may limit the effectiveness of size restrictions for improving population size structure (Myers et al. 2008). Harvest is not always the primary mode of mortality. In systems with high rates of catch, high rates of release, and low post release survival, catch and release mortality potentially could exceed harvest mortality at the population level (Myers et al. 2008). It is important that this mortality information be available to fisheries managers and studies should be conducted to find this information.

Tagging studies can be used to estimate components of fish mortality (Pine et al. 2003). A popular study design is to use a reward tagging study that relies on anglers to return tags from fish they have captured. These studies can estimate survival rates and tag recovery rates (Hoenig et al. 1998a; Pollock et al. 2001). Driscoll et al. (2007) used a tagging study to determine fishing mortality rates and the impact of black bass tournaments at Sam Rayburn Reservoir, Texas. A tagging study on Striped Bass in Chesapeake Bay was conducted by the Maryland Department of Natural Resources to estimate harvest mortality, fishing mortality, and natural mortality (Jiang et al. 2007). High reward tagging studies are used to estimate non-reporting rates for standard dollar tags. Reporting rates are lowest for species that are catch-and-release oriented such as Largemouth Bass (Meyer et al. 2012).

Two important assumptions of tagging studies are that tag loss is negligible and survival rates are unaffected by tagging (Pollock et al. 2001). Tag loss can lead to underestimation of survival rates and overestimation of population size by reducing the number of recaptures from the population (Pine et al. 2003). Similarly, survival rates will be negatively biased if survival is affected by the tag or tagging procedure (Pine et al. 2003). Thus, it is important that tag loss and tagging mortality rates are quantified and estimates from tagging studies are properly adjusted.

The objective of this study was to estimate capture and mortality rates of Largemouth Bass at Guntersville and Wheeler Reservoirs and estimate tag loss and tagging mortality rates of dart tags in Largemouth Bass. In chapter II, I determined tag loss and tagging mortality rates of dart tags using small pond studies. In chapter III, I assessed whether capture and mortality rates differed between reservoirs (Guntersville and Wheeler), among fishery sectors (tournament catch-and-release, non-tournament catch-and-release, and harvest), and across fish ages. I also determined whether tag reporting rates by anglers differed among fishery sectors and across Largemouth Bass ages.

Chapter II. Estimates of Tag Loss and Tagging Mortality for Dart Tags in Largemouth Bass

Abstract

Tagging studies are commonly used to estimate abundance and mortality of various fish species. Two important assumptions of tagging studies is that there is no tag loss and that survival rates are not affected by the tagging process. Different tag styles have varying tag loss rates for different species. Tag loss is most commonly studied by double-tagging fish and tagging mortality is commonly estimated by holding fish in cage trials to monitor survival. Dart tagged Largemouth Bass were stocked into four research ponds to monitor tag loss and were seined after several time intervals. Additionally, tagging mortality was assessed by comparing survival of tagged bass in ponds to those with untagged bass. Initial tag loss (i.e. first 2 weeks) was 0.0%. Instantaneous annual tag loss rate was 0.037 and was assumed constant over the course of the study. Tagging mortality after one month of tagging was 0.015. Also, 67.5% of bass tagged during the tag loss study after one year which suggests that tagging mortality was low. Tag loss and tagging mortality were low and similar to other studies that estimated loss rates for dart tags. Studies of tagging mortality often lack a control fish because all fish undergo the same capture and handling process. Tagging mortality should continue to be estimated by replicating the tagging process.

Introduction

Tagging studies are commonly used to study fish movements, abundance, growth, and mortality (McFarlane et al. 1990). Two important assumptions of tagging studies are that tag loss is negligible and survival rates are unaffected by tagging (Pollock et al. 2001). Tag loss can lead to underestimation of survival rates and overestimation of population size by reducing the number of recaptures from the population (Pine et al. 2003). Similarly, survival rates will be negatively biased if survival is affected by the tag or tagging procedure (Pine et al. 2003). Thus, it is important that tag loss and tagging mortality rates are quantified and estimates from tagging studies are properly adjusted.

Tag loss has been estimated for a variety of tag styles. It is commonly estimated by double-tagging fish (McFarlane et al. 1990). Using this approach, tag loss rates can be quantified as the proportion of recaptured fish with only one tag remaining (Keefer and Wilson 1993; Henry 2003). A drawback of double-tagging is that it could affect return rates of tags (e.g., double-tagged fish more likely to be reported by anglers, Muoneke 1992). Tag loss also has been estimated in holding ponds by recovering tagged fish after a period of time (Dunning et al. 1987; Renfro et al. 1995).

Tagging mortality has typically been assessed using cage trials. In these studies, fish are held in cages for a period of time and short-term survival is determined at the end of the trial. Cage trials may be unreliable since these trials prevent the indirect mortality effects (i.e., handling), which may lead to underestimates of the true mortality rate (Pollock and Pine 2007). Also, cage trials tend to only last a few days (Henry 2003; Bonvechio et al. 2014) and are usually conducted in small structures and concentrate fish at a greater density than their natural habitat. Thus, longer-term studies have been conducted in holding ponds (Tranquilli and Childers 1982;

Dunning et al. 1987) where cage effects are negligible and these studies typically last 180 days or longer.

Tag loss can differ among tag styles (Dunning et al. 1987). The T-bar anchor tag has a slim nylon ‘T’ that anchors between pterygiophore bones. This is attached to a vinyl tube that is large enough for the printing of unique identification numbers and instructions for tag reporting. This tag style has been frequently used because a hand operated tagging gun makes application easy and quick (Tranquilli and Childers 1982; Slipke et al. 2003). Internal anchor tags implanted into the abdominal cavity of the fish have also been used (Weathers et al. 1990; Keefer and Wilson 1993). These tags consist of a plastic disc on the insertion end with a vinyl tube attached to the disc. Upon application, a scalpel is used to make an incision into the abdominal cavity and the disc end is slipped into the fish. The vinyl tube is external and contains information on tag reporting. These tags generally have low tag loss, but can be time consuming to apply. Dart tags are similar to the T-bar anchor tag, but have a plastic barbed tip instead of the ‘T’ shaped anchor. This tag style is highly visible and has ample room for information about tag reporting. Dart tags have exhibited low tag loss for some fish species (Renfro et al. 1995; Bonvechio et al. 2014) and high tag loss in others (Dunning et al. 1987).

Largemouth Bass *Micropterus salmoides* are an important target of recreational fisheries in North America and are frequent subjects of tagging studies. T-bar anchor tags have commonly been used to tag Largemouth Bass, but often exhibit high tag loss rates in this species (Slipke et al. 2003). Internal anchor tags have also been used (Weathers et al. 1990), but are less popular. The use of dart tags with Largemouth Bass has become increasingly popular (Bonvechio et al. 2014; Kerns et al. 2015), but there are few estimates of tag loss and tagging mortality of these tags in Largemouth Bass. More tag loss and tagging mortality estimates are needed to provide accurate estimates for tagging studies. The objective of this study was to determine tag loss and short-term tagging-induced mortality rates of dart tags in Largemouth Bass.

Methods

Tag Loss

Eighty Largemouth Bass were collected from Lake Harding, Alabama to determine tag loss rates. Largemouth Bass greater than 305 mm were collected with boat mounted electrofishing gear (7.0 GPP, 5-7 amps) along shoreline transects in April 2014. Largemouth Bass were transported in aerated tanks to the E.W. Shell Experimental Research Station in Auburn, Alabama. Each Largemouth Bass was measured (mm) and tagged with an individually numbered Hallprint, Inc. model PDAT© dart tag. These tags were 125 mm long and 2 mm in diameter with a vinyl shaft and plastic barbed tip that had a 10 mm opening at the barb. Tags were inserted at a 45-degree angle into the dorsal pterygiophores at the base of the spiny dorsal fin with a 4 mm diameter hollow needle purchased from Hallprint. Each tag insertion was checked to insure the tag barb was firmly anchored between the pterygiophore bones.

Tagged Largemouth Bass were given an anal fin clip before being released into one of four 0.1 hectare research ponds with a mean maximum depth of 1.2 m. Each pond received 20 Largemouth Bass along with *Lepomis* spp. for forage. After four months, Blue Tilapia (*Oreochromis aureus*) were stocked for additional forage. Largemouth Bass were collected with a single pass of a 15 m long, 5 mm mesh seine two weeks after tagging to assess initial tag loss, then at one, 3, 6, 9, and 12 months to estimate long-term tag loss rates. Each Largemouth Bass collected was examined for a tag, measured to the nearest millimeter, and released back into the pond. All four ponds were drained on the last day of the study to collect all remaining fish.

Tag loss rates were estimated using a generalized linear model with a binomial sampling distribution and log link function. The model predicted the probability of tag loss as a function of the number of years (y) at large using:

$$P = \exp(-\mathrm{TL}*y)$$

where the slope coefficient, TL, is the instantaneous tag loss rate. The intercept parameter was fixed at 0.0 to reflect the assumption that all fish were tagged initially. This approach assumed that all Largemouth Bass collected were independent observations, an assumption that was clearly violated as some individual fish were collected on multiple seining occasions. However, this assumption was necessary because Largemouth Bass that had lost a tag could not be identified to the individual level due to the loss of the tag, which precluded a more sophisticated analysis. In addition to tag loss, these trials were also used to qualitatively assess tagging mortality by evaluating the proportion of released fish that survived and were recovered at pond draining.

Tagging Mortality

Short-term (i.e., one month) tagging mortality was estimated in fourteen 0.1 hectare ponds (mean maximum depth 1.5 m) at the South Auburn Experimental Research Station, Alabama. Boat mounted electrofishing gear was used to collect 210 Largemouth Bass from Lake Harding and Lake Walter F. George, Alabama in January 2015. Collection and tagging methods were identical to those described in *Tag Loss* above. Fifteen untagged Largemouth Bass were stocked on the day of collection into each pond along with *Lepomis* spp. for forage.

Largemouth Bass were allowed to acclimate to the ponds for two weeks to eliminate mortality effects of transportation and handling. Seven of the ponds were chosen randomly as treatment ponds in which Largemouth Bass were tagged via electrofishing. The other seven ponds served as controls in which Largemouth Bass were held untagged for the duration of the study. Two weeks after stocking, Largemouth Bass were collected in the seven treatment ponds via two 15 minute electrofishing runs per pond. Largemouth Bass were held in a 40 gallon non-aerated tank for a maximum of 15 minutes, tagged and released back into the pond. The process was comparable to what fish would experience during a typical tagging process on an electrofishing boat. All ponds were drained one month after the tagging event to collect live fish. A grate at the bottom of the each pond prevented the loss of Largemouth Bass from the ponds during draining. Thus, I assumed that all surviving Largemouth Bass were collected during pond draining. Tagging mortality was assessed using a Pearson's chi-square test to assess differences in recovery rates of tagged and untagged Largemouth Bass. Tagging mortality rates were estimated as the proportion of tagged Largemouth Bass that were not recovered at the end of the study. This approach assumed that all mortality of tagged Largemouth Bass during the month between tagging and pond draining was attributable to tagging.

Results

Tag Loss

I captured 340 Largemouth Bass across 7 seining events during the 12 month tag loss study (Table 1). A total of 54 Largemouth Bass were collected when the ponds were drained. Initial tag loss (i.e., first two weeks) was 0.0% because all Largemouth Bass were captured with a tag either during the first (n = 70) or a subsequent seining event (n = 10). Five (1.5%)

instances of Largemouth Bass with lost tags were recorded over the course of the study. The annual instantaneous tag loss rate was 0.037 (± 0.031 95% CI) and tag loss was significantly related to time (i.e. years) at large (P = 0.025). In addition to the four-pond tag loss study described above, tag loss during the tagging mortality study at the South Auburn Experimental Research Station was 0.0% after one month.

Tagging Mortality

Sixty-seven of 68 tagged Largemouth Bass were recovered when ponds were drained four weeks after tagging at the South Auburn Research Station, which corresponded to a tagging mortality rate of 0.015 (± 0.029 95% CI). I recovered 139 of 142 (97.9%) untagged Largemouth Bass 6 weeks after the initial stocking. There was no significant difference (P = 0.999, χ^2 = 5.84e-30, df = 1) in recovery rates between tagged and untagged Largemouth Bass. A minimum of 14 Largemouth Bass were recovered from each pond (Table 2). In addition to the 14-pond short-term tagging mortality study at the South Auburn Station, the four-pond tag loss study indicated that 54 of 80 (67.5%) tagged Largemouth Bass survived and were recovered during pond draining. All Largemouth Bass were observed alive (100% survival) on day 14 or a subsequent seining event during the tag loss study and 98.7% of the Largemouth Bass were observed alive on day 27 or a subsequent seining event.

Discussion

This study adds to the growing body of evidence suggesting that tag loss rates of dart tags in Largemouth Bass are low. My findings are similar to Renfro et al. (1995) who found 98% overall retention of dart tags in Largemouth Bass during a 15 month tag loss study at Lake Blanchester, Florida. In a Largemouth Bass reward tagging study in which dart tags were used to estimate exploitation in three Georgia small impoundments, Bonvechio et al. (2014) found 100% short-term tag retention and had no documented cases of long-term tag loss in double-tagged fish. My findings indicate that dart tag loss compares favorably with other commonly used tags. Internal passive integrated transponder (PIT) tags frequently have low tag loss in Largemouth Bass (Hangsleben et al. 2012), but these tags cannot be recognized by anglers, which limits their utility for studies that rely on angler reporting of recaptures. Internal anchor tags also have low tag loss. Keefer and Wilson (1993) determined internal anchor tag loss was less than 1% for Largemouth Bass at Lake Walter F. George. Dart tags appear to perform much better than T-bar style anchor tags. Keefer and Wilson (1993) used a T-bar style tag and estimated its tag loss rate to be 20% per year for double-tagged Largemouth Bass at Lake Walter F. George. Slipke et al. (2003) used a T-bar style tag in a Largemouth Bass exploitation study on Wheeler Reservoir, Alabama and estimated a tag loss rate of 39.5% after one month.

Short-term tagging mortality is frequently studied using pond experiments and cage trials. My results are similar to Renfro et al. (1995) who reported 94% survival of tagged Largemouth Bass after one month using dart tags in hatchery ponds. Henry (2003) reported 100% survival of Largemouth Bass after dart tagging using cage trails that lasted an average of 50 hours. Bonvechio et al. (2014) found no Largemouth Bass mortality using dart tags in cage trails that lasted up to 49 hours. Long-term tagging mortality was not explicitly tested in this study, but mortality of fish in the one year long tag loss study indicated that long-term tagging mortality was likely low. At pond draining, 54 of 80 Largemouth Bass survived one year after tagging which corresponds to an annual instantaneous mortality (Z) rate of 0.39. This mortality rate falls within the range of natural mortality estimates for Largemouth Bass (Beamesderfer and North 1995), so tagging mortality was likely low in these ponds. Moreover, I would expect mortality to be higher in these study ponds because they are shallow, which may increase susceptibility to bird and mammal predation. In addition these Largemouth Bass likely experienced additional stress because they were handled multiple times via seining, which may have contributed to mortality.

Dart tags have many qualities making them desirable for use in tagging studies. They are large and easy to read making them a good choice for study designs that depend on anglers to report recoveries. Dart tags are also inexpensive compared to PIT tags (Hallprint). However, because dart tags are large, only Largemouth Bass greater than 300 mm should be tagged given the size tag used in this study (Renfro et al. 1995). Smaller dart tags are available, but were not evaluated in this study. Small dart tags have higher tag loss rates in Largemouth Bass than the larger dart tags (Renfro et al. 1995). Dart tags can also be more difficult to apply than a T-bar or PIT tag due to a lack of mechanized applicator gun. Users willing to trade ease of application for low tag loss and tagging mortality rates will find dart tags an attractive option for tagging Largemouth Bass.

Tagging mortality studies often lack a true control fish (Pollock and Pine 2007). For example, when tagging a subset of fish when stocking an enclosure (Renfro et al. 1995), the untagged portion of the population does not serve as a true control because all fish experienced the same capture, handling, and transportation process. In my study, I allowed Largemouth bass to acclimate in the ponds for two weeks. By recapturing Largemouth Bass for tagging after the acclimation period, non-tagging effects such as transporting and handling were accounted for and could be separated from mortality associated with the capture and tagging process. I intended to tag all of the Largemouth Bass in the treatment ponds so that I could assess differences in recovery rates using ponds as the replicates (Pollock and Pine 2007). However, I was able to tag only 68 of 105 (64.8%) Largemouth Bass in the treatment ponds. Electrofishing was not an efficient way to recapture a high proportion of Largemouth Bass in these ponds. In future studies using this design, using a block net to concentrate fish into a smaller area may help capture a larger proportion of the population. I only evaluated short-term tagging mortality because obtaining supplemental forage to keep Largemouth Bass alive for a long-term study would have been cost-prohibitive. Most dart tagging mortality studies in Largemouth Bass have lasted up to a few months (Renfro et al. 1995). This tagging mortality study design can be used to estimate long-term tagging mortality. If proper amounts of forage fish are available, then long-term dart tagging mortality should be studied to obtain estimates of this possible source of mortality.

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Chapter III. Components of Largemouth Bass *Micropterus salmoides* Fishing Mortality at Guntersville and Wheeler Reservoirs, Alabama

Abstract

Catch-and-release angling for Largemouth Bass *Micropterus salmoides* has substantially increased since the 1980s, yet few studies have assessed the population-level consequences of these activities. Guntersville and Wheeler Reservoirs, Alabama, are nationally known Largemouth Bass fishing destinations with high levels of angling effort and high rates of voluntary release (>85%). I used a variable reward tagging study to estimate rates of capture, release, mortality, and angler reporting of tagged Largemouth Bass at these reservoirs. Separate estimates were obtained for non-tournament release, tournament release, and harvest fisheries to evaluate the relative magnitude of potential population impacts among these fishery sectors. An estimated 56.1% of Largemouth Bass were captured annually in year 1 of the study at Lake Guntersville and 49.5% in year 2 and 45.8% (year 1) and 30.8% (year 2) at Lake Wheeler. Harvest rates were 4.7% and 5.9% at Guntersville and 2.3% and 2.9% at Wheeler. After accounting for literature-based estimates of post-release mortality, an estimated 8.5% and 10.6% of the Largemouth Bass died due to angling at Lake Guntersville versus 5.4% and 7.8% at Lake Wheeler. Although total capture rates were high, harvest and catch-and-release mortality are low enough that the total population effect of recreational angling is low. These results could improve management strategies at heavily fished reservoirs with high rates of voluntary release.

Introduction

The population level effects of catch-and-release angling are of great interest to fishery managers and stakeholders. Population impacts are a function of not only the rates at which fish are captured and released, but also the proportion of released fish that die (post-release mortality rate, CR). Estimates of CR are relatively easy to obtain when compared with population-level capture and release rates. Consequently, there have been many studies of CR (Bartholomew and Bohnsack 2005), but relatively few have estimated the population level impacts of catch-and-release angling (Kwak and Henry 1995).

Catch-and-release angling may have negative impacts on recreational fisheries and has become an important component of mortality for several species. Catch-and-release was a larger component of total mortality than harvest for Common Snook in Florida (Taylor et al. 2006). Additionally, catch-and-release angling has been an increasingly important component of the Striped Bass fisheries of Chesapeake Bay (Jiang et al. 2007). On water bodies with no closed season for black bass fishing, Philipp et al. (1997) found that catch-and-release angling during the spawning season could have substantial effects on the fry production in some waters. Cooke et al. (2000) found that nesting black bass that were caught-and-released had higher rates of nest and brood abandonment. Furthermore, black bass enduring sub-lethal stresses during spawning (i.e. angling) had offspring that were shorter in length and weighed less compared to the offspring spawned by unstressed parents (Ostrand et al. 2004).

Largemouth Bass *Micropterus salmoides* is the most highly sought freshwater fish species by recreational anglers in the United States and Alabama (USFWS 2011). There are 10.6 million anglers that pursue black bass (*Micropterus* spp.) nationwide for a total of 171 million angler days (USFWS 2011). They are also an important species for the local economies of communities located near Largemouth Bass fisheries. For example, Guntersville Reservoir in northern Alabama generated an estimated 9.8 million dollars of direct total expenditures by anglers targeting black bass in 2012 (McKee 2013).

Voluntary catch-and-release angling is a popular practice with Largemouth Bass anglers and has undergone a significant increase since the 1980s. The practice of releasing legally harvestable-size black bass increased by 38% from 1986 to 1996 according to a survey of state fisheries management agencies (Quinn 1996). On some bodies of water, voluntary release of legal-sized Largemouth Bass may be more than 95% (Myers et al. 2008). Since 1990, the average harvest rate has decreased by 50% even though angling effort has remained relatively constant (Allen et al. 2008), and this shift has been attributed to increasing rates of voluntary catch-and-release. A study by Clark (1983) found that as release rates increased, the total catch and the catch of trophy fish increased in several species, even when the harvest of trophy fish remained relatively constant.

Tournament angling has become an increasingly important component of catch-and-release angling for black bass since the 1980s (Schramm et al. 1991, Wilde 1998, Kerr and Kamke 2003), which has raised concerns among stakeholders and fishery managers regarding potential negative fishery effects. Post-release mortality rates may be higher for tournament than non-tournament release because increased handling stress related to retention for judging (Hayes et al. 1995). Largemouth Bass released immediately generally have a lower mortality than those held in live wells for several hours (Plumb et al. 1998). Tournament fishing may deplete fish populations from intensified harvest after tournaments promote the fishery (Schramm et al. 1991). Relocation and concentration of black bass after weigh-ins is another concern (Driscoll et al. 2007). Meals and Miranda (1994) showed that size-selectivity of tournament angling mortality could affect the size structure of black bass populations. Wilde et al. (1998) reported that tournament anglers generally preferred to catch one or two large fish than ten small fish. Another concern of black bass tournaments is angling mortality during summer months. Studies have shown a positive relation between water temperature and post-release mortality of tournament-caught Largemouth Bass (Schramm et al. 1987; Plumb et al. 1988; Meals and Miranda 1994).

Few studies have assessed population-level impacts of black bass tournament fishing, but those that have been conducted have generally found that these effects are modest. Driscoll et al. (2007) estimated exploitation, tournament mortality, and catch-and-release mortality rates of Largemouth Bass for Sam Rayburn Reservoir, Texas using a tagging study. They found tournament mortality contributed 1–16% of total annual mortality, compared with 2–17% for non-tournament catch-and-release mortality. Allen et al. (2004) also found that tournament associated mortality may not significantly influence most Largemouth Bass fisheries except in fisheries where the tournament catch was substantially greater than that of harvest. Edwards et al. (2004) predicted that tournaments in Connecticut would have a low impact on black bass populations when mortality rates were less than 10%. More studies of population-level effects of tournaments, and more broadly catch-and-release fishing, are needed particularly in systems known to experience very high fishing effort.

It is important for fisheries managers to understand how different components of mortality (i.e., tournament release, non-tournament release, harvest, natural mortality) effect black bass fisheries. Assessing the population level effects of catch-and-release mortality will provide fisheries managers with a better understanding of the effectiveness and the downfalls of regulations aimed at providing quality catch-and-release angling opportunities. Estimating the components of mortality can be used in simulations to evaluate the performance of potential management options. For example, high voluntary release rates may limit the effectiveness of size restrictions for improving population size structure (Myers et al. 2008). Harvest is not always the primary mode of mortality. In systems with high rates of catch, high rates of release, and low post release survival, catch-and-release mortality potentially could exceed harvest mortality at the population level (Myers et al. 2008). Also, harvest restrictions can protect a large portion of the population leaving them only susceptible to catch-and-release mortality (Coggins et al. 2007). If tournament release mortality is high, then investments in technology to improve survival might be warranted to improve the abundance of large fish.

Understanding the relative magnitudes of mortality contributed by each fishery sector could also help alleviate stakeholder conflicts. A survey of tournament and non-tournament black bass anglers in Texas found that 88.3% of tournament anglers believed most fish survived tournament weigh-ins whereas only 55.8% of non-tournament anglers believed so (Wilde et al. 1998). This study also found that 51% of non-tournament anglers believed tournaments had negatively affected their fishing. Empirical data on the relative magnitude of different sources of mortality could foster rational data-driven debates regarding management practices and fishery allocation issues.

Fish tagging studies can be used to estimate components of fish mortality (Pine et al. 2003). A popular study design is to use a reward tagging study that relies on anglers to return tags from fish they have captured. These studies can estimate survival rates and tag recovery rates (Hoenig et al. 1998; Pollock et al. 2001). When the rate at which tags are reported by anglers can be estimated, then the total mortality rate can be separated into fishing and natural mortality rates if natural mortality is assumed constant over time (Pollock et al. 2001). Information on the timing of tag returns over the course of the year can be used as a substitute for fishing effort (Hoenig et al. 1998). There are numerous assumptions involved in making inferences from tag recovery data (Brownie et al. 1985). These assumptions are (1) the sample is representative of the target population, (2) there is no tag loss, (3) survival rates are not affected by tagging, (4) the year of tag recoveries is correctly tabulated, (5) the fate of each tagged fish is independent of the fate of other tagged individuals, (6) all high reward fish captured are reported, and (7) all tagged individuals in the sample have the same annual survival and recovery rates. Previous studies have used reward tagging studies to gather information about Largemouth Bass fisheries (Driscoll et al. 2007, Fontaine (2009), Bonvechio et al. 2014, Kerns et al. 2015).

The objective of this study was to estimate capture and mortality rates of Largemouth Bass at Guntersville and Wheeler Reservoirs. More specifically, I wanted to estimate capture and fishing mortality rates of Largemouth Bass and assess whether these rates differed between reservoirs (Guntersville and Wheeler), among fishery sectors (tournament catch-and-release, non-tournament catch-and-release, and harvest), and across fish ages. I also was interested in determining whether tag reporting rates by anglers differed among fishery sectors and across Largemouth Bass ages.

Methods

Study Area

Guntersville and Wheeler Reservoirs are 27,964 and 27,142 hectare impoundments, respectively, of the Tennessee River in northern Alabama. These reservoirs are regulated by the Tennessee Valley Authority. Lake Guntersville is nationally known for its exceptional fishing and trophy potential for Largemouth Bass. This reputation attracts many tournaments and out of state anglers (Floyd and Ekema 2011). A tournament focused creel survey on Lake Guntersville in 2013 estimated that there was 89,000 hours spent tournament angling for black bass (Snellings 2015). Catch-and-release is a popular practice by anglers on the lake. A creel survey in 2012 found that there was a 96% release rate for Largemouth Bass of all sizes (McKee 2013). No recent creel surveys have been conducted at Lake Wheeler, but the lake is known to attract numerous tournaments and out of state anglers (Ekema et al. 2011).

Study Design

I used a variable-reward tagging study to estimate different components of Largemouth Bass capture, release, and mortality at Guntersville and Wheeler Reservoirs. Tagging studies depending on tag returns can partition catch into different categories to give rates of capture and survival (Pine et al. 2003). Since some tags recovered by anglers are not returned, it is important to estimate the reporting rate to adjust tag return rates and resulting mortality estimates accordingly. The simplest approach to estimating tag reporting rates in variable reward studies is to use two levels of rewards: a low-dollar reward tag (hereafter referred to as standard tags), and a high-dollar tag with a high enough reward amount that 100% reporting can be safely assumed (Pollock et al. 2001). I used a reward amount of $5 for standard tags and $150 for high reward tags. Meyer et al. (2012) estimated that a $100 reward elicited a 100% reporting rate for Largemouth Bass in Idaho fisheries. Additionally, Taylor et al. (2006) determined $100 was a sufficient reward to obtain 100% reporting rate with Common Snook anglers in Florida. Therefore, I used $150 as the high reward in my study to ensure 100% tag reporting by accounting for inflation or any potential regional differences in angler reporting tendencies. It was important that some reward be offered on all tags because tag return rates often are very low when no reward is offered (Pollock et al. 2001). Meyer et al. (2012) estimated a 39% reporting rate when no reward was offered. Thus, the $5 standard tag value guarded against low reporting rates while limiting research costs. Four percent of the tagged population was tagged with high reward tags in year 1 of the study and this percentage was increased to 10 percent in year 2 to increase precision of reporting rate estimates. These high reward percentages were based on preliminary simulation studies that suggested these percentages were adequate to obtain reasonably precise estimates of fishing and natural mortality rates.

Largemouth Bass were collected, tagged, and released two times per year: February and November. Tagging in these two months when the water is relatively cool minimized tagging mortality by reducing stress on the Largemouth Bass. Two years of tagging were completed for a total of four release events at each reservoir. I attempted to tag a total of 1,000 bass at each lake during each release event for a total of 4,000 bass at each reservoir. I conducted two release events per year because increasing the number of release events increases the precision on natural mortality estimates. Largemouth Bass over 381 mm were tagged at Lake Guntersville, the minimum size limit on the lake, and over 305 mm were tagged at Lake Wheeler which has no minimum size limit. Many tournaments inforce a 305 mm self-imposed minimum size limit on the lake. Tagging fish at these minimum sizes or larger was chosen to reduce heterogeneity in capture probability related to fish size.

Field Operations

I tagged and released Largemouth Bass throughout each reservoir during each tagging event. Largemouth Bass were tagged with an individually numbered Hallprint, Inc. model PDAT© plastic tipped dart tag. This tag is 125 mm in length, is highly visible and has amble room for tag reporting instructions. Collection and release sites at each lake were selected to spread tagged fish throughout the reservoir in proportion to their abundance but also to complete the tagging efficiently in 8 to 10 sampling days per lake. Lake Guntersville was sampled from Guntersville Dam to the mouth of Mud Creek, including Mud Creek (Figure 1). Lake Wheeler was sampled from Wheeler Dam to the mouth of Limestone Creek, including Limestone Creek (Figure 2). Each lake was divided into sections of roughly equal surface area. There were 16 sections on Lake Guntersville each averaging 1,313 hectares and 13 sections on Lake Wheeler each averaging 1,143 hectares.

Largemouth Bass were collected by boat mounted electrofishing gear (7.0 GPP, 5-7 amps, pulsed DC) along the shoreline at each reservoir. Largemouth Bass were removed from the live-well, measured to the nearest millimeter (total length), tagged and released. Since the majority of black bass disperse less than 1.6 kilometers from release sites (Gilliland 2001; Wilde 2003), tagged Largemouth Bass collected from a given transect were released at multiple locations within each section. Pollock et al. (2001) recommended this approach to improve mixing of tagged individuals into the population. In year 1, two or three high reward tags were released in each section on Lake Guntersville and three or four high reward tags released in each section on Lake Wheeler. In year 2, these numbers were increased to six or seven on Lake Guntersville and seven or eight on Lake Wheeler. Both levels of tags were spread out within each section so that an angler was not likely to encounter multiple tags (Pollock et al. 2001). The tagger was unaware of which tags were high reward in order to remove tagging bias with respect to fish size. Largemouth Bass that appeared injured or diseased were measured and released, but not tagged.

Tag Reporting

Informational posters with instructions on tag reporting were placed at several boat landings and local tackle stores at each lake (Appendix A). I also placed posters at other reservoirs in northern Alabama (Neely Henry, Pickwick, Weiss, and Wilson Reservoirs) that did not receive tags in an attempt to prevent the attraction of fishing effort to the two study lakes. Each tag also contained information for tag reporting. Tags were reported either by email or telephone. Anglers reporting by email received an automatic response containing (1) a questionnaire to collect information on the capture (date, location, fate of the fish, etc.) and (2) instructions on how to collect the reward (Appendix B). Anglers reporting by telephone were asked to leave a message with their name, tag number, telephone number, and a good time to contact them. After all the information was collected, anglers were asked to mail the tag to the Auburn School of Fisheries, Aquaculture, and Aquatic Sciences in order to process the reward. Once a tag was received in the mail, an invoice was submitted to the finance department, who distributed the reward to the angler. Tag returns were collected for 24 months after the initial tagging event.

Tag Returns Analysis

I analyzed tag return data using Brownie models (Brownie et al. 1985) that have been modified for catch-and-release applications (Jiang et al. 2007). These models have become the standard method for these types of analyses. These models allow for tag outcomes to be separated into harvest and catch-and-release categories. I used an age-dependent model outlined by Jiang et al. (2007). I further modified this model by separating each year into quarterly recapture seasons each containing three months. The full model estimated seasonal (i.e., quarterly) harvest rates, fishery-specific (i.e. tournament, non-tournament) seasonal catch-and-release rates, sector-specific time-invariant reporting rates of standard tags, age-specific reporting rates, lake-specific natural mortality rates and age-specific capture vulnerabilities. Reporting rates were assumed to be the same at each reservoir. Largemouth Bass were assigned ages proportionally based on an age-length key generated from a concurrent age and growth study at both lakes (Feltz 2015). Largemouth Bass in this age and growth study were aged using sagittal otoliths.

The probability of a tag being reported was estimated as the product of survival, time period-specific capture rates, and the rate at which recaptured tags are reported by anglers (hereafter "reporting rate", λ). The survival rate (S) in Brownie models can be expressed in terms of instantaneous rates of harvest capture (F'_h), non-tournament catch-and-release capture (F'_{ntr}), tournament catch-and-release capture (F'_{tr}) and instantaneous natural mortality rate (M):

$$S = \exp(-F'_h - F'_{ntr} - F'_{tr} - M)$$

where the total instantaneous rate of tags removed from the system is the sum of F'_h, F'_{ntr}, F'_{tr} and M. The expected number of standard dollar tag returns from a fishery sector (c) (i.e. harvest, catch-and-release, tournament release) tagged and released at lake l and at age k in release period i and captured in recapture period j is

$$E(R_{cijk}) = N_{cik} P_{cijk} \ ,$$

where

$$P_{lcijk} = \left(\prod_{v=i}^{j-1} S_{lcivk}\right)\left(1 - S_{lcijk}\right)\frac{F'_{cj} Vul_{lk+j-i}}{Z_{lcjk}}\lambda_{ck} \quad \text{(when } j > i\text{)}$$

and

$$P_{lcijk} = \left(1 - S_{lcijk}\right)\frac{F'_{cj} Vul_{lk+j-i}}{Z_{lcjk}}\lambda_{ck} \quad \text{(when } j = i\text{)}$$

and N_{cik} is the number of fish tagged at each age k. Tag reporting rates (λ_{ck}) for standard tags were estimated as a logistic function of fishery sector, c, and age, k, via

$$\lambda_{ck} = \exp(\beta_0 + \beta_1(c) + \beta_2(k)) / (1+ \exp(\beta_0 + \beta_1(c) + \beta_2(k))).$$

Tag return probabilities of high reward tags used the same equations as above, except the reporting rate was assumed 1.0. Age-specific angling vulnerabilities (Vul_k) at each lake were estimated as free parameters within the model. The Brownie model estimates survival and tag recovery rates by fitting to the observed tag recoveries using a multinomial maximum likelihood function.

Tag returns from caught-and-released Largemouth Bass indicated the instantaneous release rate (i.e. F'_{ntr}, F'_{tr}), but not the rate of mortality (i.e. F_{ntr}, F_{tr}). Fishery-specific instantaneous capture (i.e. release) rates were transformed to finite capture rates (u'_c) by (Ricker 1975):

$$u'_c = F'_c*(1-S)/Z$$

where F'_c is a fishery specific capture rate, S is survival and Z is instantaneous total mortality. Tournament and non-tournament estimates of hooking mortality (CR_{tr} and CR_{ntr}, respectively) from the literature were multiplied by the respective release rates to estimate sector-specific release mortality rates. Hooking mortality of released non-tournament (CR_{ntr}) Largemouth Bass is generally considered to be close to 5% when artificial lures are used (Hayes et al. 1995). Largemouth Bass anglers generally restrict themselves to using only artificial lures, thus I assumed all non-tournament releases suffered 5% post-release mortality. Tournament mortality (CR_{tr}) estimates vary among studies and often related to water temperature (Wilde 1998). I used the equation:

$$TM = 0.1042 \times temp^{1.6831}$$

where TM is total mortality due to tournament weigh-ins and $temp$ is the water temperature in degrees Celsius (Wilde 1998). Average seasonal water temperatures (°C) are 11, 22, 30, and 21 for winter, spring, summer, and fall, respectively, for Lake Guntersville (McKee 2013). I assumed seasonal water temperatures to be the same at Lake Wheeler. Standard error for each seasonal CR rate was calculated using a coefficient of variation of 25%. Harvest mortality (F_h) and exploitation (u_h) were directly estimated by the tag returns from harvested fish.

The instantaneous natural mortality rate (M) was assumed constant over the course of the study, but was allowed to differ between lakes. Estimates of natural mortality can be unreliable even over long-term tagging studies (Pollock et al. 2004) and the preliminary results were high in this study ($M > 0.85$ yr^{-1}). Therefore, I estimated natural mortality with a penalized likelihood approach using a prior distribution from a combined telemetry-conventional tag return study ($M \sim$ normal distribution, $\mu = 0.37$, SD = 0.053; Kerns 2013). An additional model with M freely estimated was run to evaluate whether capture and reporting estimates changed using the prior distribution.

Multi-model Comparison

Multi-model comparisons using corrected Akaike's information criterion (AICc) evaluated relative empirical support for candidate models. I tested whether reporting rates differ among fisheries (harvest, non-tournament release, tournament release) and between ages. Additionally, I tested models that allowed for natural mortality to vary between lakes, for capture rates to vary among fishery sectors, lakes, and seasons and for angling vulnerability to vary among Largemouth Bass ages.

Results

A total of 3,885 Largemouth Bass were tagged at Lake Guntersville from November 2013 to February 2015 compared to 3,562 at Lake Wheeler during the same time period (Table 3). There were 280 high dollar reward Largemouth Bass released into each lake. Over the course of the 2 year study, 890 tags were reported as captured (22.9% of total tagged) at Lake Guntersville (Table 4). Of these reported recoveries, 13.6%, 73.4%, and 13.0% were reported as harvested, caught and released, or weighed-in at a tournament, respectively. There were 547 tags reported as captured (15.4%) at Lake Wheeler (Table 4) with 10.6%, 69.5%, and 19.9% being reported as reported as harvested, caught and released, or weighed-in at a tournament, respectively.

Multi-model selection using corrected Akaike's information criterion supported that there was no difference in natural mortality between lakes, angling vulnerability was age independent, reporting rates varied by fishery sector, but not by age, and capture rates varied by lake, sector, and season (Table 5). A total of 40 models were assessed, but only 34 of these models converged to give results. The top four models included capture rates that varied by lake, sector, and season. In addition, these top four models supported that angling vulnerability was independent of age.

Capture rates were generally higher at Lake Guntersville than Wheeler. Capture rates were highest in the spring and lowest in the winter at both lakes (Figure 3; Figure 4). The total annual finite capture rate on fully-vulnerable fish (u'_o) at Lake Guntersville was 0.561 (95% confidence interval [CI] = ± 0.111; Table 6; Figure 5) in year 1 of the study and 0.495 (± 0.087 CI) in year 2. The annual finite capture rate u'_o at Lake Wheeler was 0.458 (± 0.106 CI; Figure

5) in year 1 and 0.308 (± 0.057 CI) in year 2. Sector-specific estimates of capture rates at both lakes are found in Table 6 and Figure 5. At Lake Guntersville, 35% of the tagged fish were angled and immediately released in the non-tournament sector versus 23% and 21% at Lake Wheeler. In the tournament sector, 16% in year 1 and 10% in year 2 were caught at Lake Guntersville versus 21% in year 1 and 7% in year 2 were caught at Lake Wheeler. After applying CR rates to capture rates, total annual angling mortality u_o was 0.106 (± 0.038 CI) and 0.085 (± 0.027 CI; Figure 6) at Lake Guntersville. Total annual fishing mortality u_o was 0.078 (± 0.027 CI; Figure 6) and 0.054 (± 0.018 CI) at Lake Wheeler. Sector-specific estimates of fishing mortality rates are reported in Table 4 and Figure 6. In most cases, capture and mortality rates were higher in year 1 than they were in year 2. Harvest mortality contributed the most to the total fishing mortality at Lake Guntersville in both years of the study (Table 7). At Lake Wheeler, tournament release mortality in year 1 and harvest in year 2 contributed the most to the total fishing mortality.

Multi-model comparison suggested that annual instantaneous natural mortality was similar at both lakes, 0.462 (± 0.065 CI) and was assumed constant in both years of the study. When annual M was freely estimated, it was estimated at 0.856 (± 0.165 CI). Reporting rates were about 10% lower using the prior distribution from the telemetry study compared to the freely estimated M model. However, capture rates were not influenced by using the prior distribution on M.

Capture rates did not vary systematically as a function of fish age. The AICc comparisons strongly suggested all ages of Largemouth Bass were fully vulnerable to angling at both lakes. Thus, angling vulnerability was estimated at 1.0 for all age classes. Multi-model comparisons with AICc suggested each fishery sector had a different reporting rate (Table 6).

The reporting rate for the harvest sector λ_h was 0.488 (± 0.211 CI; Figure 7). Non-tournament catch-and-release λ_{ntr} was lower at 0.379 (± 0.052 CI). The tournament release reporting rate λ_{tr} was 0.152 (± 0.042 CI) and was significantly lower than the other two sectors. Multi-modal comparison suggested that reporting rates were not age-dependent.

Discussion

The results of this study are similar to other studies that have looked at Largemouth Bass capture rates. Finite capture rates were 46% and 31% at Lake Wheeler and 56% and 50% at Lake Guntersville. The Lake Wheeler rates were similar to what Driscoll et al. (2007) found at Sam Rayburn Reservoir, Texas where an estimated 38% of the tagged Largemouth Bass were caught per year. Lake Guntersville capture rates were higher than Lake Wheeler, but were still lower than what Fontaine (2009) found in two pools of the Arkansas River where the estimated that annual capture rates were 68.6% and 69.1% for pool 2 and pool 4, respectively. In two Florida lakes, Renfro et al. (1999) estimated annual capture rates were 56% and 57%. Also in Florida, Henry (2003) estimated total catch of Largemouth Bass at Rodman Reservoir at 42%. These rates are high enough to cause substantial population level mortality impacts if voluntary release rates are low or if post release mortality rates are high.

After applying literature-based post-release mortality rates, I found that total angling mortality was low (<10%) and generally consistent with other studies. Recent estimates of total angling mortality have been lower than historical estimates and reflect the trend of catch-and-release angling (Allen et al. 2008). Total angling mortality at both of the study lakes was low with estimates at 7.8% and 5.4% at Lake Wheeler and 10.6% and 8.5% at Lake Guntersville. These annual mortality rates are similar to other systems that have high rates of catch-and-release angling. In simulations with harvest exploitation set at 6%, Driscoll et al. (2007) predicted that total angling mortality would range from 7.3% to 10.8% at Sam Rayburn Reservoir. Total angling mortality was estimated at 23% in 1996 and 16% in 1997 at Norris Reservoir, Tennessee (O'Bara et al. 1999). In three Georgia small impoundments, Bonvechio et al. (2014) estimated total angling mortality to range between 13% and 30%. Although total capture rates were high in my study, harvest and catch-and-release mortality are low enough that the total population impact of recreational angling was low at these reservoirs.

The largest portion of the total captures at each lake was due to the recreational catch-and-release sector. An estimated 35% of the tagged bass were caught and released annually at Lake Guntersville and an average of 22% were caught and released at Lake Wheeler. These estimates are similar to Driscoll et al. (2007) who estimated that 27% and 5% of the tagged bass were caught-and-released and weighed-in during a tournament, respectively, at Sam Rayburn Reservoir. Most studies separate harvest angling from catch-and-release angling, but few have estimated separate rates for the tournament sector. Henry (2003) estimated that 31% of the bass were caught and released at Rodman Reservoir, Florida. This is lower than both years at Lake Guntersville (51% and 45%) and year 1 at Lake Wheeler (44%). Only 28% were caught and released at Lake Wheeler in year 2. However, the estimates of this study were lower than what Fontaine (2009) found at the Arkansas River where 55.3% and 57.1% were released in two pools. Capture and release rates vary among different bodies of water. Perceived fishing quality, human population density and number of alternative fishing sites can alter how much effort occurs at a body of water (Sullivan 2003). Lake Guntersville and Lake Wheeler both have a positive perception with the angling public (Keith Floyd, Alabama Department of Conservation and Natural Resources, personal communication), so angling effort is high at both of these lakes.

Harvest exploitation is one of the most studied fishery metrics and is of great interest to fishery managers. Early tagging studies were designed to only estimate exploitation of harvested fish. Annual harvest exploitation was 3%and 2% at Lake Wheeler and 6% and 5% at Lake Guntersville. Allen et al. (2008) estimated that nationwide exploitation averaged 35% from 1976 to 1989, but then decreased to 18% from 1990 to 2003. This shows the trend that black bass fishing has become more catch-and-release orientated. Slipke et al. (2003) estimated seasonal exploitation at Lake Wheeler ranged from 6% to 15% in springs of 2001 and 2002 and the fall of 2002. Driscoll et al. (2007) estimated the annual exploitation at Sam Rayburn to be 7%. Kerns et al. (2015) also estimated annual exploitation to be 7% in central Florida lakes. Fontaine (2009) estimated annual exploitation to be 11.5% and 13.8% in two pools of the Arkansas River. Additionally, Bonvechio et al. (2014) estimated average annual exploitation at 22% in three Georgia small impoundments. With high rates of catch-and-release angling occurring at both of the study lakes, it is not surprising to have estimates similar to the recent estimates at other lakes and lower than the results of Allen et al. (2008).

The mortality impacts of black bass tournament angling are of interest to many stakeholders. At Lake Guntersville, tournament mortality contributed 24.7% and 28.3% to the total angling mortality at the lake. In the first year of the study, Lake Wheeler tournament mortality contributed 55.6% to the total angling mortality, but was only 30.0% in year 2. Even though tournament angling contributed substantially to total angling mortality, tournament angling likely did not substantially effect the Largemouth Bass population because total angling mortality was low overall. Driscoll et al. (2007) estimated in their most realistic simulation that tournament angling mortality contributed 16% to the total angling mortality whereas non-tournament catch-and-release contributed 20%. They concluded that the impact of tournaments at Sam Rayburn Reservoir was low. In this study, the non-tournament catch-and-release sector contributed 20% and 16% at Lake Guntersville and 19% and 15% at Lake Wheeler. Edwards et al. (2004) concluded that tournament impacts on two Connecticut lakes were low. Allen et al. (2004) simulated the effects of tournament angling in the southeast United States. They predicted that tournaments could make a significant impact at lakes where tournament catch is substantially higher than harvest. To make a large impact on the population, rates of harvest exploitation would have to exceed 15% (Allen et al. 2004). With low rates of tournament and harvest exploitation at both study lakes, the population-level impact of tournaments is likely low.

The initial annual natural mortality estimate in this study was much higher than literature estimates. Therefore, I used an estimate of natural mortality from a previous telemetry study (Kerns 2013) to influence the natural mortality estimate. This studies instantaneous natural mortality estimate of 46.2% was largely influenced by the estimate of the Kerns (2013) telemetry study. Natural mortality rates are difficult to obtain for most fish species (Hoenig et al. 1998). In a review of mortality rates of Largemouth Bass, Allen et al (2008) estimated the average natural mortality to be 49%, but point estimates varied widely. Kerns et al. (2015) estimated natural mortality to be on average 40% across their study lakes in Florida. Natural mortality can also vary by Largemouth Bass size. Henry (2003) estimated 41%, 37%, and 29% for 356-379 mm TL, 380-509mm TL, and ≥ 510-mm TL, respectively. The high estimates for natural morality when it was not constrained by the prior in my study may have been due to anglers not recognizing the tags over time. Algae covered tags were reported by anglers and were discovered on subsequent electrofishing at the lakes. Therefore, the longer Largemouth Bass were at-large, the probability of a tag not being reported may have increased. The way for a Brownie model to account for this occurrence would be to inflate the natural mortality rate.

Capture rate estimates were similar regardless of whether *M* was freely estimated or estimated from the prior distribution. Thus, my capture rates appear insensitive to variation in the natural mortality rate.

The reporting rate for standard dollar tags differed among fishery sectors. Non-tournament anglers reported tags at a higher rate than tournament anglers. The estimates from the harvest and non-tournament catch-and-release sectors were similar to other reward tagging studies. Kerns et al. (2015) reported a 55% reporting rate for standard tags in their study. Bonvechio et al. (2014) had varying reporting rates from three Georgia small impoundments and ranged from 43% to 70%. In a tag study combined with a creel survey, Fontaine (2009) estimated a 42.1% reporting rate with tags that had no reward value posted on them. All of these studies did not separate reporting rates based on fishery sector. Commonly, only one reporting rate is estimated for all fishery sectors. This can have a significant effect on capture estimates if there are large differences in reporting rates between the fishery sectors. My analysis has demonstrated that under the sample sizes I encountered, sector-specific reporting rates were estimable. Future studies should attempt to estimate sector-specific reporting rates to avoid estimation bias. For example, tournament angling reporting rate was low in this study and would have biased the tournament capture rate estimates high if not estimated separately.

The assumption of 100% reporting rate for high dollar tags was likely violated in this study. I know of one instance in which a high dollar tag was caught during a televised professional bass fishing tournament. I confirmed that this tag was never reported because the angler’s name was mentioned on the telecast, and no high dollar tag reports were received from this angler. The $150 reward may not have been high enough to elicit 100% reporting by tournament anglers, especially those fishing for a substantially larger prize. I know of no other instances of failure to report high-dollar tags in my study, but I cannot completely rule out additional occurrences. If 100% of the high reward tags were not reported by tournament anglers, then there would be a negative bias in capture and mortality rates and a positive bias in the natural mortality estimate (Pollock et al. 2001).

Another important assumption of tagging studies is that tag loss and tagging mortality are either negligible or estimated and incorporated into the model. These assumptions were not violated in my study because capture estimates were adjusted based on tag loss and tagging mortality studies conducted at the E.W. Shell Experimental Research Station, Auburn, AL (Chapter II). However, the assumption of independence of individual fish was violated in this study. Of the 1,196 standard dollar tags reported, 2.7% were reported along with high dollar tags. Also, 5.7% of standard dollar tags were reported with other standard dollar tags. Pollock et al. (2001) suggested that anglers may have a tendency to collect standard dollar tags until they are worth reporting. This likely inflated the reporting rates in the study. Henry (2003) also encountered this problem at Rodman Reservoir, Florida. I tagged a large number of Largemouth Bass (1,000 per lake per tagging event) to facilitate precise estimation of capture rates stratified on a seasonal basis. However, because there were many tags at large in the system, there was an increased probability for anglers to encounter multiple tags.

Multi-model comparison did not support differences in angling vulnerability based on age. Of the models carrying 100% of the AICc model weight, none included age-specific angling vulnerability. Thus, angling vulnerability was set at 1.0 in this study meaning that all ages of Largemouth Bass were fully vulnerable to capture. In a previous Lake Wheeler study, Slipke et al. (2003) determined that anglers caught-and-released and harvested fish in proportion to the tagged population, thus selectivity was minimal. At Lake Eufuala, Alabama, anglers selected for slightly smaller fish than were present in the population for data collected from 1997 to 1999 (J. W. Slipke and M. J. Maceina, Auburn University, unpublished data). In a study of Chesapeake Bay Striped Bass, Jiang et al. (2007) determined that there was a moderate difference in vulnerability of younger Striped Bass versus older Striped Bass. When age data is available, the use of an age-dependent model should be considered since age vulnerability has the potential to play a role in reporting and capture rates.

Tagging studies should continue to be utilized by fishery managers and researchers to determine the effects of catch-and-release angling. This study estimated capture on a seasonal basis which was important because capture varied by season. To further expand this study, tagging fish below the minimum size limit could also be done, provided that an appropriate tag is used that doesn’t affect survival and mobility of the fish. This would allow researchers to estimate mortality on smaller fish before they recruit to legal size. In systems with a high capture rate, mortality of sublegal fish could be significant, particularly if these size/age classes are more vulnerable to angling than older/larger class.

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Tables

Table 1. Number of Largemouth Bass captured during seining at E.W. Shell Experimental Research Station and number of Largemouth Bass with lost tags in parentheses. Percent lost is in parentheses of the total column.

	Pond				
Day of Seining	1	2	3	4	Total
14	16 (0)	18 (0)	18 (0)	18 (0)	70 (0.0%)
27	17 (1)	15 (0)	16 (0)	5 (0)	53 (1.9%)
83	18 (0)	12 (0)	18 (0)	17 (1)	65 (1.5%)
182	13 (0)	14 (0)	14 (0)	12 (0)	53 (0.0%)
284	13 (0)	14 (0)	12 (0)	6 (1)	43 (2.3%)
365	15 (0)	15 (0)	12 (0)	12 (2)	54 (3.7%)
Total	92 (1)	88 (0)	90 (0)	70 (4)	340 (1.5%)

Table 2. Numbers of Largemouth Bass in tagging mortality research ponds at South Auburn Research Station. All ponds started with 15 fish each. All untagged Largemouth Bass in tagged ponds were recovered alive on day of seining. All tagged Largemouth Bass retained their tag for the duration of this study.

Pond Number	Pond Treatment	Number Tagged	Tagged Fish Recovered	Untagged Fish Recovered	Total Recovered
1	Control	0	0	15	15
2	Control	0	0	14	14
3	Control	0	0	15	15
4	Control	0	0	15	15
5	Control	0	0	15	15
6	Control	0	0	14	14
7	Control	0	0	14	14
8	Treatment	13	13	2	15
9	Treatment	9	8	6	14
10	Treatment	7	7	8	15
11	Treatment	9	9	6	15
12	Treatment	7	7	8	15
13	Treatment	13	13	2	15
14	Treatment	10	10	5	15

Table 3. Total number of Largemouth Bass tagged during each release event by lake and reward level (US$).

	Lake Guntersville		Lake Wheeler	
Release Event	$5	$150	$5	$150
November 2013	960	40	892	40
February 2014	960	40	960	40
November 2014	900	100	826	100
February 2015	785	100	604	100
Overall Total	3605	280	3282	280
	3885		3562	

Table 4. Number of tags reported as harvested (Harv), caught and released non-tournament (NTR), or tournament weighed and released (TR) at Lake Guntersville and Lake Wheeler. Year 1 of the study lasted from December 2013 to November 2014 and year 2 lasted from December 2014 to November 2015.

			Returns Year 1			Returns Year 2		
Lake	Reward	Tagging Year	Harv	NTR	TR	Harv	NTR	TR
Guntersville	$5	1	54	273	53	8	51	5
		2				40	236	32
	$150	1	5	22	7	0	1	1
		2				14	70	18
Wheeler	$5	1	21	154	55	7	24	0
		2				26	135	22
	$150	1	1	14	11	0	4	1
		2				3	49	20

Table 5. All converged models compared using corrected Akaike's information criterion. Models that did not converge are not included in this table. See Table 6 for model name definitions.

Model	Parameters	AICc	ΔAICc	Weight
M(.), λ(c), Vul(.), F(l*c*j)	52	12290.07	0	0.54
M(l), λ(c), Vul(.), F(l*c*j)	53	12292.09	2.02	0.20
M(.), λ(c+k), Vul(.), F(l*c*j)	53	12292.19	2.12	0.19
M(l), λ(c+k), Vul(.), F(l*c*j)	54	12294.21	4.15	0.07
M(.), λ(c), Vul(k), F(c*j)	40	12302.28	12.21	0.00
M(l), λ(c), Vul(k), F(c*j)	41	12303.03	12.96	0.00
M(.), λ(c+k), Vul(k), F(l*c*j)	65	12306.33	16.26	0.00
M(.), λ(c), Vul(k), F(l*c*j)	64	12307.59	17.52	0.00
M(l), λ(c+k), Vul(k), F(l*c*j)	66	12308.49	18.42	0.00
M(l), λ(c), Vul(k), F(l*c*j)	65	12309.69	19.62	0.00
M(.), λ(.), Vul(.), F(l*c*j)	50	12312.62	22.55	0.00
M(l), λ(.), Vul(.), F(l*c*j)	51	12314.47	24.40	0.00
M(l), λ(k), Vul(.), F(l*c*j)	52	12316.55	26.48	0.00
M(.), λ(c), Vul(.), F(l*$c_{tr=c_h}$*j)	36	12319.31	29.24	0.00
M(l), λ(c), Vul(.), F(l*$c_{tr=c_h}$*j)	37	12321.15	31.08	0.00
M(.), λ(.), Vul(k), F(c*j)	38	12321.68	31.61	0.00
M(l), λ(c+k), Vul(k), F($c_{tr=c_h}$*j)	34	12322.13	32.06	0.00
M(l), λ(.), Vul(k), F(c*j)	39	12322.61	32.54	0.00
M(l), λ(c), Vul(k), F($c_{tr=c_h}$*j)	33	12323.38	33.31	0.00
M(l), λ(.), Vul(k), F(l*c*j)	63	12331.46	41.39	0.00
M(l), λ(c+k), Vul(.), F(c*j)	30	12334.36	44.29	0.00
M(l), λ(c), Vul(.), F(c*j)	29	12336.98	46.91	0.00
M(.), λ(c), Vul(.), F(c*j)	28	12350.07	60.00	0.00
M(l), λ(c+k), Vul(k), F(l*j)	34	12435.45	145.38	0.00
M(l), λ($c_{ntr=c_h}$), Vul(.), F(l*c*j)	52	12437.01	146.94	0.00
M(.), λ($c_{ntr=c_h}$), Vul(.), F(l*c*j)	51	12450.21	160.14	0.00
M(.), λ(c), Vul(.), F(j)	12	12481.17	191.10	0.00
M(.), λ(c), Vul(.), F(l*j)	20	12849.82	559.75	0.00
M(l), λ(c), Vul(k), F(l*j)	31	13214.73	924.66	0.00
M(.), λ(c), Vul(.), F(l*c)	11	13224.94	934.87	0.00
M(.), λ(c), Vul(.), F(c)	7	13234.66	944.59	0.00
M(.), λ(c), Vul(.), F(l)	6	13294.37	1004.30	0.00
M(.), λ(c), Vul(.), F(.)	5	13355.07	1065.00	0.00
M(.), λ(.), Vul(.), F(.)	3	18048.17	5758.10	0.00

Table 6. Estimates and 95% confidence interval of highest weighted model according to corrected Akaike's information criterion (see Table 3).

Lake	Year	Parameter	Estimate	± Confidence Interval
Wheeler	1	u'_{h}	0.0231	0.0173
		u'_{ntr}	0.2283	0.0574
		u'_{tr}	0.2070	0.0879
		u'_{o}	0.4584	0.1063
	2	u'_{h}	0.0278	0.0158
		u'_{ntr}	0.2058	0.0433
		u'_{tr}	0.0739	0.0341
		u'_{o}	0.3076	0.0573
	1	u_{h}	0.0231	0.0173
		u_{ntr}	0.0114	0.0030
		u_{tr}	0.0433	0.0202
		u_{o}	0.0778	0.0268
	2	u_{h}	0.0278	0.0158
		u_{ntr}	0.0103	0.0023
		u_{tr}	0.0162	0.0081
		u_{o}	0.0544	0.0179
Guntersville	1	u'_{h}	0.0593	0.0342
		u'_{ntr}	0.3459	0.0744
		u'_{tr}	0.1561	0.0745
		u'_{o}	0.5613	0.1107
	2	u'_{h}	0.0465	0.0245
		u'_{ntr}	0.3488	0.0698
		u'_{tr}	0.1001	0.0450
		u'_{o}	0.4955	0.0866
	1	u_{h}	0.0593	0.0342
		u_{ntr}	0.0173	0.0039
		u_{tr}	0.0297	0.0152
		u_{o}	0.1063	0.0377
	2	u_{h}	0.0465	0.0245
		u_{ntr}	0.0174	0.0037
		u_{tr}	0.0212	0.0101
		u_{o}	0.0852	0.0268
Both	Both	M	0.4623	0.0651
		λ_{h}	0.4879	0.2107
		λ_{ntr}	0.3792	0.0515
		λ_{tr}	0.1526	0.0424

Table 7. Percent contribution of each fishery sector to total angling mortality by lake and study year.

	Guntersville		Wheeler	
	Year 1	Year 2	Year 1	Year 2
Harvest	55.8	54.6	29.7	51.1
Non-Tournament Release	16.3	20.4	14.7	18.9
Tournament Release	27.9	25.0	55.6	30.0

Table 8. Descriptions for common symbols used in chapter II and AICc table codes.

Symbol	Description
CR	Post-release mortality rate
λ_h	Harvest sector reporting rate
λ_{ntr}	Non-tournament release sector reporting rate
λ_{tr}	Tournament release sector reporting rate
S	Survival
F'_h	Harvest sector instantaneous capture rate
F'_{ntr}	Non-tournament release sector instantaneous capture rate
F'_{tr}	Tournament release sector instantaneous capture rate
M	Instantaneous natural mortality rate
Z	Instantaneous total mortality rate
u'_h	Harvest sector finite capture rate
u'_{ntr}	Non-tournament release sector finite capture rate
u'_{tr}	Tournament release sector finite capture rate
u'_o	Overall finite capture rate
u_h	Harvest sector finite mortality rate
u_{ntr}	Non-tournament release sector finite mortality rate
u_{tr}	Tournament release sector finite mortality rate
u_o	Overall finite mortality rate
M(.)	Natural mortality assumed equal at both lakes
M(l)	Natural mortality assumed different at both lakes
λ(.)	Reporting rate assumed equal for all ages and same for all sectors
$\lambda(c)$	Reporting rate assumed equal for all ages and different for all sectors
$\lambda(k)$	Reporting rate assumed equal for all sectors and different for all ages
λ(c+k)	Reporting rate assumed different for all sectors and all ages
$\lambda(c_{ntr=}c_h)$	Reporting rate assumed equal for non-tournament release and harvest sectors
Vul(.)	Vulnerability not estimated and assumed 1.0 for each age
Vul(k)	Vulnerability estimated for each age
F(.)	Capture rates equal for both lakes, all seasons, all sectors
F(l)	Capture rates different for both lakes, equal among sectors and all seasons
F(c)	Capture rates different among sectors, equal at both lakes and all seasons
F(j)	Capture rates different among seasons, equal at both lakes and among sectors
$F(l{*}c_{tr=}c_h{*}j)$	Capture rates equal for harvest and tournament release
$F(l{*}c{*}j)$	Capture rates different for both lakes, all seasons, all sectors
$F(c{*}j)$	Capture rates different for all seasons and all sectors, equal at both lakes
$F(l{*}j)$	Capture rates different for both lakes and all seasons, equal among sectors
$F(l{*}c)$	Capture rates different for both lakes and all sectors, equal among seasons

Figures

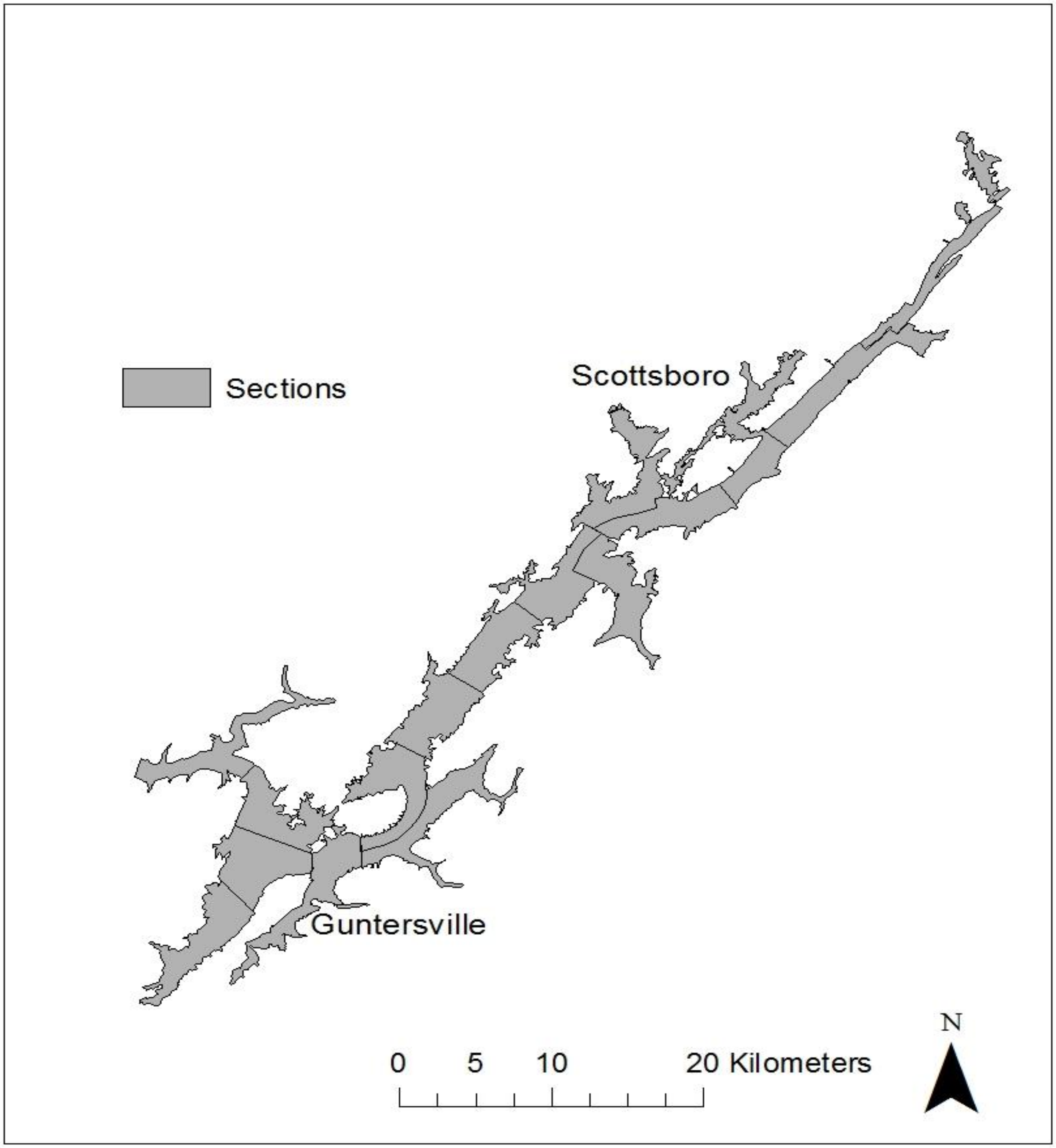

Figure 1. Sections sampled at Lake Guntersville, Alabama. Lake was sampled from the Guntersville Dam in the southwest to the mouth of Mud Creek in the northeast. Locations of cities are labeled.

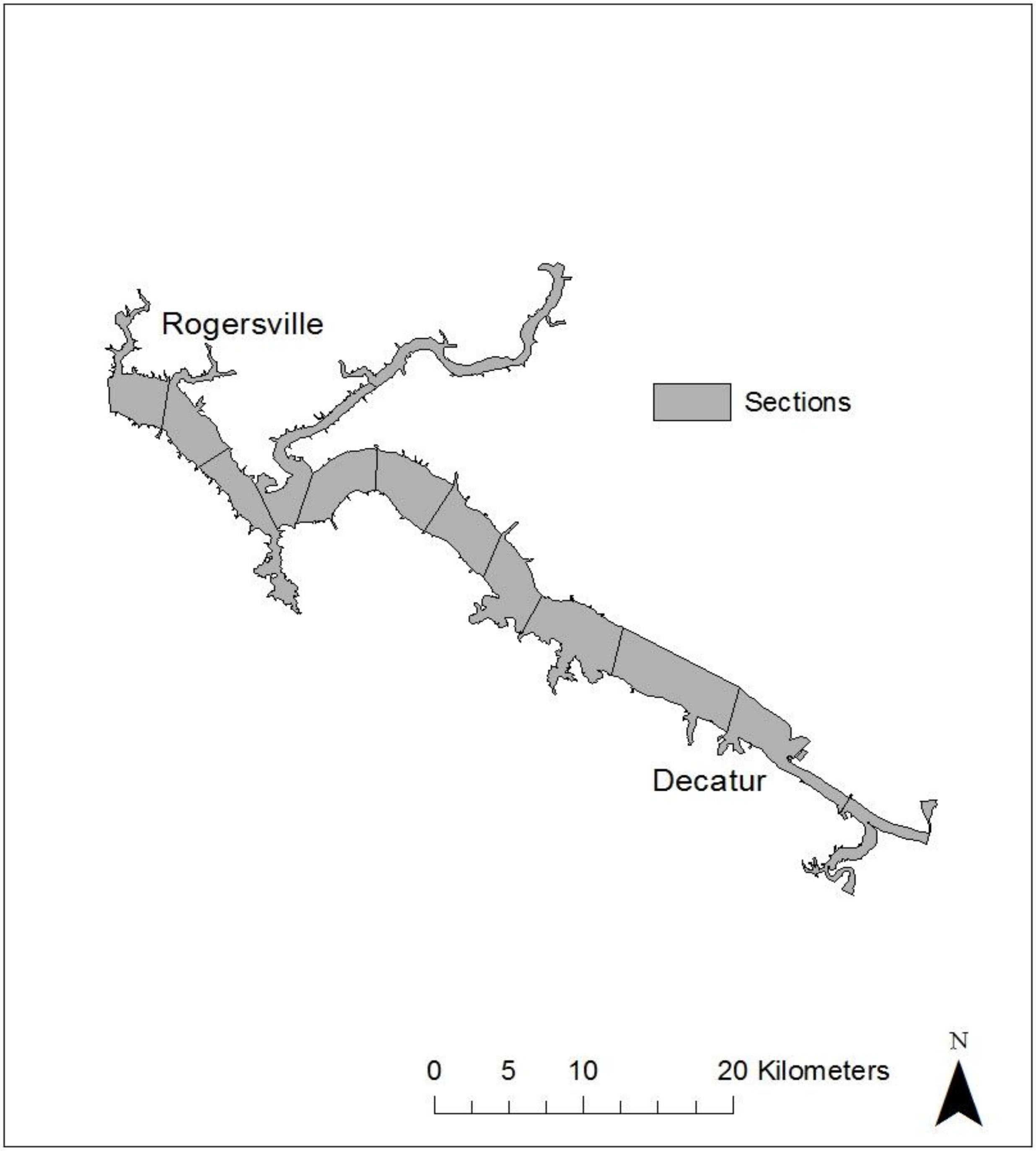

Figure 2. Sections sampled at Lake Wheeler, Alabama. Lake was sampled from the Wheeler Dam in the northwest to the mouth of Limestone Creek in the southeast. Locations of cities are labeled.

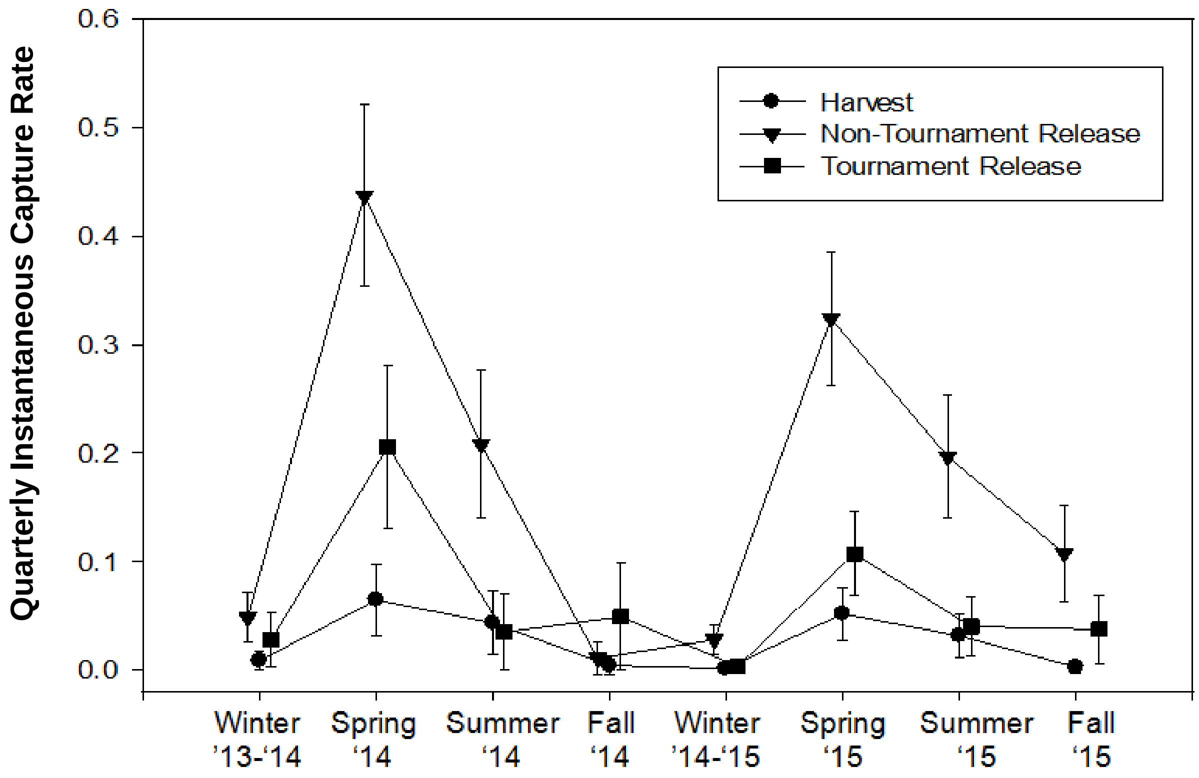

Figure 3. Seasonal instantaneous capture rates (*F'*) by fishery sector at Lake Guntersville with 95% confidence intervals.

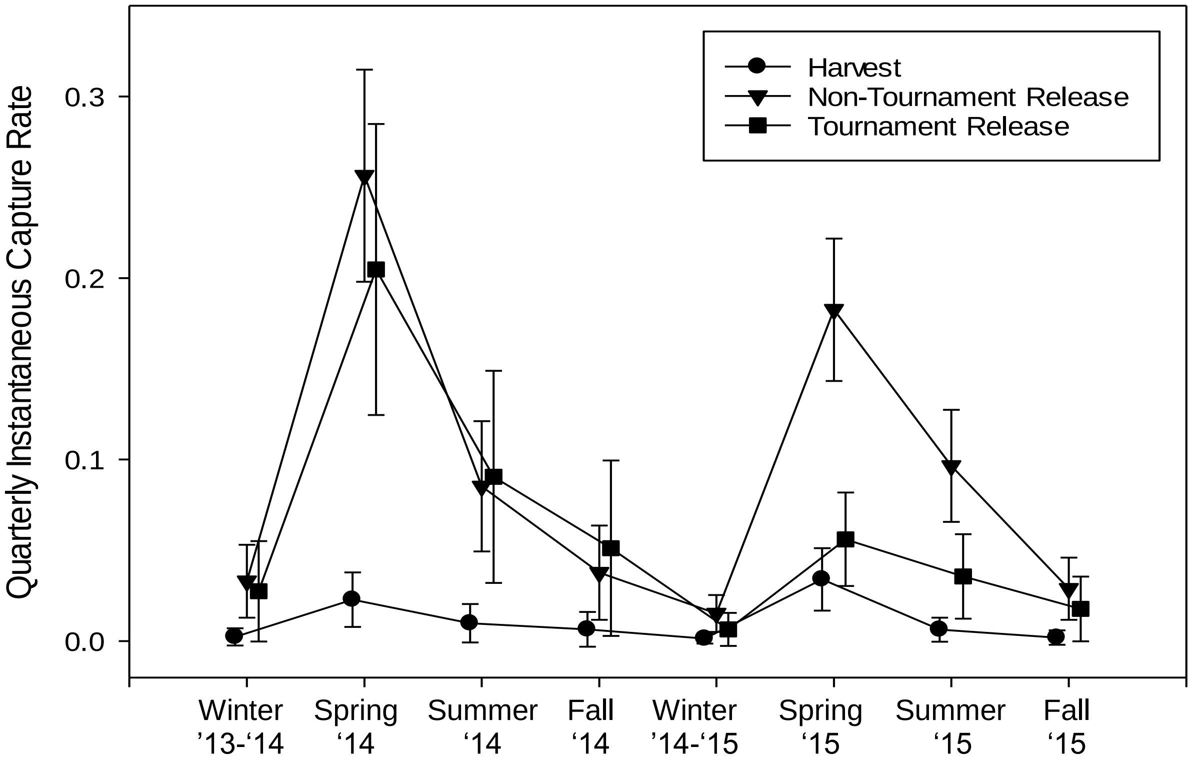

Figure 4. Seasonal instantaneous capture rates (*F'*) by fishery sector at Lake Wheeler with 95% confidence intervals.

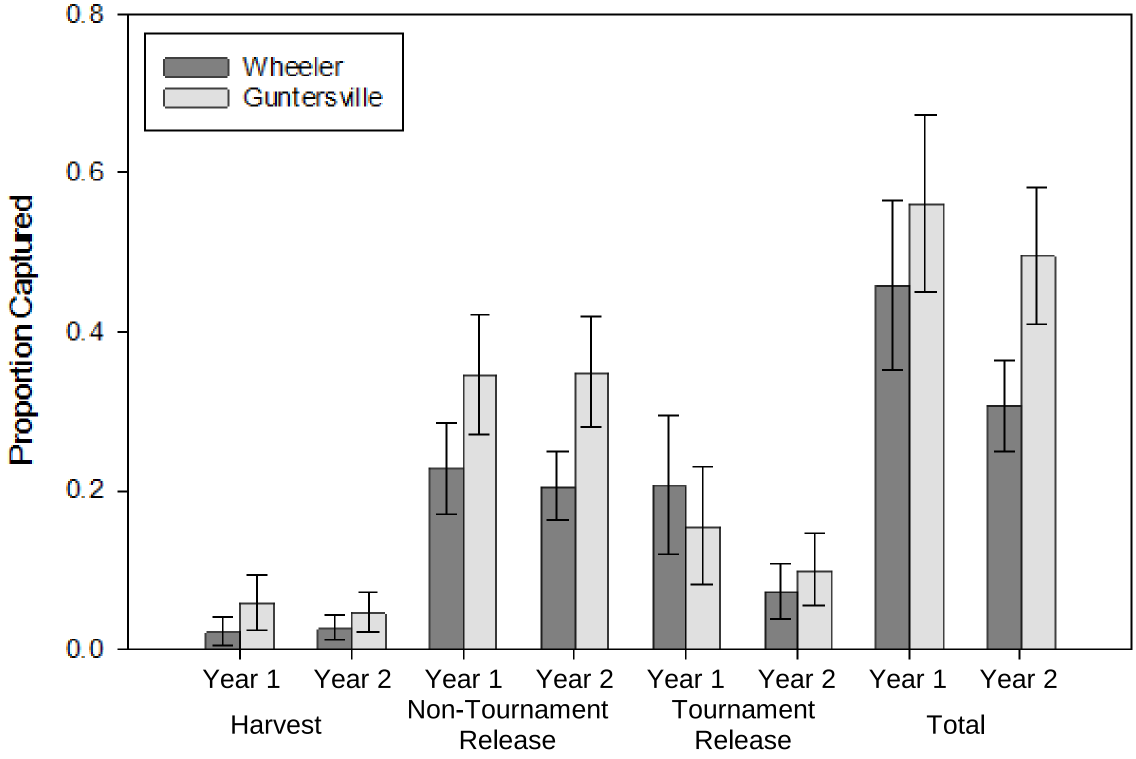

Figure 5. Annual finite capture rates (*u'*) by fishery sector and all sectors combined and by study year at Lake Guntersville and Lake Wheeler with 95% confidence intervals.

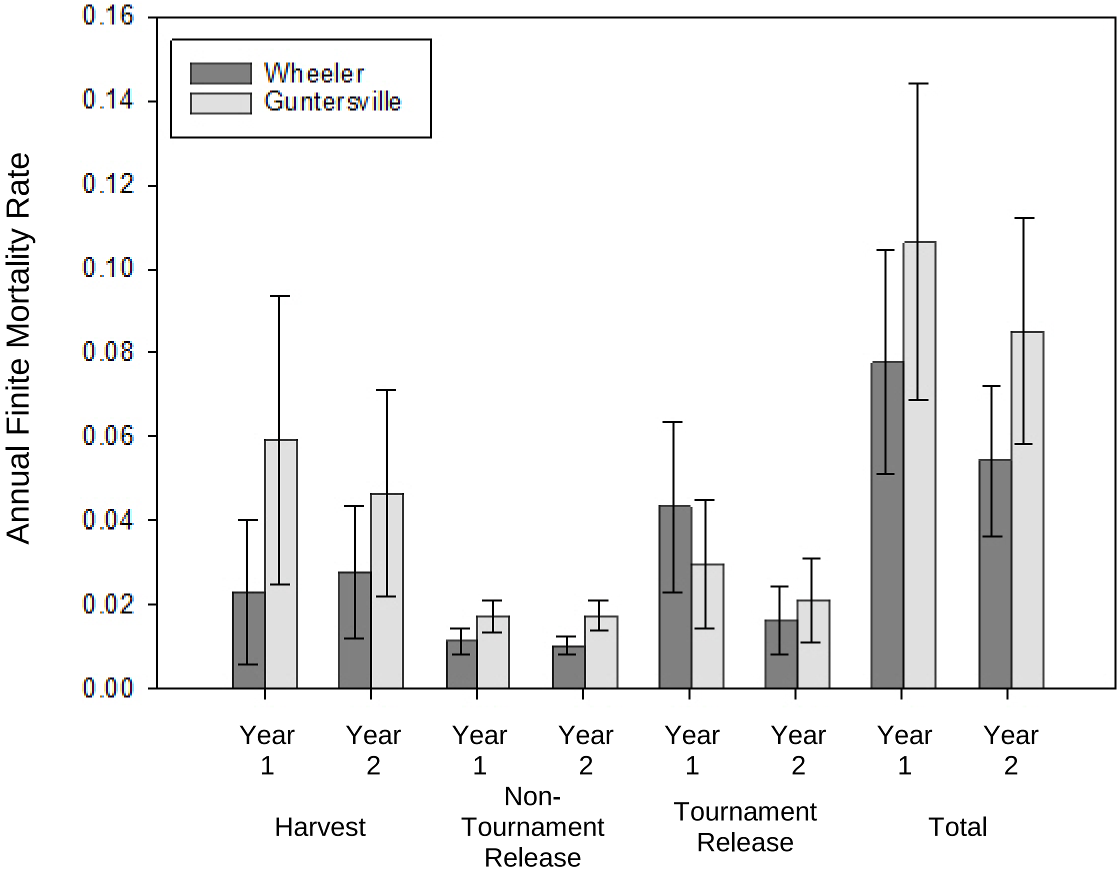

Figure 6. Annual finite mortality rates (*u*) by fishery sector and all sectors combined and by study year at Lake Guntersville and Lake Wheeler with 95% confidence intervals.

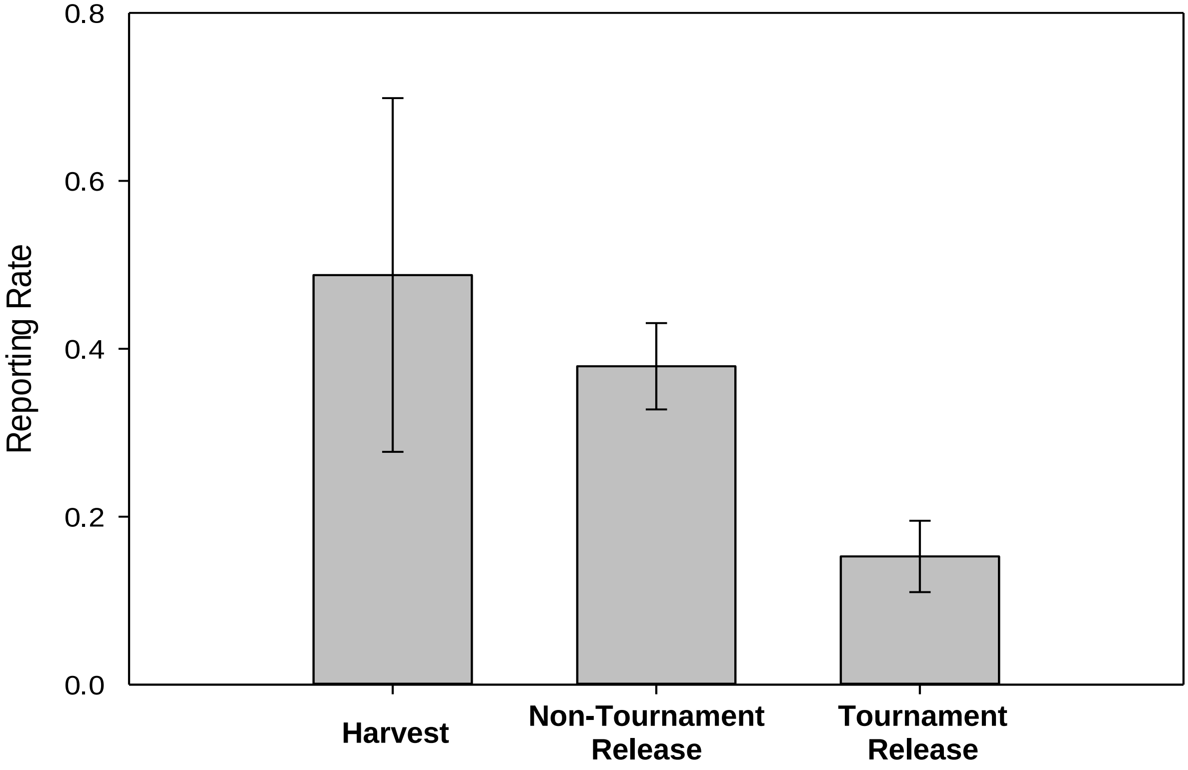

Figure 7. Reporting rates (λ) by fishery sector with 95% confidence intervals. Rates were assumed to be equal at both lakes.

Appendix A: Informational Poster

Bass Tagging Study

Tagged largemouth bass have been released into this lake. If you catch a tagged bass, keep the tag and report your catch, you will receive a cash reward.

If you catch a tagged bass, cut the tag off close to the fish and email the Tag Return Center at **fishtag@auburn.edu** or call **1-800-774-2847** and give the following information:
(*you must cut the tag off the fish and mail the tag to the address below to receive a reward*)

- Tag Number
- Date of Catch
- Kept or Released
- Catch Location
- Target species
- Fish Length
- Tournament Relation

Photo Courtesy of Florida FWC

Tag Return Center:
fishtag@auburn.edu
Hotline: 1-800-774-2847

Please provide your **name**, **address**, and **phone number**. All tag returns receive a cash reward.

Mail tag to:
Auburn Department of Fisheries
Attn: Jeff Buckingham
203 Swingle Hall
Auburn University, AL 36849

Appendix B: Automatic Email Response Form

Congratulations on catching a tagged bass! We appreciate you taking the time to return the tag. The fish was tagged as part of a study being conducted by the Fisheries Department at Auburn University and funded by the Alabama Department of Conservation and Natural Resources. There are two easy steps you will need to do before we can send you your reward.

Step 1: Please reply to this email and answer the following questions by typing your answer next to the question. It is important that this form be filled out COMPLETELY and emailed back to us.
*If content does not show up when replying, you may have to click the SHOW TRIMMED CONTENT button.

1. What is the tag number?:
2. What is the date of catch?:
3. The lake and general location of catch (creek name, landmark)?:
4. The estimated fish length in inches?:
5. Did you keep or release the fish?:
6. What would you have done with this fish (kept or released) had it not had a tag in it? (Examples below):

Example 1: If you were catch-and-release fishing but kept the fish only because you didn't have a tool to cut off the tag, then answer "released".

Example 2: If you were harvesting but released the fish only because you feared the tag damaged the meat, then answer "kept".

7. Was largemouth bass the species you were targeting?:
8. Was the fish caught during a tournament? If yes, was it culled, weighed in, or immediately released?:

9. Did you keep the tag?:
10. What is your name, address and phone number? (Used to mail reward and for questions):

NAME:
ADDRESS:
CITY:
STATE:
ZIP CODE:
PHONE NUMBER:

Step 2: Mail the tag to us at the following address:
Auburn Department of Fisheries
Attn: Jeff Buckingham
203 Swingle Hall
Auburn University, AL 36849

To process your reward, we must receive the completed information from step 1 above **AND** the tag (step 2). Failure to complete both steps will result in an unpaid reward. If you would like a prepaid envelope, we can send you one in the mail.