Mortality components for two *Micropterus spp.* in a Southeastern reservoir: a high-value reward and radio telemetry approach.

by

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Abstract

For black bass species (*Micropterus spp.*) post-release mortality rates are higher for tournaments than non-tournaments and may be a significant component of total fishing mortality. On Neely Henry Reservoir in Alabama there is concern that catch-and-release may be a substantial component of black bass mortality. In particular perceived high effort tournament angling could be causing high fishing mortality. To address this concern, I used a combined high-value reward and radio telemetry approach to partition mortality for Largemouth (*Micropterus nigricans*) and Alabama Bass (*Micropterus henshalli*) into harvest, non-tournament catch-and-release, tournament, and natural mortality. Anglers were incentivized by high value rewards to report angling captures, and manual telemetry searches were used to ascertain the survival status of fish. I present an analytical approach that builds on previous studies to incorporate misclassification of survival from radio tags, tag shedding, tagging mortality, and angler non-reporting. I found the relative magnitude of catch-and-release fishing mortality as a component of total mortality was 0.17 and 0.03 for Alabama and Largemouth Bass, respectively. Catch-and-release angling contributed 52% and 20% of total fishing mortality for Alabama Bass and Largemouth Bass respectively, indicating that different black bass species are subject to differential effects of recreational angling. I found the relative magnitude of catch-and-release fishing mortality as a component of total fishing mortality is considerable for black bass species in Neely Henry Reservoir. Results from this study are applicable to other freshwater sport fisheries and indicate that importance of incorperating catch-and-release mortality as a component of total when volunraty release is high.

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List of abbreviations

Symbol	Description
ALB	Alabama Bass
LMB	Largemouth Bass
F_{NT}	Instantaneous non-tournament mortality rate
F_{T}	Instantaneous tournament mortality rate
F_{h}	Instantaneous harvest rate
F_{CR}	Instantaneous catch-and-release mortality rate
F'_{NT}	Instantanous non-tournament capture rate
F'_{T}	Instantaneous tournament capture rate
u_{NT}	Finite non-tournament mortality rate
u_{T}	Finite tournament mortality rate
u_{h}	Finite harvest rate
u_{CR}	Finite catch-and-release mortality rate
u'_{NT}	Finite non-tournament capture rate
u'_{NT}	Finite non-tournament capture rate
$M_{\square}$	Instantaneous mortality rate
a_{NT}	Post-release non-tournament mortality
a_{T}	Post-release tournament mortality
m_{a}	False suvial (dead fish coding alive)
m_{d}	False mortality (alive fish coding dead)
$meanp_{\square}$	Logit scale mean detection probabity
sd$p$	Logit scale variation in monthly detection probability
vr$_{\square}$	Probability of voluntart release
$S_{\square}$	Survival probability
$TL_{\square}$	Tag shedding
$TM_{\square}$	Tagging mortality
$Z_{\square}$	Instantaneous total mortality
$\lambda_{NT,\$100}$	Reporting rate of \$100 tags caught not in a tournament
$\lambda_{NT,\$200}$	Reporting rate of \$200 tags caught not in a tournament
$\lambda_{T,\$100}$	Reporting rate of \$100 tags caught in a tournament
$\lambda_{T,\$200}$	Reporting rate of \$200 tags caught in a tournament
$F'(4)$	Seasonal capture probabilies
$F'(2)$	High and low effort season capture probabilities
$F'(\%)$	Capture probability with telemetry period as a random effect
$F'(*)$	Capture probability with telemetry period as a fixed effect
F'(c)	Capture probability as constant
$M(c)$	Natural Mortality is constant for each species
$M(\%)$	Natural Mortality as a random effect with variation equal between species
λ(c)	Equal reporting rate between angling sectors
λ(s)	Different reporting rate between angling sectors
a_{T}(c)	Tournament effect equal between species
a_{T}(s)	Different tournament effect between species

Introduction

Over the past three decades recreational angling for some fish stocks in North America have shifted from harvest oriented to catch-and-release (Allen et al. 2008; Myers et al. 2008; Isermann et al. 2013). Reflective of the shift to catch-and-release angling voluntary release rates for some species historically targeted for consumption are now more than 90% (Gaeta et al. 2013). The shift to catch-and-release reflects stakeholders' desire to improve angling quality and conserve natural resources. Compared to harvest-driven angling, catch-and-release reduces fish mortality, increases fish abundance, and increases the probability of catching trophy fish (Clark JR 1983; Allen et al. 2008). Adoption of catch-and-release has coincided with decreased harvest mortality for freshwater sportfish in North America. For example, Allen et al. (2008) reported that harvest-only fishing mortality of Largemouth Bass (*Micropterus nigricans*) decreased by roughly 50% between 1976 and 2003 indicating that trends from consumptive to catch-and-release angling have reduced fish mortality dramatically. Like Allen et al. (2008), many fisheries models assume that catch-and-release mortality is inconsequential compared to harvest and is ignored. As voluntary release rates increase, we expect catch-and-release mortality to be larger component of total fish mortality. In fact catch-and-release mortality could exceed harvest mortality in fisheries with catch-and-release rates close to 100% (Myers et al. 2008). Previous research has shown catch-and-release mortality to be a significant component of fishing mortality when voluntary release rates are high. Kerns et al., (2015) found that catch-and-release mortality contributed up to 18-20% of total fishing mortality in a Florida Bass fishery. Catch-and-release angling is attributed to 35% of total fishery-related mortality for Common Snook in Florida despite post-release mortality being relatively low (3%) (Muller and Taylor 2006). When voluntary release rates are high, we can expect including catch-and-release mortality as a componet of fishing mortality to be most important.

Tournament angling

There is a growing concern among fishery managers that increases in tournament angling effort may affect angling quality. Tournament angling differs from non-tournament angling by adding competition for prizes that often incentivize targeting larger fish. To mitigate negative population-level effects of tournaments many recreational fishing tournaments require live-release; however, fish caught in tournament are often subject to additional stressors that increase mortality compared to non-tournaments (Suski et al. 2004). For many species, fish caught in tournaments are kept in a livewell and weighed in later. The distance between where a fish is captured, and where it is weighed-in can be large. Weigh-in processes add aditional stress to fish compared to those caught in non-tournaments (Suski et al. 2004). Post-release mortality has been show to be higher for fish caught in tournaments than non-tournaments (Muoneke and Childress 1994). To mitigate negative effects of tournament angling technologies have been implemented to reduce post-release mortality of tournament angled fish; however, these have been largely ineffective (Wilde 1998).

Catch-and-relase mortality can be difficult to partition from other mortality sources. Research investigating the population-level effects of tournament angling have had mixed results. Hessenauer et al. (2018) found that high levels of tournament angling alone may influence population size structure. However, Sylvia et al. (2021) found that the population-level effects of tournament and non-tournament mortality are minimal compared with natural mortality. It is unclear if discrepancies around the population-level effects among studies result from variation in study areas, or the difficulty in estimating catch-and-release fishing mortality. Population-level effects of catch-and-release angling are expected to be largest in catch-and-release driven fisheries with high post-release mortality rates; however, catch-and-release angling can be a substantial component of fishing mortaltiy even if post-release mortality rates are low (Muller and Taylor 2006).

Black bass species (*Micropterus spp.*) are the most recreationally targeted fish genus in the United States with nearly ten million anglers targeting black bass in 2016 (US Fish & Wildlife Service, 2018). Black bass are the most targeted fish genus by tournament anglers as well (Schramm Jr et al. 1991). The popularity of black bass as an angling target makes them an economically valuable sportfish. There has been a substantial increase in the popularity of catch-and-release angling of black bass species, and voluntary release has been observed as high as 99% (Myers et al. 2008; Isermann et al. 2013). There is concern that increases in the popularity of catch-and-release angling could contribute to high fishing mortality. Catch-and-release mortality for Largemouth Bass is highly variable and has been found to range from 3-38% (Muoneke and Childress 1994). Variation in estimated post-release mortality is high across studies, as are the predicted population-level effects of catch-and-release angling. Because of the variation in post-release mortality estimates across locations, system-specific black bass post-release mortality estimates may be necessary to best manage populations.

Many southern bass fisheries are mixed species where anglers target more than one member of the same genus. Previous research suggests that different species within the same genus have different stress responses (White et al. 2008; Pottinger 2010). Differing stress responses could contribute to different post-release mortality rates. Additionally, different *Micropterus* species select different habitat types (Miranda et al. 2021). Differences in habitat selection may allow anglers to target one species by fishing in certain habitats. Implications include tournament anglers targeting species that reach larger size. Conversely, non-tournament anglers may target species for other characteristics such as aggression.

Because of the importance of black bass fisheries and the potential for negative effects of catch-and-release angling, further research is needed on the relative magnitude of catch-and-release mortality. Mixed species black bass fisheries would benefit from an understanding of the relative magnitude of fishing associated mortality between species. If catch-and-release angling is assumed to be inconsequential, fisheries managers may underestimate total fishing mortality. Information regarding the contribution of catch-and-release angling to total mortality would aid managers in implementing strategies to protect stocks that may be more vulnerable to angling pressure.

Goals and Study Questions

The goal of this study was to estimate the total catch-and-release fishing mortality from tournament and non-tournament angling on Neely Henry Reservoir, Alabama. I aimed to improve knowledge on catch-and-release angling as a component of fish mortality. To accomplish the goal of this project, I addressed the following questions for Largemouth Bass and Alabama Bass (*Micropterus henshalli*).

1. What is the total tournament and non-tournament catch-and-release mortality rate for black bass species?
2. Do annual capture probabilities differ between species?
3. What are the tournament, non-tournament catch-and-release, and harvest exploitation rates for Largemouth Bass and Alabama Bass?
4. Does total annual mortality differ between species?

5. How do annual mortality components compare between species?
6. What is the relative magnitude of all mortality components?
7. Does catch-and-release mortality exceed harvest mortality?

Study Area

Neely Henry Reservoir is a 4,500-hectare impoundment and is the second reservoir on the mainstem Coosa River in Northeast Alabama. Neely Henry Reservoir is a eutrophic reservoir with an average depth around 11 ft (ADEM 2005). Anglers on the reservoir primarily target Largemouth Bass and Alabama Bass. The upstream portion of Neely Henry Reservoir is run of the river, while the downstream portion incorporates large creek arms (Figure 1; Figure 2). Reliable estimates of angling effort do not exist for Neely Henry Reservoir, but angling pressure is thought to be relatively high. Boozer et al. (2019) found that there were 143 angling tournaments in 2017, with 8,490 participating anglers. Given the considerable number of yearly angling tournaments the Alabama Department of Natural Resources (ADCNR) is concerned that catch-and-release mortality from angling tournaments may be a substantial component of adult fish mortality. Total annual mortality from catch-curve analysis is estimated to be 40% and 41% for both Alabama and Largemouth Bass respectively (Holley et. al. 2016). Anglers and biologists believe that angling effort is much lower upstream of Ferry Park than the rest of the reservoir. Because angling effort in this region is believed to be low, it was excluded from my study and is not included in figures 1-4.

Methods

I used a combined high value reward and radio telemetry approach to partition adult mortality components for Largemouth Bass and Alabama Bass. High value rewards were used to determine fish capture history, and radio-transmitters were used to assess survival status.

Combined high-value reward and radio-telmetry tagging studies are an effective approach to estimate different sources of fish mortality (Hightower and Harris 2017). This approach has been used for *Micropterus nigricans* (Kerns et al. 2016), *Morone saxatilis* (Harris and Hightower 2017), and *Sciaenops ocellatus* (Bacheler et al. 2009). Combining radio telemetry and high value rewards facilitates the estimation of catch-and-release mortality for fish that have been captured and released previously and therefore no longer can be observed as captured (Hightower and Harris 2017). My analysis builds on previous studies by allowing for angler non-reporting of angling capture and misclassification of radio-tagged fish survival status.

Sampling methods

Alabama Bass and Largemouth Bass were captured and tagged using boat mounted electrofishing in January-February 2022, December 2022-January 2023, and May 2023. Electrofishing was conducted at one hundred randomly-selected 1.6 km shoreline sites for both of the January-February 2022 and December 2022-January 2023 sampling periods. After the 100 sites were all sampled, sites were revisited to increase the number of Alabama Bass tagged. Eighteen randomly-selected sites were sampled in May 2023, and none of them were revisited. A Midwest Infinity control box that produced 12-15 peak amps was used. One net operator collected fish from the bow of the boat. All captured Alabama Bass and Largemouth Bass over 300 mm were placed into an aerated live well until the entire site had been sampled. Sampling was stopped to process fish mid-site to avoid live well crowding in rare instances when catch rates were high. I avoided tagging more than ten fish per species per site, although this was violated on several occasions to increase sample size (Figures 1-4).

Tagging was stratified by fish length, and I attempted to tag 66 fish in each of six 50 mm length bins from 300-600 mm. Once bin specific tagging goals were achieved, subsequent sizes were released. I was unable to fill all length bins in both years, so I tagged more fish in filled length bins to achieve the target number of fish tagged (400 fish per species per year). Every fish above 300 mm was tagged with a high value external dart tag manufactured by (Hallprint Inc. model: PDAT; length: 120 mm; color: yellow). Tags and tagging equipment were sterilized in a 2% chlorohexidine solution prior to tag insertion. Tags were inserted between the second and third pterygiophores on the left side of the fish at a 45-degree angle. These dart tags read "CLIP TAG AND CALL XXX-XXX-XXXX FOR REWARD" to instruct the angler to remove the tag, call a phone number, and receive the reward value specified on the tag. Fish were tagged with $100, $200, and $300 reward levels. Every third fish was tagged with a second external dart tag of the same value inserted between the sixth and seventh pterygiophores on the left side of the fish, with the exception that May 2023 fish were tagged with a single external dart tag only to minimize stress response in higher water temps. Tag rewards were paid on a per-fish basis and thus double rewards were not paid for double tagged fish. This policy was communicated to anglers on signage placed at every public boat ramp on the reservoir, on the project website, and verbally to anglers during stakeholder meetings and when encountered on the reservoir.

Fifty fish of each species were surgically implanted with a radio transmitter in January-February 2022 (hereafter referred to as 2022). We opted to use coded tags for fish tagged in December 2022-January 2023 (hereafter referred to as 2023) allowing us to conduct manual searches for more fish. In 2023 we increased the number of radio-tagged fish to 75. All radio transmitters were model F-185 manufactured by Advanced Telemetry Systems (Isanti, Minnesota). Standard VHF (Very High Frequency) transmitters with a 24-hour mortality switch were used in 2022. Transmitters sent a distinct signal indicating mortality if a tag remained motionless for a period greater than its switch. If movement was later detected, the tag would reset to send a normal signal. VHF transmitters with an 8-hour switch were used in 2023 after multiple fish that were believed to be dead indicated survival. Use of a mortality switch differs from the typical movement-based approach of assessing mortality. Previous studies conclude that a fish has died based on consecutive detections of a fish at the same location (Kerns et al. 2015, 2016; Harris and Hightower 2017). This approach requires determining a precise location for each individual fish on multiple occasions. With the mortality switch approach, only one detection is needed to determine survival making it more appropriate for larger systems. Additionally, black bass species can display a sedentary nature making survival based on movement difficult to determine.

All fish over 350 mm in total length were eligible for radio transmitter implantation. Fish were selected at random and sedated in a 250-ppm carbon dioxide solution created from mixing acetic acid and sodium bicarbonate (Marking and Meyer 1985). Fish were kept in the anesthetic until they were unable to maintain equilibrium. Reaction to touch stimuli was assessed using a caudal pinch. If fish did not react to stimuli, they were placed onto a surgical board where water was constantly run through the fish's gills. Radio transmitters were inserted into the body cavity through a 20 mm incision that was made anterior to the fish's vent. The trailing antenna of the transmitter was fed through a piercing of the abdomen just posterior to the main incision. Two sutures were used to close the wound with a 30 mm 3/8c reverse cutting needle and 3-0 ethilon poyamide 6 non-absorbing sutures manufactured by Ethicon LLC. Surgical adhesive manufactured by VetOne was applied liberally to the wound. All radio-transmitters were verified to be in working condition prior to implantation.

Angler Reporting

Anglers who caught a tagged fish were instructed by text on the tag to call a phone number to receive a reward. The reward value ($100-300) was printed on the tag, so the angler knew the reward value upon capture. Instructions on how to report angler captured fish were also communicated by high visibility signs at all public boat ramps. I collaborated with local tournament organizers and the Neely Henry Lake Association to advertise the reward tagging program. The angler reporting hotline was monitored from 8 am to 8 pm central time 7 days a week. If anglers called after hours, they were instructed to leave a voicemail and were called back the next day.

Anglers that called the hotline were asked to complete a brief phone survey. Information recorded included: the tag number of the fish, the date, time, and location of capture, if the fish was kept or released, the reason for releasing or harvesting the fish, if the fish was caught in a tournament or non-tournament, and if the fish was weighed in at a tournament. After completing the phone survey anglers were emailed detailed instructions on how to claim their reward. Anglers were instructed to mail the tag(s) to Auburn University prior to payment. Anglers who caught fish with two external dart tags were asked to remove both tags.

Radio Telemetry

Monthly manual searches beginning in March 2022 were to monitor the survival status of radio tagged that were tagged in the winter of 2021-2022 (2022 fish). Manual searches for 2022 fish were conducted from boats using an R4000 receiver manufactured by Advanced Telemetry Systems. The date and time of detection was recorded and compared with angler reporting data to determine the capture status of all fish. If fish with radio transmitters were harvested or if the transmitter was destroyed, I ceased searches for that fish. Survival was indicated by a 35-pulse per minute signal for 2022 fish, while a 70-pulse per minute signal indicated fish mortality. Searches for 2022 fish were stopped in the spring of 2023. Bi-weekly searches were conducted for fish tagged in the winter of 2022-2023 (2023 fish). A similar approach was used in 2023, but an R4500C receiver was used to decode the transmitter's individual ID and the survival status of the fish. Using coded tags increased the speed I was able to conduct manual searches, allowing for more frequent telemetry events. Searches for 2023 fish were stopped in March of 2024.

Analytical Methods

I used an integrated mark-recapture model to estimate capture and mortality rates for tagged Alabama Bass and Largemouth Bass. Information from angler reported captures was used to create an observed capture history for each fish. Observed survival history was incorporated into the model for fish that also had a radio transmitter. Multinomial counts were used for capture histories of fish without a transmitter. State uncertainty exists from angler non-reporting, tag shedding, and survival misclassification from tags. Many previous studies using combined high value reward and radio telemetry multi-state models have assumed no misclassification in survival, no tag shedding, and 100% reporting of reward tags (Hightower et al. 2001; Kerns et al. 2016; Hightower and Harris 2017). To relax these assumptions, I used a multi-event model. The multi-event model is an extension of the multi-state model and allows uncertainty in state assignment (Pradel 2005). Individual based capture histories were used for fish with radio tags.

Accounting for tag shedding is important in any tagging study (Arnason and Mills 1981). To estimate external tag shedding I double tagged approximately 1/3 of all fish with a second high value reward. External tag shedding rates were informed by the rate double-tagged fish were reported by anglers as having only one tag upon capture. Individual tags were assumed to be lost independently of each other. External tag shedding, angler reporting, and capture rates were assumed equal for external tagged only fish and fish that had a radio tag.

In addition to tag shedding, fish may lose their marks by being caught and having their tag(s) removed. As the number of fish captured increases, the number external tags decrease regardless of if fish are released or harvested. To account for the loss of tags from capture and natural mortality the finite survival of tags (S') is modeled separately from true finite survival of fish (S). The instantaneous rate of angling capture (F') is sum of the instantaneous rate of tournament capture (F_T') and non-tournament capture (F_{NT}'). Non-tournament capture is comprised of instantaneous catch-and-release (F_{NTR}') and harvest (F_h) rates. The relationship between the finite survival of tags and instantaneous mortality of tags (Z') can be defined as

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

where

$$Z' = F' + M$$

and M is the instantaneous natural mortality rate of tagged fish.

Instantaneous fishing mortality (F) is defined as

$$F = F_{CR} + F_h$$

where F_{CR} is the instantaneous catch-and-release mortality rate and F_h is the instantaneous harvest rate. F_{CR} is comprised of the instantaneous non-tournament catch-and-release (F_{NTR}) and tournament (F_T) mortality rates. F_{CR} can be expressed mathematically as

$$F_{CR} = F_{NTR} + F_T.$$

Both F_{NTR} and F_T are the products of the instantaneous rate of capture for each sector (F_{NT}' and F_T'), voluntary release (vr), and the post-release mortality rate for each sector (a_{NT} and a_T). The instantaneous catch-and-release mortality rate for non-tournaments and tournaments is expressed as

$$F_{NTR} = F'_{NTR} * a_{NT}$$

and

$$F_T = F'_T * a_T$$

respectively. F_h is defined as

$$F_h = F_{NT}(1 - vr).$$

The relationship between the finite annual survival of fish (S) and the instantaneous mortality of fish (Z) is defined as

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

where

$$Z = F_{CR} + F_h + M.$$

The annual finite survival of tags (A') and of fish (A) are expressed as

$$A' = 1 - S' \text{ and}$$

$$A = 1 - S.$$

The finite annual angling capture rate (u') is defined as the ratio of the number of angler-captures to the population size at the time of tagging:

$$u' = \frac{F'}{Z} * A$$

The finite annual non-tournament capture rates (u'_{NT}) and the finite annual tournament capture rate (u'_T) are defined as

$$u'_{NT} = \frac{F'_{NT}}{Z} * A$$

and

$$u'_T = \frac{F'_T}{Z} * A.$$

Annual fishing exploitation (u), harvest exploitation (u_h), non-tournament catch-and-release. exploitation (u_{NTR}), tournament exploitation (u_T), and total catch and release exploitation (u_{CR}) are defined as the proportion of fish dying from each cause:

$$u = \frac{F}{Z} * A,$$

$$u_h = \frac{F_h}{Z} * A,$$

$$u_{NTR} = \frac{F_{NTR}}{Z} * A,$$

$$u_T = \frac{F_T}{Z} * A,$$

and

$$u_{CR} = \frac{F_{CR}}{Z} * A.$$

The relative magnitude of any mortality component as a source of mortality was determined by the proportion of total mortality attributed to that component. For example, the relative magnitude of tournament mortality ($u_{T^{mag}}$) is expressed as

$$u_{T^{mag}} = \frac{u_T}{A}.$$

Similarly, the relative magnitude of any fishing mortality component as a source of total fishing mortality was determined by the proportion of total fishing mortality attributed to that component.

High value rewards without radio transmitters

Externally tagged fish without radio-transmitters were observed as either caught-and-released in a tournament, caught-and-released not in a tournament, or as harvested (Table 1).

Additionally, double-tagged fish can be observed as captured with one or two tags. The probability of an angler tag return is a product of the tag surviving to time j, the probability of external tag shedding (TL),the fish being captured, and the fish being reported by the angler (λ). The Brownie model is expanded to include the tag return probability from a fish tagged as

$$\left(\prod_{v=i}^{j-1} S'_v\right)(1 - TL) * F'_j * \frac{1 - S'_j}{Z'_j} * \lambda_{\$100} \quad \text{when } j > i$$

$$(1 - TL) * F'_j * \frac{1 - S'_j}{Z'_j} * \lambda_{\$} \quad \text{when } j = i$$

where *i* is the occasion of tagging, $\lambda_{\$}$ is the angler reporting rate of a tag of a given reward value, and subscript *j* represents the period of recapture (Brownie et al. 1993; Polluck et al. 2001; Jiang et al. 2007; Bacheler et al. 2009).

Period-specific (period between telemetry events) tag return probabilities were stored in an array called *omega* with dimensions equal to the number of possible tag combinations (i.e., double- or single-tagged fish; n=2), number of reward levels (n=3), number of species (n=2), number of time periods in the study (n=34), and the number of possible observed states (n=6). Fish that are not reported as caught during period *j* are not observed. As an example, the expected number of Alabama Bass tagged with two $100 tags in period 1 that are reported as captured in a tournament with one tag in period 5 is

$$E_{5,4}\left[R_{1,2,\$100}\right] = N_{2,1,\$100} P_{2,4,5}$$

where

$$P_{2,4,5} = \left(\prod_{v=1}^{5-1} S'_v\right) omega_{2,\$100,ALB,5,4}$$

and

$$omega_{2,\$100,ALB,5,4} = \frac{F'_{T,5}(1 - S'_5)}{Z'_5} 2TL(1 - TL)\lambda_{\$100}.$$

I assumed that all \$300 tags are reported, thus $\lambda_{\$300} = 1$.

Externally tagged fish with radio transmitters

There are a total of 17 possible observed states for radio-tagged fish (Table 2) that are functions of the biological states of fish (Table 3). Angler tag return probabilities for radio-tagged fish were calculated identically to fish that received only a dart tag. The probability of detecting a fish via radio telemetry during a single period-specific radio-tracking event is defined as parameter *p*. I assumed a closed system, and that the only way for radio-tagged fish to exit the study area was from harvest. To account for tag failure, capture histories were truncated to 2 periods after the last detection for each fish.

Uncertainty exists regarding the true biological state of fish with radio transmitters. Fish may not be reported as captured by an angler, making it impossible to ascertain the capture status of unreported fish. Additionally, captures of fish that have shed all tags are unobservable. State uncertainty extends past capture uncertainty to survival and mortality status. Misclassification of survival status is an important consideration in radio telemetry studies (Bird et al. 2017). I addressed survival misclassification in the forms false survival (m_a) and false mortality (m_d). The model was able to estimate false mortality based on the number of times a fish indicated mortality prior to capture. False survival was assessed by the frequency of tags indicating survival after a was determined to have died.

Tagging mortality from radio tags can bias natural mortality rates if not accounted for. Any radio-tagged fish that indicated mortality during the first manual search after tagging were ascertained to have died from radio-tag implantation. We did not exclude fish that indicated death from radio-tagging from our analysis, because of the possibility misclassified survival status. Instead, we allow the model to explore situations where fish that indicated survival during the first radio telemetry search had died from tagging. We assumed the tagging mortality rate for external tags was zero for both species.

Fish are assumed to transition among biological states as a function of their previous biological state, capture probability, tag-shedding, natural mortality, voluntary release, post-release mortality, and harvest. We assumed that fish were only caught once in any period (time between manual searches), and that post-release mortality happened within period of angling capture. Additionally, we assumed no heterogeneity in the probability of capture for individual fish. Observed states of fish are a function of the fish's biological state, radio-detection probability, angler reporting rate, and survival misclassification rates. Code was modified from existing multi-state models to incorporate uncertainty in state assignment (Kéry and Schaub 2011; Hightower and Harris 2017; Schaub and Kéry 2021). Instead of explicitly modeling biological states of fish, I used the forward algorithm to marginalize over the latent biological states to improve computational efficiency and mixing (Turek et al. 2016, 2021; Blunsom 2004; Ponisio et al. 2020). A user defined density function was modified from Gimenez (2023).

Model selection

I evaluated thirty-eight different models that represented differing assumptions regarding temporal variation in angler capture, effects of tournament capture on mortality, angler reporting, and natural mortality. Parameters were treated as species specific fixed effects unless otherwise noted. Detection probability was treated as a random effect, with variation in detection probability equal between species. I considered between telemetry period-specific instantaneous capture and natural mortality rates as either random or fixed effects. I also explored high and low effort season, and seasonal fixed effects for instantaneous capture rates. I considered the low effort season to be from October 1st-March 1st. Seasonal capture was broken into spring, summer, autumn, and winter. Random effects for instantaneous capture rates were fit to have different means and variances for each species, with period as the random effect. Random effects for natural mortality assumed that variance was equal for both species, with period as the random effect. Models with differing reporting rates for tournaments and non-tournaments were considered. I assumed tournament effects on post-release mortality were additive to baseline species-specific post-release non-tournament mortality rates. I explored constant and species-specific tournament effect on post-release mortality. All other parameters did not vary among models (Table 4).

I used Pareto-smoothed importance sampling approximate leave-one-out cross validation (PSIS-LOO) to compare among candidate models (Vehtari et al. 2017). The loo package in program R was used to compute PSIS-LOO, and models which had any Pareto k values exceeded 0.7 were not considered for selection (Vehtari et al. 2017, 2021). Models with Pareto k values below the 0.7 threshold and that used the same tournament effect for each species were refit with an informative prior from for post-release tournament mortality from Schramm Jr et al. (1987), and these models were considered for selection if Pareto k values did not exceed 0.7. Model averaging was used, and model weights were determined post-hoc by stacking (Yao et al. 2018).

Hypothesis testing regarding parameter value comparisons was conducted by constructing posterior distributions for the differences between parameters of interest. The probability that one parameter was larger than the other was determined by the proportion of posterior sample differences above or below zero. Difference probabilities that exceeded 0.95 were considered statistically meaningfull.

Prior distributions and MCMC methods

Analyses were conducted with noncommercial software R using the NIMBLE package (R Team 2022; Valpine et al. 2017; Valpine et al. 2023). Priors were uninformative unless otherwise noted. Convergence was evaluated using the Gelman Rubin statistic ($\hat{R} < 1.05$) and visually inspecting the trace plots (Gelman and Shirley 2011; Youngflesh 2018). Three independent chains were run for 30,000 iterations. A burn in period of 10,000 iterations was used. Posterior processing was done using the postpack package (Staton 2022). I chose not to thin my samples.

Pattern Matching

The ability for the model averaged parameter estimates to simulate observed data was used to assess model perfromance. The predicted number of fish reported as captured was simulated post-hoc using model averaged parameter estimates. Discrepancies between the observed and predicted angler captures was visually assessed. If deviations between the obseved and predicted number of fish caught among telemetry periods was neither biased high low we continued with analysis.

Results

Tagging and angler reported capture

Over the two-year study period, 806 Alabama Bass and 925 Largemouth Bass were tagged at Neely Henry Reservoir with high-value external dart tags. Of these, 125 fish of each species were implanted with a radio transmitter. Anglers reported the capture of 426 Alabama Bass and 381 Largemouth Bass over the course of the study (52.8% and 41.1% respectively). Non-tournament catch-and-release, tournament capture, and harvest made up 60.8%, 34.5%, and 4.7% of reported captures of Alabama Bass, respectively. Non-tournament catch-and-release, tournament capture, and harvest made up 52.8%, 45.4%, and 1.8% of reported angler captures of Largemouth Bass, respectively.

The proportion of fish reported as captured by anglers in the second year following tagging was much lower than return rates in the first year. Of Alabama Bass tagged in January-February 2022, 42.7% were reported as caught in 2022 and 4.1% were reported as caught in year 2023 (Table 5). For Largemouth Bass tagged in January-February 2022, 34.1% 2022 and 5.1% in 2023. For Alabama Bass tagged in December 2022-January 2023, 53.4% were caught in 2023, and none were reported as captured in January-March 2024. For Largemouth Bass, 42.4% of the fish tagged in the December 2022-January 2023 fish were reported as captured in 2023, and 0.4% were reported as captured in January-March 2024.

Model selection

After discarding eighteens models with Pareto k values that exceeded 0.7, a total of eighteen models were considered for model selection (Table 4). The top weighted model included, seasonal capture rates, natural mortality with telemetry search period as a random effect, and a species-specific tournament effect on post-release mortality (Table 4). Models including informative priors for post-release tournament mortality overall were not favored by weighting (Table 4). All modes with period-specific fixed-effect instantaneous capture rates contained Pareto k values greater than 0.7 and were discarded. Convergence was achieved for all models, and parameter estimates from the top 4 performing models are in tables 8-11.

Angler Capture Rates

Finite non-tournament and tournament capture rates for Alabama Bass were 0.69 (CI 0.45-1.19) and 0.50 (CI 0.25-1.21), respectively (figure 5). For Largemouth Bass the finite rate of capture was 0.43 (CI 0.32-0.60) for non-tournaments and was 0.41 (CI 0.27-0.81) for tournaments (figure 6). The finite annual non harvest capture rate (u'_{CR}) was 1.18 (CI 0.75-2.32) for Alabama Bass and 0.83 (CI 0.61-1.36) for Largemouth Bass. The total finite capture rate (u') for Alabama Bass was 1.26 (CI 0.80-2.44) and 0.86 (CI 0.63-1.40) for Largemouth Bass. Voluntary release was 0.89 (CI 0.86-0.93) for Alabama Bass and 0.94 (CI 0.90-0.97) for Largemouth. The probability that u'_{NT} for Alabama Bass exceeded that of Largemouth Bass was 0.99. The probability that u'_{T} was higher for Alabama Bass than for Largemouth Bass was 0.77. The probability that u'_{CR} for Alabama Bass exceeded that of Largemouth Bass was 0.98, and the probability that u' was higher for Alabama Bass was 0.99.

Mortality and exploitation

The model averaged instantaneous total catch-and-release non-tournament mortality rate for Alabama Bass and Largemouth Bass was 0.03 (CI 0.00-0.30) and 0.00 (CI 0.00-0.01), respectively (Figure 8). For tournaments, the instantaneous mortality rate was 0.18 (CI 0.02-0.65) for Alabama Bass and 0.03 (CI 0.01-0.29) for Largemouth Bass (Figure 8). Non tournament catch-and-release exploitation (u_{NTR}) was 0.02 (CI 0.00-0.17) and 0.00 (CI 0.00-0.01) for Alabama and Largemouth Bass respectively (Figure 6). The probability that u_{NTR} was higher for Alabama Bass or Largemouth Bass was 0.77. Harvest exploitation was higher for Alabama Bass (0.08; CI 0.04-0.13) than Largemouth Bass (0.03; CI 0.01-0.05) ($p > 0.99$) (Figure 6). Tournament exploitation u_{T} was 0.10 (CI 0.01-0.37) and 0.02 (CI 0.00-0.17) for Alabama Bass and Largemouth Bass respectively. The probability that u_{T} is higher for Alabama Bass was 0.98. Catch-and-release exploitation (u_{CR}) for Alabama Bass was 0.12 (CI 0.01-0.43) for Alabama Bass and 0.02 (CI. 0.00-0.18) for Largemouth Bass. The probability that u_{CR} was higher for Alabama Bass than Largemouth Bass was greater than 0.99. The finite total annual mortality was 0.70 (CI 0.59-0.79) for Alabama Bass (A_{ALB}) and 0.61 (CI 0.53-0.69) for

Largemouth Bass (A_{LMB}) (Table 6; Table 7; figure 9). The probability that A_{ALB} exceeded A_{LMB} was 0.94. The Alabama Bass finite annual natural mortality (V_{ALB}) was 0.50 (CI 0.18-0.68) and Largemouth Bass annual natural mortality (V_{LMB}) was 0.57 (CI 0.44-0.66) (Table 6; Table 7). The probability that V_{LMB} exceeded V_{ALB} was 0.67. For Alabama Bass the probability that catch-and-release fishing exploitation was a larger component of total mortality than harvest was 0.56. The probability that catch-and-release fishing exploitation was higher than harvest for Largemouth Bass was 0.13.

For Alabama Bass, the proportion of mortality due to natural mortality (V_{mag}) was 0.71 (0.25-0.90). The relative magnitude of tournament mortality ($u_{T^{mag}}$) was 0.15 (CI 0.01-0.53) for Alabama Bass. The magnitude of non-tournament mortality ($u_{NTR^{mag}}$) for Alabama Bass was 0.03 (CI 0.00-0.23). The relative magnitude of harvest as a mortality component ($u_{h^{mag}}$) was 0.11 (CI 0.06-0.19). For Largemouth Bass V_{mag} was 0.93 (CI 0.68-0.97), $u_{T^{mag}}$ was 0.03 (CI 0.00-0.26), $u_{NT^{mag}}$ was 0.00 (CI 0.00-0.01), and $u_{h^{mag}}$ was 0.04 (CI 0.02-0.08). The magnitude of catch-and-release fishing mortality ($u_{CR^{mag}}$) was 0.18 (CI 0.02-0.60) and 0.03 (CI 0.00-0.27) for Alabama and Largemouth Bass respectively. The probability that V_{mag} is higher for Largemouth Bass than Alabama Bass was greater than 0.99. The probability that $u_{NTR^{mag}}$, $u_{T^{mag}}$, $u_{CR^{mag}}$, and $u_{h^{mag}}$ are higher for Alabama Bass than Largemouth Bass was 0.77, 0.98, 0.98, and 0.99 respectively. For Largemouth the probability that catch-and-release fishing exploitation was a larger component of total mortality than harvest was 0.13. The probability that catch-and-release fishing exploitation was a larger component of total mortality than harvest for Alabama Bass was 0.57. The probability that $u_{T^{mag}}$ exceeded $u_{NTR^{mag}}$ was 0.94 and 0.97 for Alabama and Largemouth Bass, respectively. The probability that the relative magnitude of total fishing mortality $u_{F^{mag}}$ exceeded V_{mag} was 0.17 for Alabama Bass and less than 0.00 for

Largemouth bass. For Alabama Bass I found that the relative magnitude of non-tournament catch-and-release angling ($u_{NTR^{mag_F}}$), tournament mortality ($u_{T^{mag_F}}$), and harvest ($u_{h^{mag_F}}$) as a component of total fishing mortality was 0.07 (CI 0.00-0.39), 0.46 (CI 0.13-0.78), and 0.48 (CI 0.18-0.84) respectively. For Largemouth Bass I found $u_{NTR^{mag_F}}$, $u_{T^{mag_F}}$, and $u_{h^{mag_F}}$ to be 0.02 (CI 0.00-0.15), 0.18 (CI 0.00-0.83), and 0.80 (CI 0.16-1.00) respectively. Tournament post-release mortality was 0.19 (CI 0.03-0.40) for Alabama Bass and 0.03 (CI 0.00-0.32) for Largemouth Bass. Non-tournament post-release mortality was 0.02 (CI 0.00-0.17) for Alabama Bass and 0.00 (CI 0.00-0.02) for Largemouth Bass.

Tag shedding, radio-tagging mortality, and radio-tag misclassification

Out of 234 double-tagged Alabama Bass, 130 were reported as captured. Of the captured double tagged Alabama Bass 30 had lost a tag. Anglers reported capturing 115 of the 271 double tagged Largemouth Bass, 13 of which had lost a tag. The model averaged rate of tag shedding for Alabama Bass and Largemouth Bass was 0.13 (CI 0.09-0.18) and 0.07 (CI 0.04-0.11) respectively. The mean radio telemetry detection probability was 0.84 (CI 0.82-0.87) for Alabama Bass and 0.87 (CI 0.85-0.89) for Largemouth Bass. False mortality was low (posterior mean = 0.02; CI 0.01-0.03) as only one instance was observed of a fish indicating mortality via radio telemetry prior to its capture by an angler. False survival was 0.10 (CI 0.09-0.12).

Angler reporting

The estimates of the angler non-reporting rate for non-tournament captures were 0.55 (CI 0.64-0.88) and 0.86 (0.73-0.98) for \$100 and \$200 tags respectively. For tournaments, the a reporting rate was 0.71 (CI 0.44-0.84) for \$100 tags and 0.82 (0.51-0.96) for \$200 tags. To consider the possibility of angler non-reporting of \$300 tags we re-ran the top performing model under 70%, 80%, and 90% reporting scenarios. Changing the reporting rates of \$300 tags had a small effect on parameter values (Table 12). This suggests that the model is relatively insensitive to unreporting.

Pattern Matching

Model predicted and observed angler tag returns were overall similar, with a few deviations (Figures 10-13). Period-specific capture probabilities were not favored for by model selection; however, using seasonal or low and high effort season capture probabilities likely contributed to these deviations. The model appears to have overestimated angling capture in the late autumn of 2022 and underestimated capture in spring 2023. Overall, deviations from the mean were neither biased low or high.

Discussion

In fisheries with high rates of voluntary catch-and-release angling, species with higher capture rates are likely to experience higher fishing mortality rates due to post-release mortality, all else being equal. Non-tournament, tournament, and total capture rates were higher for Alabama Bass than Largemouth Bass. Differences in capture rates between species are important to consider when evaluating the potential population-level effects of catch-and-release mortality.

Overall capture rates were high for Alabama Bass at Neely Henry Reservoir were higher compared to previous black bass studies. Estimates for the instantaneous capture rate for Alabama Bass (2.13) exceeded the findings Kerns et al. (2015) (0.33) and Kerns et al. (2016) (1.34) for black bass in Florida. The instantaneous capture rate for Largemouth Bass (1.31) was similar to Kerns et al. (2016). Finite annual capture for both species ($ALB = 1.24, LMB = 0.85$) was higher than Buckingham (2016), which found Largemouth Bass finite annual capture rates averaged 0.39 at Lake Wheeler and 0.53 at Guntersville Reservoir. Finite capture rates suggest that individual Alabama Bass are being caught more than once every year. Hakala and Sammons

(2015) did not report the finite capture rate for Alabama Bass in Allatoona Reservoir, Georgia, but based on other parameter values reported it can be acertained to have ranged from 0.78 to 1.02. I found the finite annual capture rate for Alabama Bass at Neely Henry Reservoir (1.24) to have been higher than Hakala and Sammons (2015). Little previous research exists comparing capture rates between Alabama Bass and Largemouth Bass; however, comparing the findings of Hakala and Sammons (2015) to studies focusing on Largmouth Bass there is some indication that Alabama Bass may be more vulnerable to angling. High angling capture rates suggest that angling effort is high on Neely Henry Resevoir. There are no literature based estimates of angling pressure for Neely Henry Reservoir; however, it is a known to be a popular fishery (Holley. M. P, ADCNR, personal communication). Neely Henry Reservoir has hosted large tournaments bringing nationwide attention, including a Bass Master Elite event. The suggestion that angling effort is high is supported by the finidings of Boozer et al. (2019) which found over 8,000 anglers participating in tournaments annually on Neely Henry Reservoir.

The relative magnitude of catch-and-release angling as a component of total mortality is another important consideration when assessing overall fish mortality. I found that the relative magnitude of tournament mortality was higher than the magnitude of non-tournament catch-and-release mortality for both species. I did not find tournament, non-tournament catch-and-release, or total catch-and-release (tournament and non-tournament) mortality to be a larger component of total mortality than harvest for either species. However, the relative magnitude of natural mortality was higher for Largemouth Bass than Alabama Bass. In addition, the relative magnitude of fishing mortality components differs between species. Indeed, total catch-and-release, harvest mortality, tournament mortality rates, and their relative magnitudes as a component of total fishing mortality, were higher for Alabama Bass than Largemouth Bass at

Neely Henry Reservoir. Thus, fishing likely has a greater potential to negatively affect Alabama Bass in this system when compared with Largemouth Bass.

Estimates of post-release mortality for black bass across locations are highly variable across studies. Post-release non-tournament mortality for both Alabama Bass (0.02) and Largemouth bass (0.00) at Neely Henry Reservoir was lower than Kerns et al. (2016), which found post-release non-tournament mortality to be 0.06 for Florida Bass. Hightower and Gilbert (1984) found mortality of Largemouth Bass tagged after angling capture to be 0% and 20% in different years. Kerns et al. (2016) found post-release tournament mortality for Florida Bass to be 0.20. Hartley and Moring (1995) found post-release tournament mortality to be 0.05 for Largemouth and Smallmouth Bass. Schramm Jr et al., (1987) found tournament mortality to be 0.27 for Largemouth Bass. Estimated post-release mortality for Alabama Bass (0.19) was similar to previous literature for other black bass specices; however, there is an indication that post-release tournament mortality in Neely Henry Reservoir is lower than closely related species in other systems. Muonke (1992) found hooking mortality for Spotted Bass, a close relative of Alabama Bass, to be 0.85, which exceeds our estimate for tournament and non-tournament post-release mortality. Estimated post-release mortality for Largemouth Bass (0.03) was low compared to most previous literature. Estimates for post-release tournament mortality at Neely Henry Reservoir may be lower than other published studies because my analysis estimated a tournament post-release mortaltiy rate for all fish caught-and-released in tournaments regardless of whether a tournament-caught fish was releasesed on the water or held in the livewell and weighed-in. Clearly, these two fates for tournament-caught fish are very different with fish that are weighed-in having to endure much more stressful conditions for a longer period of time, which likely leads to higher mortality rates.

Estimates of natural mortality for both species are high compared to previous literature. Kerns et al. (2015) found instantaneous natural mortality to be 0.40 for Florida Bass. Allen et al. (2008) found M to be 0.55 for Largemouth Bass. Waters et al. (2005) found natural mortality for Florida Bass to be 0.31. Total instantaneous fishing mortality for Alabama Bass (0.35) was similar to the findings of previous black bass studies in the southeastern United States. Compared to other studies, F was low for Largemouth Bass (0.07). Kerns et. al (2016) found F to be 0.48 and Kerns et al. (2015) found F to be 0.33. Non-tournament catch-and-release mortality, and tournament mortality were smaller components of total mortality for Largemouth Bass than in previous studies. The realative magnitude of tournament mortality for Alabama Bass (0.15) was similar to previous research on black bass species; however, the relative magnitude of non-tournament catch-and-release mortality (0.03) was lower than previous research. For Largemouth Bass the relative magnitude of tournament mortality (0.03) and non-tournament mortality (0.00) is lower than previous literatrue. Kerns et al. (2015) found tournament mortality to contribute 12% of total fishing mortality. Buckingham (2016) found non-tournament mortality to contribute 15-20% of fishing mortaltity, and tournaments to contrbute 25-56% of total fishing mortality.

Across both species in the study, the percentage of tags reported in the year after tagging were far lower than could be explained by the number of tags captured within the year of tagging. In other words, there was a high rate of unobserved loss of tags and/or fish from the system that was not directly attributable to removel via angler capture. The way the model had to explain this discrepancy is via some other source of non-fishing mortality. The only other such source of mortality in my model is natural mortality. Thus, the model produced esimates of natural mortality that were much higher than the literature would suggest. If natural mortality is in fact overestimated by the model, then some other mechanisms for losses of tags/fish from the system must have been operating. One possible explanation for this discrepancy would be that reporting of $300 tags is not 100%. The variable reward approach I employed can be used to infer 100% reporting of high-dollar tags if reporting rates reach an asymptote at a reward level that is less than the highest reward. Results from the model indicate that $200 tags had not reached asymptotic reporting. In my study, the reporting rate on the second highest reward level ($200) was only 0.86 and 0.82 for non-tournaments and tournametns respectively. Thus I was not able to conclude that $300 tags were reported 100% of the time by anglers. If $300 tags were not fully reported, then this unaccounted for loss of tags could at partially explain the low tag returns in the year after tagging. If non-reporting of $300 tags is substanital, capture rates would be higher than estimated by my model. Given that angling capture rates for both species are high compared to literature values, non-reporting of $300 tags would mean that capture rates for black bass in Neely Henry Reservoir are extreme. I suspect that unexplained losses of tags and/or fish cannot be explained simply by unobserved non-reporting because radio tracking data indicated that annual survival of radio-tagged fish was low. Thus, results from my study suggest that survival of black bass in Neely Henry reservoir is lower than suggested by both previous literature and the catch-curve.

Aside from high natural mortality, another possible source of fish mortality in this sytem could have been the misclassification of post-release mortality as natural mortality. I assumed that all post-release mortality happened within between the time of capture and the next mannual radio-telemetry search. Violation of this assumption would result in post-release mortality being misattributed as natural mortality. Additionally, the amount of time between fish death and the expulsion of the transmitter from the fish carcass is unknown and likely depends on temperaturerelated tissue decay rates. These decay rates are important for interpreting tag mortality signals from radio transmitters because these devices appear to be very sensitive to movement. This sensitivity may preclude the transmitters from signaling mortality when the transmitter is still contained within the body cavity of a dead fish due to wave action and natural currents.

More broadly, misclassification of mortality can bias any tagging study. If false survival is high, mortality rates will be biased low. Conversely, if false mortality is high mortality will be biased positively. We found both forms of survival misclassification to be low in this study. A limitation of my approach was assuming that the probability of a dead fish indiciating survival is equal at any point after death in this model. There is a possibility that dead fish are more likely to indicate survival immediately after death, before the fish has decomposed. Additionally, non-reporting of $300 tags may result in post-release mortality being attributed to *M*. Our approach appears to be robust to the assumption of 100% reporting of $300 tags; however, we were unable to test for other possible sources of misattributed natural mortality. Another limitation that may lead catch-and-release mortality to be missatributed to natural mortality is the assumption that there is no individual heterogenity in the probability of anglig capture. It is possible that fish that have been previously caught are more suceptable to angling. If there is an assosiation between previous capture and the probability of subsequent captures fish may be recaught more than the model predicts. Anlgers often fish known tournament release sites to increase their chances of catching large fish. If fish do not disperse from the tournament release site, they likely experience higher regional angling effort than they did prior to capture. Higher regional effort may lead to subsequent captures and post-release mortality that my model may not account for. Additionally, if lethal effects of angling capture extend past the period of capture, post-release mortality will be misattributed to natural mortality.

Limitations from the study design may have negatively biased post-release mortality rates. Tag returns for tournaments and non-tournaments were highest in the spring when water temperatures are lower. Post-release mortality has been positively associated with temprature and is likely lower during the spring (Graeb et al. 2005; Wilde 1998). It is possible that post-release mortality is informed to be low from spring captured fish, and that I underestimated post-release mortality during warmer months. Capture rates are lower in the summer, thus anglers are less likely to catch fish with radio-transmiters. Additionally, many fish were caught in the spring and had there tags removed. If fish no longer had a tag subsequent captures of that fish were not observable and post-release mortlaity may be attributed to natural mortality. I did not allow the model to explore seasonal variation in post-release mortality due to limitations imposed by low sample size. Additionally, I assumed that post-release mortality was equal across all fish sizes; however, previous research suggests that post-release mortality may be higher in larger fish (Meals and Miranda 1994). Given the mentioned limitations my estimates of fishing mortality are likely conservative.

As temporal trends continue towards 100% catch-and-release for some freshwater sportfish the importance of incorporating catch-and-release will become more apparent. Results from this study are consistent with previous research that suggests that catch-and-release angling is a substantial component of total fishing mortality for some freshwater sportfish. Estimated annual mortality for both Alabama Bass (0.7) and Largemouth Bass (0.61) exceed estimated mortality for both species from the catch-curve (0.4 and 0.41). As demonstrated by Dunn et al. (2002) there is potential for negative bias using a catch-curve; however, the discrepancy between my total mortality estimates and the catch-curve is larger than expected. Either an unknown mechanism is greatly reducing the survival of both fish with and without radio tags or significant fish mortality is not being reflected in the catch curve. Further research is needed to validate approaches for estimating fish mortality; however, results from my study clearly indicate incorporating catch-and-release mortality is important for sport fisheries with high voluntary release rates.

Tables

Table 1. Observed states for fish without radio transmitters.

State	Description
1	Non-tournament capture with two tags, released
2	Non-tournament capture with one tag, released
3	Tournament capture with two tags
4	Tournament capture with one tag
5	Non-tournament capture with two tags, harvested
6	Non-tournament capture with one tag, harvested

Table 2. Observed states of fish with radio transmitters.

State	Description
1	Not reported as captured, detected alive
2	Caught and released in a non-tournament with 2 tags, detected alive
3	Caught and released in a non-tournament with 1 tag, detected alive
4	Caught and released in a tournament with 2 tags, detected alive
5	Caught and released in a tournament with 1 tag, detected alive
6	Not reported as captured, detected dead
7	Caught and released in a non-tournament with 2 tags, detected dead
8	Caught and released in a non-tournament with 1 tag, detected dead
9	Caught and released in a tournament with 2 tags, detected dead
10	Caught and released in a tournament with 1 tag, detected dead
11	Harvested with 2 tags
12	Harvested with 1 tag
13	Caught and released in a tournament with 2 tags, not detected
14	Caught and released in a tournament with 1 tag, not detected
15	Caught and released in a tournament with 2 tags, not detected
16	Caught and released in a tournament with 1 tag, not detected
17	Not reported as captured and not detected

Table 3. Biological states of fish with radio transmitters

State	Description
1	Alive with 2 tags
2	Alive with 1 tag
3	Caught and released in a non-tournament with 2 tags and survived
4	Caught and released in a non-tournament with 1 tag and survived
5	Caught and released in a tournament with 2 tags and survived
6	Caught and released in a tournament with 1 tag and survived
7	Alive without a tag
8	Natural mortality, non-harvest death, or previous C+R death
9	Caught and released in a non-tournament with 2 tags and died
10	Caught and released in a non-tournament with 1 tag and died
11	Caught and released in a tournament with 2 tags and died
12	Caught and released in a tournament with 1 tag and died
13	Harvested with 2 tags
14	Harvested with 1 tag
15	Harvested without a tag or previous harvest with tag(s)

Table 4. Leave one out information criterion (LOOIC) for all models with no Pareto k values > 0.7 ranked by model weight. Model weights were determined by stacking. Models included capture as a telemetry period specific fixed effect (F'(*)), period specific random effect (F'(%)), high and low effort fixed effect (F'(2)), and seasonal fixed effect. Natural mortality was explored as constant (M(c)), and as a period specific random effect (M(%)). Angler reporting was either constant across angling sectors (λ(c)) or allowed to differ between sectors (λ(s)). Post-release tournament mortality was assumed as either an equal additive effect between species to post-release non-tournament mortality (a_T(c)), a species-specific additive effect (a_T(s)), or an informative prior was used (a_T(p)).

Model	Weight	LOOIC	SE LOOIC
F'(4),M(%),λ(c),a_T(s)	0.57	8578.74	364.14
F'(4),M(c),λ(c), a_T(s)	0.13	8620.57	367.93
F'(2),M(c),λ(c),a_T(s)	0.09	8881.56	392.3
F'(2),M(c),λ(c),a_T(p)	0.06	8887.75	391.63
F'(2),M(%),λ(c), a_T(s)	0.05	8827.21	386.4
F'(4),M(c),λ(s),a_T(s)	0.05	8623.32	368.21
F'(2),M(c),λ(c),a_T(c)	0.03	8880.32	391.88
F'(4),M(%),λ(s),a_T(s)	0	8582.43	364.6
F'(4),M(%),λ(s),a_T(c)	0	8582.45	364.5
F'(2),M(%),λ(s),a_T(s)	0	8881.72	392.43
F'(4),M(c),λ(c), a_T(c)	0	8579.71	364.21
F'(2),M(c),λ(s),a_T(c)	0	8882.29	392.31
F'(4),M(c),λ(s), a_T(s)	0	8621.01	367.87
F'(2),M(%),λ(c),a_T(c)	0	8882.32	392.23
F'(4),M(%),λ(c), a_T(p)	0	8627.34	367.83
F'(2),M(c),λ(s),a_T(c)	0	8881.43	392.38
F'(2),M(%),λ(c), a_T(p)	0	8889.86	391.54

Table 5. Angler tag returns by tag the number of tags tagged (T_T), tags captured (T_c), year of capture, period tagged (t_R), numbers tagged (n), reward level, species, and angling sector. H, NT, and T refer to fish harvested, caught-and-released in non-tournaments, and caught in tournaments Tagging period 1 was in in January-February 2022, period 2 was in December 2023-January 2023, and period 3 was in May 2023.

	t_R	Reward level	T_T	T_C	n	H 2022	NT 2022	T 2022	H 2023	NT 2023	T 2023	H 2024	NT 2024	T 2024
ALB	1	$100	2	2	73	0	15	9	0	2	1	0	0	0
		$100	2	1	0	0	6	7	0	0	1	0	0	0
		$100	1	1	109	0	28	19	0	4	2	0	0	0
		$200	2	2	32	0	12	3	0	0	0	0	0	0
		$200	2	1	0	1	1	3	0	0	0	0	0	0
		$200	1	1	95	3	30	15	0	3	2	0	0	0
		$300	2	2	5	0	2	2	0	0	0	0	0	0
		$300	2	1	0	0	0	0	0	0	0	0	0	0
		$300	1	1	30	0	14	6	0	1	0	0	0	0
ALB	2	$100	2	2	66	0	0	0	3	14	12	0	0	0
		$100	2	1	0	0	0	0	0	3	2	0	0	0
		$100	1	1	132	0	0	0	6	41	22	0	0	0
		$200	2	2	58	0	0	0	2	18	4	0	0	0
		$200	2	1	0	0	0	0	0	6	0	0	0	0
		$200	1	1	103	0	0	0	2	31	25	0	0	0
		$300	2	2	0	0	0	0	0	0	0	0	0	0
		$300	2	1	0	0	0	0	0	0	0	0	0	0
		$300	1	1	40	0	0	0	2	14	5	0	0	0
ALB	3	$100	1	1	43	0	0	0	1	10	4	0	0	0
		$200	1	1	16	0	0	0	0	3	3	0	0	0
		$300	1	1	4	0	0	0	0	1	1	0	0	0
LMB	1	$100	2	2	100	0	16	14	0	3	3	0	0	0
		$100	2	1	0	0	2	0	0	0	1	0	0	0
		$100	1	1	153	0	30	18	0	4	4	0	0	0
		$200	2	2	43	0	7	4	1	0	1	0	0	0
		$200	2	1	0	0	0	2	0	0	0	0	0	0
		$200	1	1	110	1	20	24	0	3	2	0	0	0
		$300	2	2	4	0	0	2	0	0	0	0	0	0
		$300	2	1	0	0	1	0	0	0	0	0	0	0
		$300	1	1	41	0	8	5	0	0	1	0	0	0
LMB	2	$100	2	2	73	0	0	0	1	11	14	0	0	0
		$100	2	1	0	0	0	0	0	2	1	0	0	0
		$100	1	1	129	0	0	0	2	25	17	0	0	0
		$200	2	2	50	0	0	0	1	13	9	0	0	0
		$200	2	1	0	0	0	0	0	1	2	0	0	0
		$200	1	1	111	0	0	0	2	23	19	0	0	2
		$300	2	2	1	0	0	0	0	1	0	0	0	0
		$300	2	1	0	0	0	0	0	0	0	0	0	0
		$300	2	1	37	0	0	0	0	11	13	0	0	0
LMB	3	$100	1	1	39	0	0	0	0	8	7	0	0	0
		$200	1	1	26	0	0	0	0	5	7	0	0	0
		$300	1	1	8	0	0	0	0	4	1	0	0	0

Table 6. Finite annual mortality components for Alabama Bass. Results come from model averaging.

	$u_{CR}^{\square}$	$u_{h}^{\square}$	V	A
mean	0.12	0.08	0.5	0.7
sd	0.12	0.02	0.14	0.05
median	0.08	0.07	0.54	0.7
2.5%	0.01	0.04	0.18	0.59
97.5%	0.43	0.13	0.68	0.79

Table 7. Finite annual mortality components for Largemouth Bass. Results come from model averaging.

	u_{CR}	u_{h}	V	A
mean	0.02	0.03	0.57	0.61
sd	0.04	0.01	0.05	0.04
median	0	0.03	0.57	0.61
2.5%	0	0.01	0.44	0.53
97.5%	0.18	0.05	0.66	0.69

Table 8: Parameter values from model F'(4),M(%),λ(c),a_T(s) with Gelman Rubin convergence criterion $\hat{R}$.

parameter	mean	sd	50%	2.50%	97.50%	$\hat{R}$
$F_{NT,ALB}$	0.01	0.03	0	0	0.1	1.02
$F_{NT,LMB}$	0	0	0	0	0.01	1
$F_{T,ALB}$	0.09	0.06	0.08	0.01	0.23	1
$F_{T,LMB}$	0.01	0.01	0	0	0.05	1
$F_{h,ALB}$	0.11	0.02	0.11	0.08	0.16	1
$F_{h,LMB}$	0.04	0.01	0.04	0.02	0.07	1
$F'_{NT,ALB}$	1	0.11	1	0.81	1.23	1
$F'_{NT,LMB}$	0.62	0.07	0.62	0.49	0.78	1
$F'_{T,ALB}$	0.63	0.08	0.63	0.49	0.81	1
$F'_{T,LMB}$	0.53	0.06	0.53	0.42	0.67	1
M_{ALB}	1.04	0.15	1.03	0.75	1.35	1
M_{LMB}	0.91	0.1	0.91	0.73	1.12	1
$a_{NT,ALB}$	0.01	0.03	0	0	0.1	1.02
$a_{NT,LMB}$	0	0.01	0	0	0.02	1
$a_{T,ALB}$	0.15	0.08	0.13	0.02	0.33	1
$a_{T,LMB}$	0.02	0.03	0.01	0	0.09	1
m_a	0.1	0.01	0.1	0.09	0.12	1
m_d	0.02	0	0.02	0.01	0.03	1
$meanp_{ALB}$	1.67	0.1	1.67	1.49	1.87	1
$meanp_{LMB}$	1.89	0.1	1.89	1.7	2.09	1
sd$p$	0.39	0.07	0.39	0.26	0.55	1
vr$_{ALB}$	0.9	0.02	0.9	0.86	0.93	1
vr$_{LMB}$	0.94	0.02	0.94	0.9	0.97	1
S_{ALB}	0.29	0.04	0.29	0.21	0.37	1
S_{LMB}	0.38	0.04	0.38	0.31	0.46	1
TL_{ALB}	0.13	0.02	0.12	0.09	0.17	1
TL_{LMB}	0.07	0.02	0.07	0.04	0.1	1
TM_{ALB}	0.05	0.03	0.05	0	0.12	1
TM_{LMB}	0.03	0.02	0.02	0	0.08	1
Z_{ALB}	1.26	0.14	1.25	1	1.56	1
Z_{ALB}	0.96	0.1	0.96	0.78	1.17	1
$\lambda_{NT,\$100}$	0.75	0.05	0.75	0.67	0.85	1
$\lambda_{NT,\$200}$	0.86	0.05	0.86	0.77	0.97	1
$\lambda_{T,\$100}$	0.75	0.05	0.75	0.67	0.85	1
$\lambda_{T,\$200}$	0.86	0.05	0.86	0.77	0.97	1

Table 9: Parameter values from model $F'(4)$,M(c),λ(c),a_T(s) with Gelman Rubin convergence criterion $\hat{R}$.

parameter	mean	sd	50%	2.50%	97.50%	$\hat{R}$
$F_{NT,ALB}$	0.03	0.04	0	0	0.16	1
$F_{NT,LMB}$	0	0	0	0	0.01	1
$F_{T,ALB}$	0.14	0.07	0.13	0.03	0.29	1
$F_{T,LMB}$	0.01	0.02	0	0	0.05	1
$F_{h,ALB}$	0.12	0.02	0.12	0.08	0.17	1
$F_{h,LMB}$	0.04	0.01	0.04	0.02	0.06	1
$F'_{NT,ALB}$	1.08	0.11	1.08	0.88	1.32	1
$F'_{NT,LMB}$	0.6	0.07	0.6	0.48	0.74	1
$F'_{T,ALB}$	0.7	0.09	0.7	0.54	0.88	1
$F'_{T,LMB}$	0.51	0.06	0.51	0.41	0.64	1
M_{ALB}	0.73	0.09	0.73	0.54	0.92	1
M_{LMB}	0.85	0.08	0.85	0.7	1.01	1
$a_{NT,ALB}$	0.02	0.04	0	0	0.14	1
$a_{NT,LMB}$	0	0.01	0	0	0.02	1
$a_{T,ALB}$	0.2	0.09	0.19	0.05	0.39	1
$a_{T,LMB}$	0.02	0.03	0.01	0	0.11	1
m_a	0.1	0.01	0.1	0.09	0.12	1
m_d	0.02	0	0.02	0.01	0.03	1
$meanp_{ALB}$	1.68	0.1	1.67	1.49	1.87	1
$meanp_{LMB}$	1.89	0.1	1.89	1.7	2.09	1
sd$p$	0.4	0.07	0.4	0.27	0.55	1
vr$_{ALB}$	0.9	0.02	0.9	0.86	0.93	1
vr$_{LMB}$	0.94	0.02	0.94	0.9	0.97	1
S_{ALB}	0.36	0.04	0.36	0.3	0.43	1
S_{LMB}	0.41	0.03	0.41	0.35	0.47	1
TL_{ALB}	0.13	0.02	0.12	0.09	0.17	1
TL_{LMB}	0.07	0.02	0.07	0.04	0.11	1
TM_{ALB}	0.02	0.02	0.02	0	0.07	1
TM_{LMB}	0.01	0.01	0.01	0	0.05	1
Z_{ALB}	1.02	0.1	1.01	0.83	1.22	1
Z_{ALB}	0.9	0.08	0.9	0.75	1.06	1
$\lambda_{NT,\$100}$	0.76	0.04	0.76	0.68	0.86	1
$\lambda_{NT,\$200}$	0.88	0.05	0.88	0.78	0.98	1
$\lambda_{T,\$100}$	0.76	0.04	0.76	0.68	0.86	1
$\lambda_{T,\$200}$	0.88	0.05	0.88	0.78	0.98	1

Table 10: Parameter values from model $F'(2)$,M(c),λ(c),a_T(s) with Gelman Rubin convergence criterion $\hat{R}$.

parameter	mean	sd	50%	2.50%	97.50%	$\hat{R}$
$F_{NT,ALB}$	0.05	0.09	0	0	0.34	1.03
$F_{NT,LMB}$	0	0	0	0	0.01	1.01
$F_{T,ALB}$	0.5	0.14	0.5	0.24	0.8	1
$F_{T,LMB}$	0.02	0.03	0.01	0	0.12	1
$F_{h,ALB}$	0.17	0.03	0.17	0.11	0.24	1
$F_{h,LMB}$	0.05	0.01	0.04	0.02	0.08	1
$F'_{NT,ALB}$	1.58	0.18	1.57	1.26	1.98	1
$F'_{NT,LMB}$	0.72	0.09	0.71	0.57	0.9	1
$F'_{T,ALB}$	1.53	0.2	1.52	1.14	1.93	1
$F'_{T,LMB}$	0.92	0.12	0.92	0.69	1.17	1
M_{ALB}	0.45	0.11	0.45	0.22	0.68	1
M_{LMB}	0.8	0.08	0.8	0.66	0.95	1
$a_{NT,ALB}$	0.03	0.05	0	0	0.2	1.03
$a_{NT,LMB}$	0	0.01	0	0	0.02	1
$a_{T,ALB}$	0.33	0.08	0.33	0.17	0.48	1
$a_{T,LMB}$	0.02	0.03	0.01	0	0.13	1
m_a	0.1	0.01	0.1	0.09	0.12	1
m_d	0.02	0	0.02	0.01	0.03	1
$meanp_{ALB}$	1.68	0.1	1.68	1.5	1.88	1
$meanp_{LMB}$	1.89	0.1	1.89	1.7	2.09	1
sd$p$	0.4	0.07	0.4	0.27	0.55	1.01
vr$_{ALB}$	0.9	0.02	0.9	0.87	0.93	1
vr$_{LMB}$	0.94	0.02	0.94	0.9	0.97	1
S_{ALB}	0.31	0.04	0.31	0.24	0.39	1
S_{LMB}	0.42	0.03	0.42	0.36	0.49	1
TL_{ALB}	0.15	0.02	0.15	0.11	0.2	1
TL_{LMB}	0.07	0.02	0.07	0.04	0.11	1
TM_{ALB}	0.03	0.03	0.03	0	0.09	1
TM_{LMB}	0.02	0.01	0.01	0	0.05	1
Z_{ALB}	1.18	0.12	1.17	0.95	1.43	1
Z_{ALB}	0.87	0.08	0.87	0.72	1.03	1
$\lambda_{NT,\$100}$	0.78	0.07	0.78	0.64	0.93	1
$\lambda_{NT,\$200}$	0.87	0.07	0.88	0.72	0.99	1
$\lambda_{T,\$100}$	0.52	0.07	0.51	0.41	0.67	1
$\lambda_{T,\$200}$	0.61	0.08	0.6	0.48	0.79	1

Table 11: Parameter values from model F'(2),M(%),λ(s),a_T(p) with Gelman Rubin convergence criterion $\hat{R}$.

parameter	mean	sd	50%	2.50%	97.50%	$\hat{R}$
$F_{NT,ALB}$	0.11	0.17	0.02	0	0.57	1
$F_{NT,LMB}$	0.01	0.02	0	0	0.05	1.01
$F_{T,ALB}$	0.56	0.11	0.55	0.35	0.79	1
$F_{T,LMB}$	0.28	0.06	0.27	0.17	0.4	1
$F_{h,ALB}$	0.21	0.04	0.21	0.14	0.3	1
$F_{h,LMB}$	0.06	0.02	0.06	0.03	0.09	1
$F'_{NT,ALB}$	1.97	0.24	1.96	1.56	2.5	1
$F'_{NT,LMB}$	0.91	0.12	0.9	0.71	1.17	1
$F'_{T,ALB}$	2.06	0.27	2.06	1.52	2.6	1
$F'_{T,LMB}$	1.28	0.18	1.27	0.95	1.64	1
M_{ALB}	0.4	0.11	0.4	0.18	0.63	1
M_{LMB}	0.75	0.09	0.75	0.58	0.92	1
$a_{NT,ALB}$	0.05	0.08	0.01	0	0.27	1
$a_{NT,LMB}$	0.01	0.02	0	0	0.05	1.01
$a_{T,ALB}$	0.27	0.04	0.27	0.2	0.35	1
$a_{T,LMB}$	0.22	0.04	0.22	0.15	0.29	1
m_a	0.1	0.01	0.1	0.09	0.12	1
m_d	0.02	0	0.02	0.01	0.03	1
$meanp_{ALB}$	1.69	0.1	1.68	1.49	1.88	1
$meanp_{LMB}$	1.9	0.1	1.9	1.7	2.1	1
sd$p$	0.4	0.07	0.4	0.26	0.56	1
vr$_{ALB}$	0.9	0.02	0.9	0.87	0.93	1
vr$_{LMB}$	0.94	0.02	0.94	0.91	0.97	1
S_{ALB}	0.28	0.04	0.28	0.2	0.35	1
S_{LMB}	0.34	0.03	0.34	0.28	0.4	1
TL_{ALB}	0.15	0.02	0.15	0.11	0.2	1
TL_{LMB}	0.08	0.02	0.08	0.04	0.12	1
TM_{ALB}	0.04	0.03	0.03	0	0.1	1
TM_{LMB}	0.02	0.01	0.01	0	0.06	1
Z_{ALB}	1.28	0.14	1.27	1.04	1.6	1
Z_{ALB}	1.09	0.09	1.09	0.92	1.26	1
$\lambda_{NT,\$100}$	0.76	0.08	0.76	0.61	0.91	1
$\lambda_{NT,\$200}$	0.86	0.08	0.86	0.7	0.99	1
$\lambda_{T,\$100}$	0.48	0.06	0.47	0.38	0.62	1
$\lambda_{T,\$200}$	0.56	0.07	0.55	0.44	0.71	1

Table 12: Parameter values from model F'(4),M(%),λ(c),a_T(s) when ran under a range of \$300 angler reporting rate scenarios.

parameter	$\lambda_{\$300} = 1$ mean (95 CI)	$\lambda_{\$300} = 0.9$ mean (95 CI)	$\lambda_{\$300} = 0.8$ mean (95 CI)	$\lambda_{\$300} = 0.7$ mean (95 CI)
$F_{NT,ALB}$	0.01 (0-0.1)	0.02 (0-0.13)	0.03 (0-0.17)	0.04 (0-0.23)
$F_{NT,LMB}$	0 (0-0.01)	0 (0-0.01)	0 (0-0.01)	0 (0-0.01)
$F_{T,ALB}$	0.09 (0.01-0.22)	0.12 (0.02-0.27)	0.14 (0.03-0.31)	0.17 (0.04-0.36)
$F_{T,LMB}$	0.01 (0-0.05)	0.01 (0-0.05)	0.01 (0-0.06)	0.01 (0-0.08)
$F_{h,ALB}$	0.11 (0.07-0.16)	0.12 (0.08-0.17)	0.13 (0.08-0.18)	0.13 (0.09-0.19)
$F_{h,LMB}$	0.04 (0.02-0.07)	0.04 (0.02-0.07)	0.05 (0.02-0.07)	0.05 (0.02-0.08)
$F'_{NT,ALB}$	1 (0.81-1.22)	1.07 (0.86-1.31)	1.13 (0.91-1.39)	1.19 (0.96-1.46)
$F'_{NT,LMB}$	0.62 (0.49-0.78)	0.67 (0.53-0.83)	0.71 (0.56-0.88)	0.75 (0.59-0.92)
$F'_{T,ALB}$	0.63 (0.49-0.8)	0.68 (0.52-0.88)	0.73 (0.56-0.93)	0.78 (0.6-1)
$F'_{T,LMB}$	0.53 (0.42-0.67)	0.57 (0.45-0.71)	0.61 (0.48-0.75)	0.64 (0.5-0.79)
M_{ALB}	1.04 (0.76-1.35)	0.97 (0.68-1.29)	0.9 (0.6-1.23)	0.83 (0.51-1.17)
M_{LMB}	0.91 (0.73-1.12)	0.88 (0.69-1.09)	0.85 (0.66-1.06)	0.82 (0.63-1.03)
$a_{NT,ALB}$	0.01 (0-0.09)	0.02 (0-0.12)	0.02 (0-0.14)	0.03 (0-0.18)
$a_{NT,LMB}$	0 (0-0.01)	0 (0-0.02)	0 (0-0.02)	0 (0-0.02)
$a_{T,ALB}$	0.15 (0.02-0.33)	0.17 (0.03-0.36)	0.19 (0.04-0.39)	0.22 (0.05-0.42)
$a_{T,LMB}$	0.02 (0-0.09)	0.02 (0-0.1)	0.02 (0-0.1)	0.02 (0-0.12)
m_a	0.1 (0.09-0.12)	0.1 (0.09-0.12)	0.1 (0.09-0.12)	0.1 (0.09-0.12)
m_d	0.02 (0.01-0.03)	0.02 (0.01-0.03)	0.02 (0.01-0.03)	0.02 (0.01-0.03)
$meanp_{ALB}$	1.67 (1.49-1.87)	1.67 (1.49-1.86)	1.68 (1.49-1.88)	1.68 (1.49-1.87)
$meanp_{LMB}$	1.89 (1.71-2.09)	1.89 (1.7-2.08)	1.9 (1.7-2.1)	1.89 (1.7-2.09)
sd$p$	0.4 (0.27-0.55)	0.39 (0.26-0.54)	0.4 (0.27-0.55)	0.4 (0.27-0.55)
vr$_{ALB}$	0.9 (0.86-0.93)	0.9 (0.86-0.93)	0.9 (0.86-0.93)	0.9 (0.86-0.93)
vr$_{LMB}$	0.94 (0.9-0.97)	0.94 (0.9-0.97)	0.94 (0.9-0.97)	0.94 (0.91-0.97)
S_{ALB}	0.29 (0.21-0.37)	0.3 (0.22-0.38)	0.31 (0.23-0.39)	0.31 (0.23-0.4)
S_{LMB}	0.38 (0.31-0.46)	0.4 (0.32-0.47)	0.41 (0.33-0.49)	0.42 (0.34-0.5)
TL_{ALB}	0.13 (0.09-0.17)	0.12 (0.08-0.17)	0.12 (0.08-0.16)	0.12 (0.08-0.16)
TL_{LMB}	0.07 (0.04-0.1)	0.07 (0.04-0.1)	0.06 (0.04-0.1)	0.06 (0.03-0.1)
TM_{ALB}	0.05 (0.01-0.12)	0.06 (0.01-0.13)	0.06 (0.01-0.13)	0.06 (0.01-0.13)
TM_{LMB}	0.03 (0-0.08)	0.03 (0-0.08)	0.03 (0-0.08)	0.03 (0-0.08)
Z_{ALB}	1.26 (1-1.56)	1.23 (0.97-1.52)	1.19 (0.94-1.49)	1.17 (0.92-1.47)
Z_{ALB}	0.96 (0.78-1.17)	0.93 (0.75-1.14)	0.91 (0.72-1.12)	0.88 (0.69-1.09)
$\lambda_{NT,\$100}$	0.76 (0.67-0.85)	0.72 (0.64-0.81)	0.69 (0.61-0.78)	0.67 (0.59-0.75)
$\lambda_{NT,\$200}$	0.86 (0.77-0.97)	0.83 (0.73-0.93)	0.79 (0.7-0.89)	0.77 (0.68-0.86)
$\lambda_{NT,\$300}$	1 (1-1)	0.9 (0.9-0.9)	0.8 (0.8-0.8)	0.7 (0.7-0.7)
$\lambda_{T,\$100}$	0.76 (0.67-0.85)	0.72 (0.64-0.81)	0.69 (0.61-0.78)	0.67 (0.59-0.75)
$\lambda_{T,\$200}$	0.86 (0.77-0.97)	0.83 (0.73-0.93)	0.79 (0.7-0.89)	0.77 (0.68-0.86)
$\lambda_{T,\$300}$	1 (1-1)	0.9 (0.9-0.9)	0.8 (0.8-0.8)	0.7 (0.7-0.7)

Figures

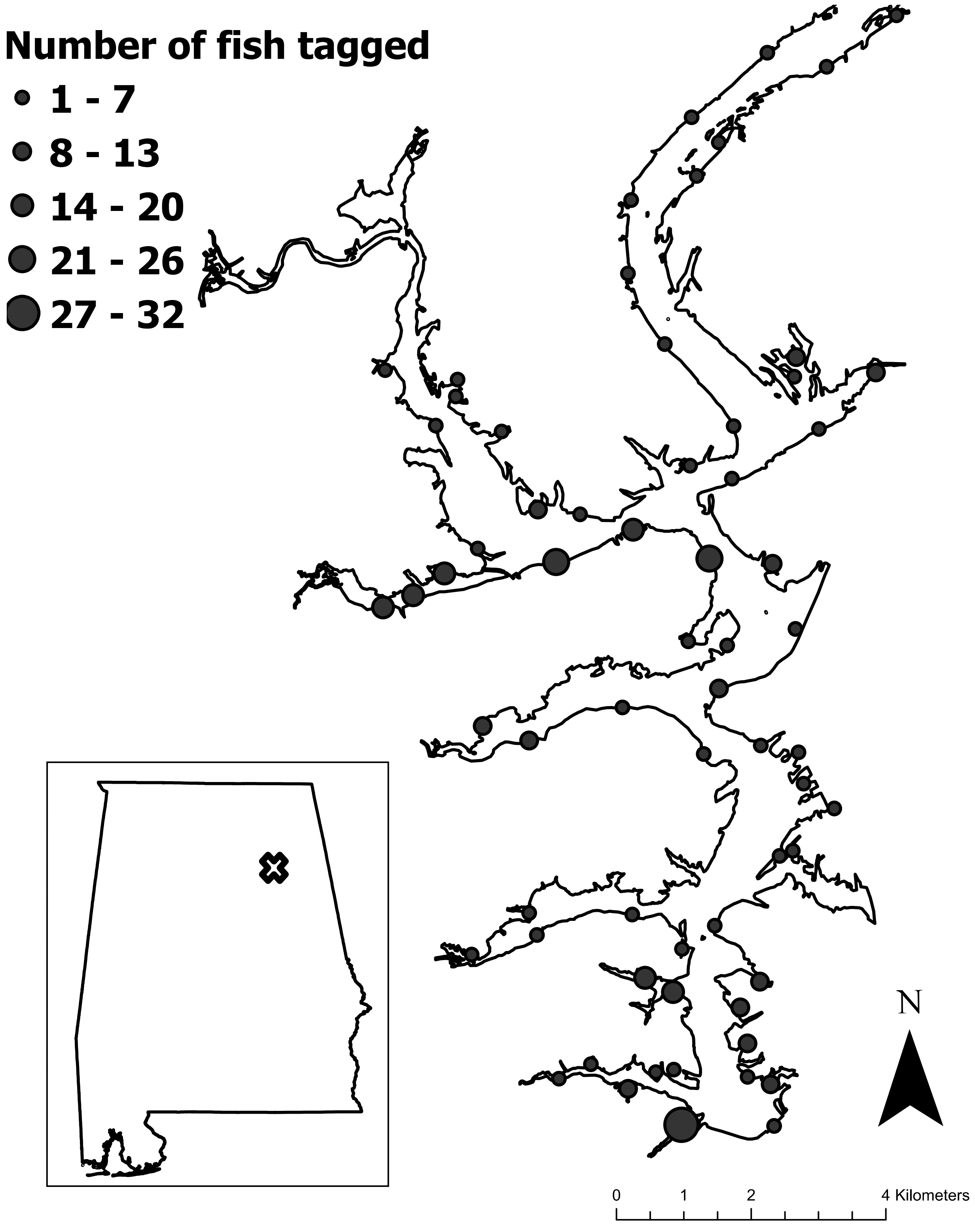

Figure 1. Map of the number of Largemouth and Alabama Bass tagged per site from January-February 2022 in lower Neely Henry Reservoir.

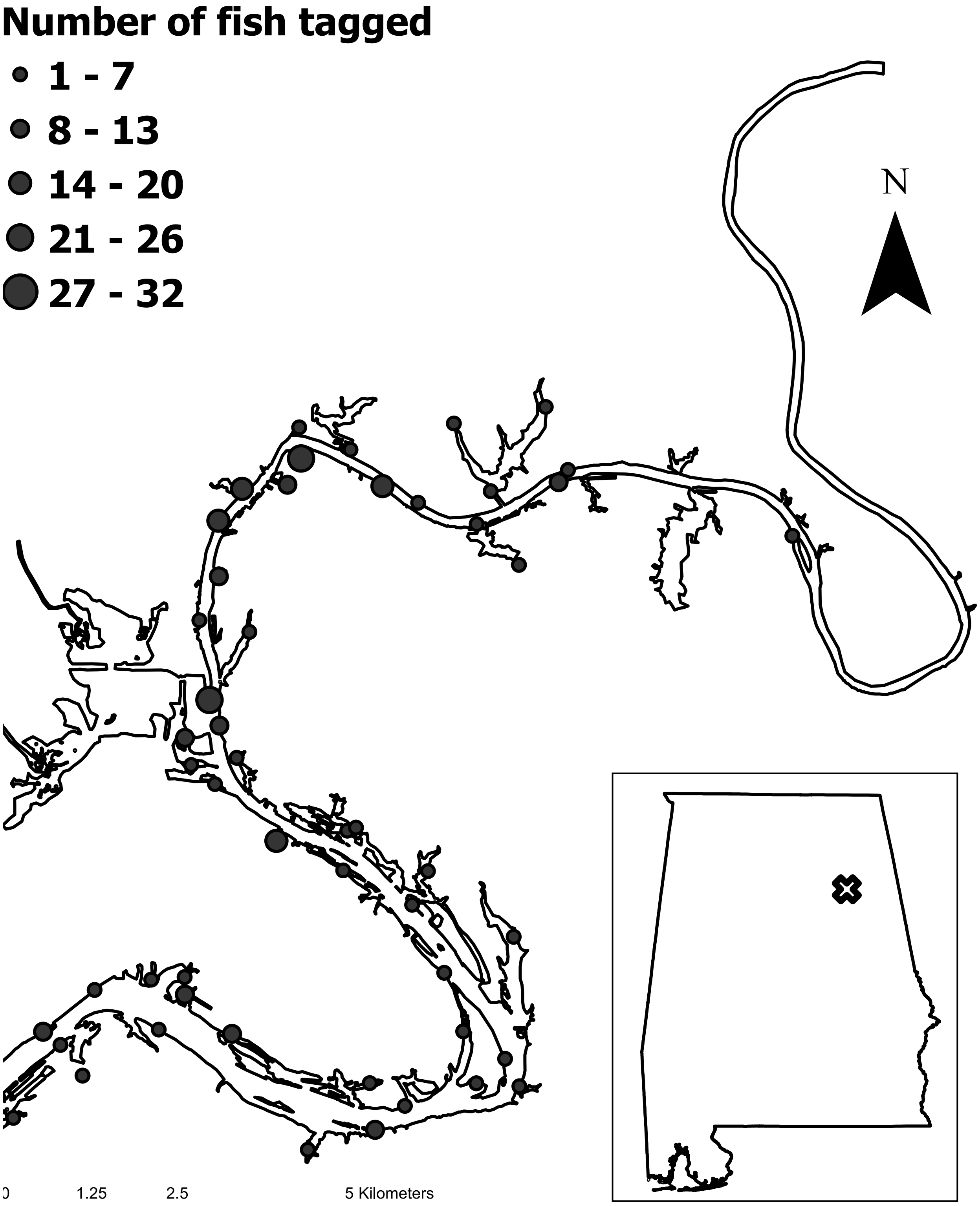

Figure 2. Map of number of fish tagged per site from January-February 2022 in upper Neely Henry Reservoir.

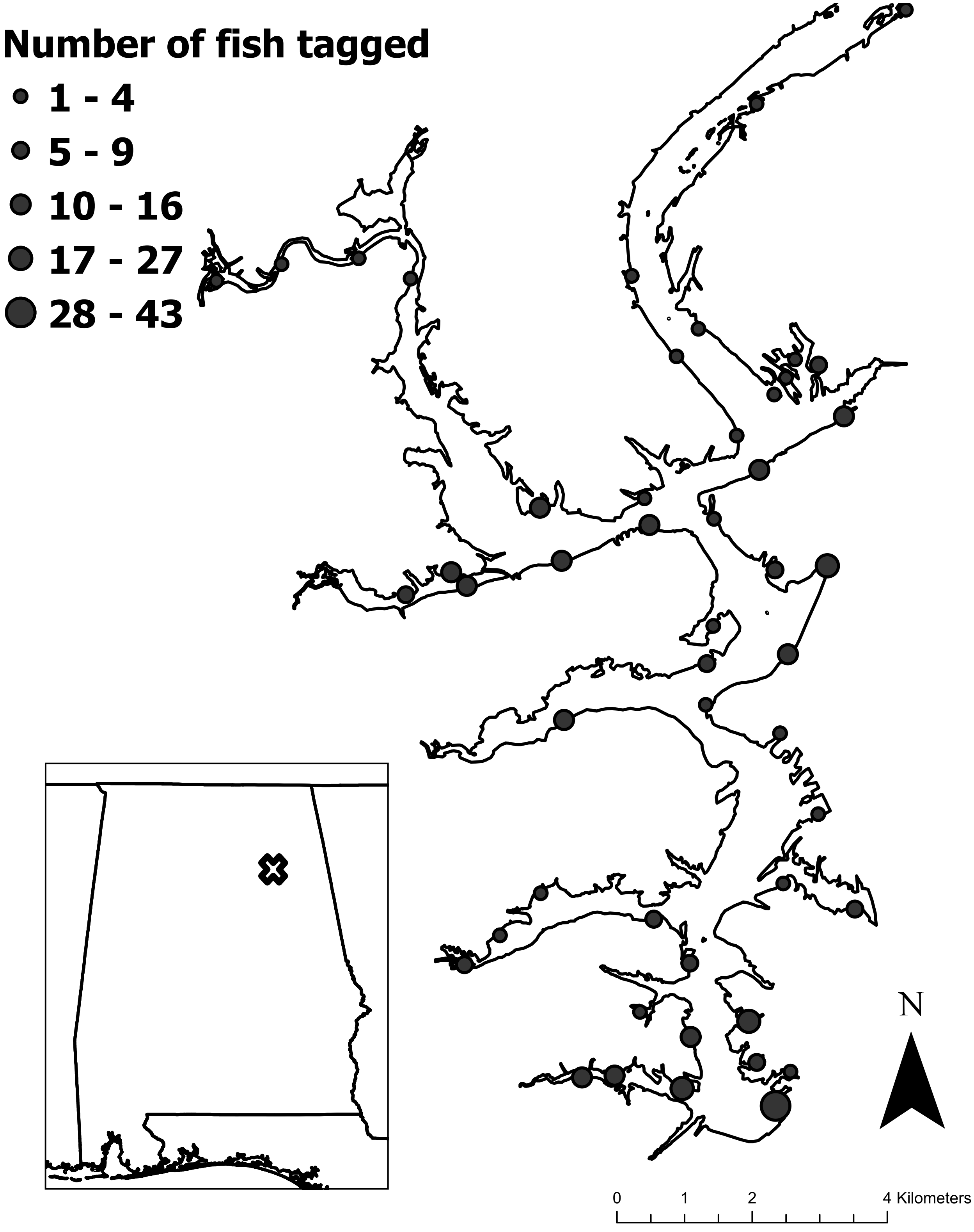

Figure 3. Map of number of fish tagged per site from December 2022-January 2023 in lower Neely Henry Reservoir.

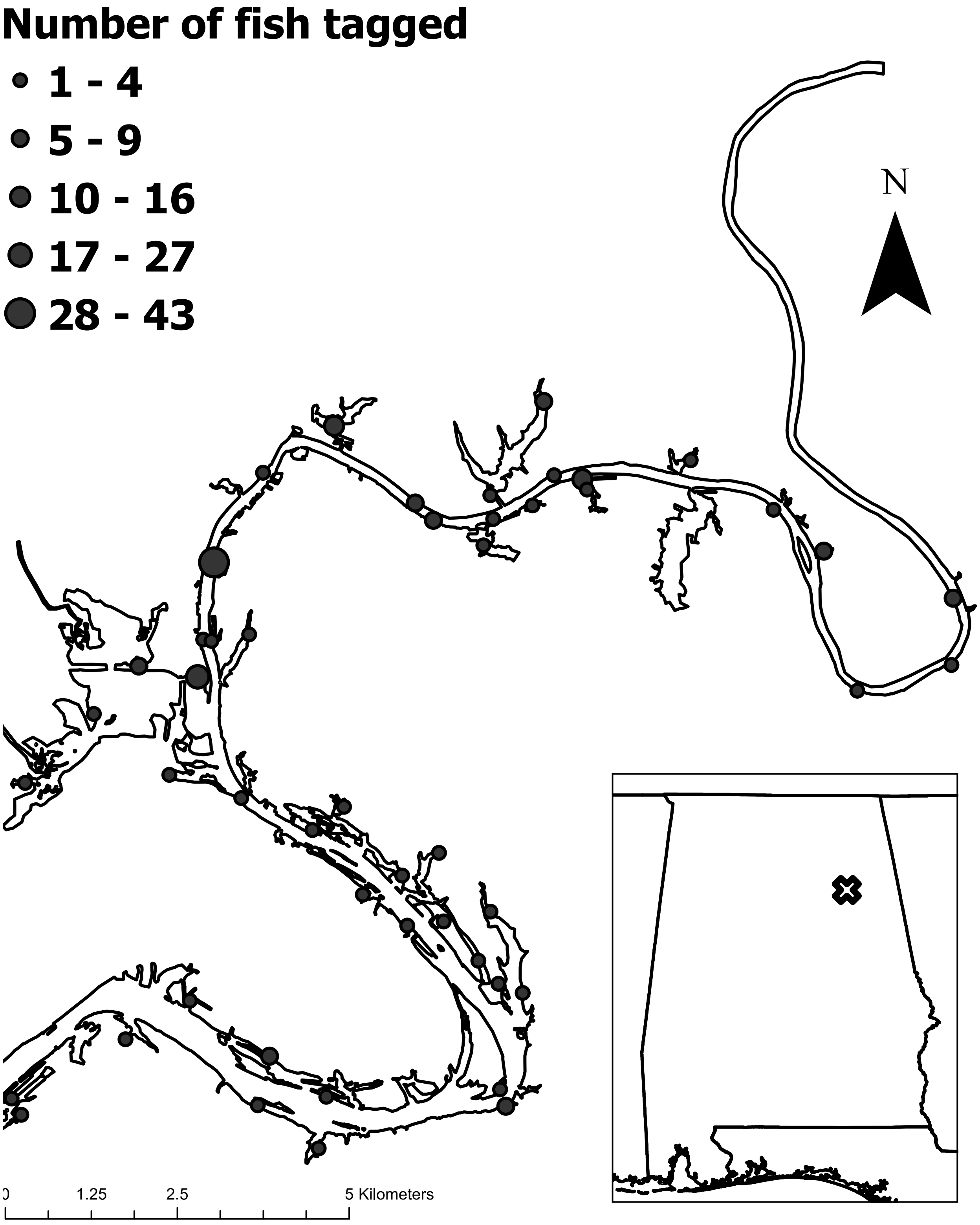

Figure 4. Map of number of fish tagged per site from December 2022-January 2023 in upper Neely Henry Reservoir.

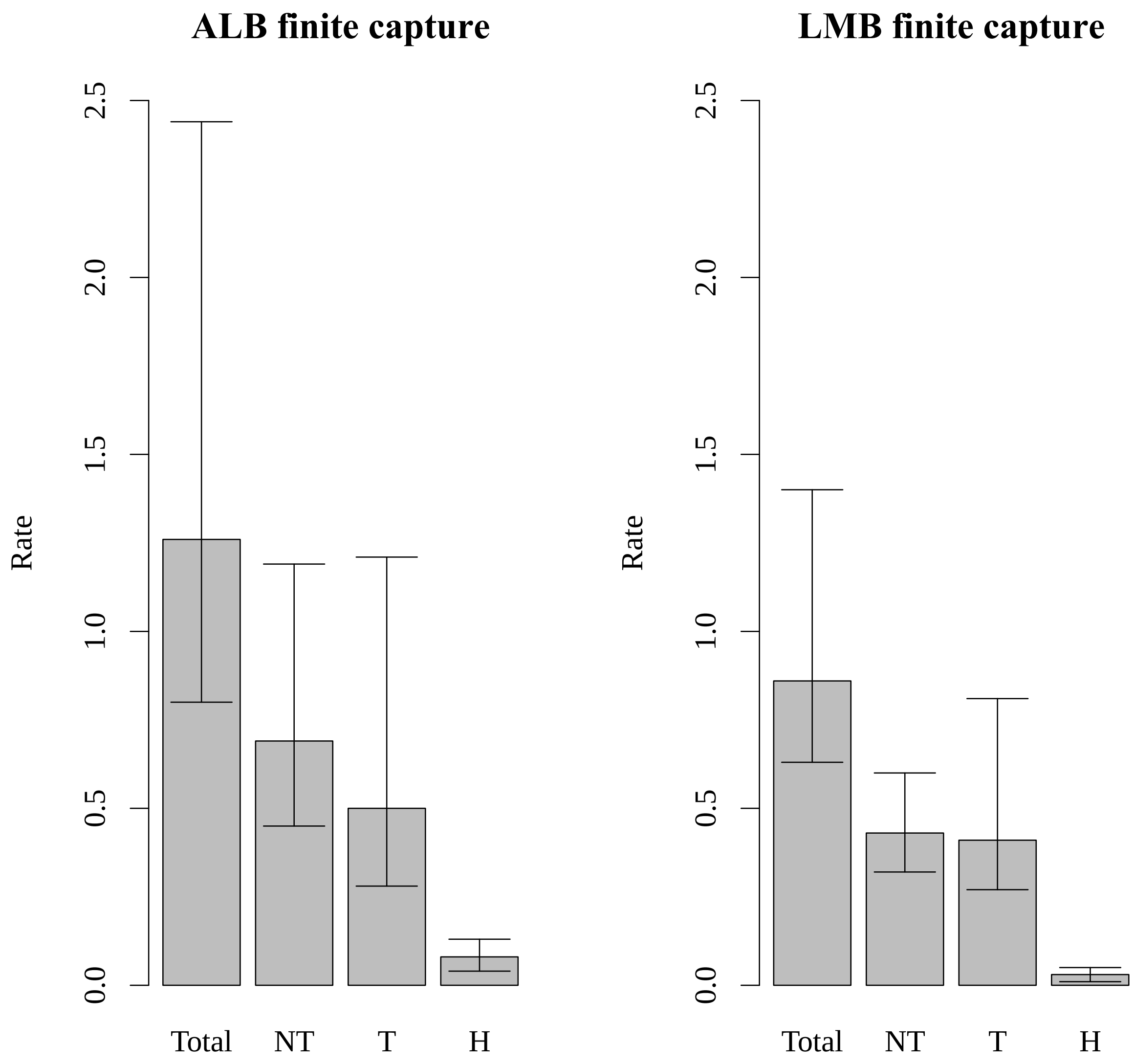

Figure 5. Annual finite non-tournament catch-and-release, tournament capture, and harvest rates (+/- 95%CI) for Alabama Bass (left panel) and Largemouth Bass (right panel) at Neely Henry Reservoir.

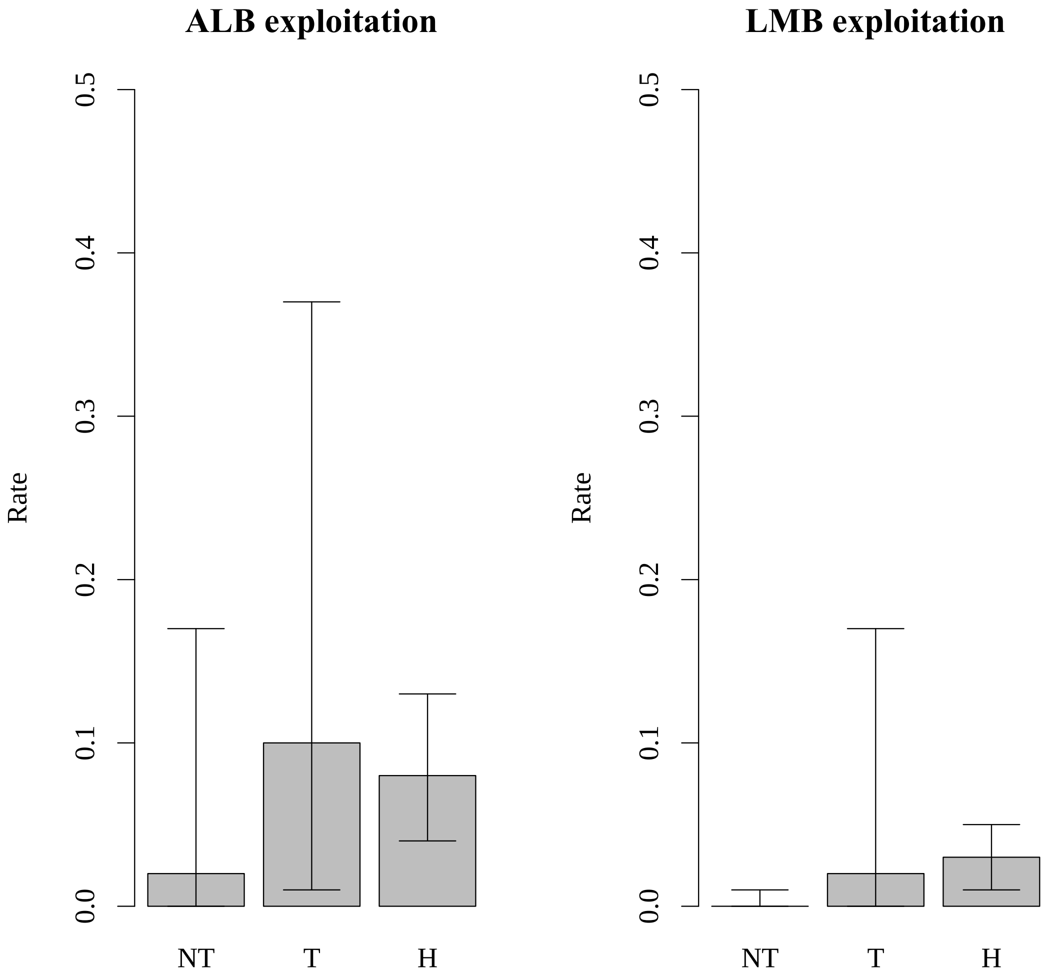

Figure 6. Annual finite non-tournament catch-and-release, tournament, and harvest exploitation rates (+/- 95%CI) of Alabama Bass (left panel) and Largemouth Bass (right panel) at Neely Henry Reservoir.

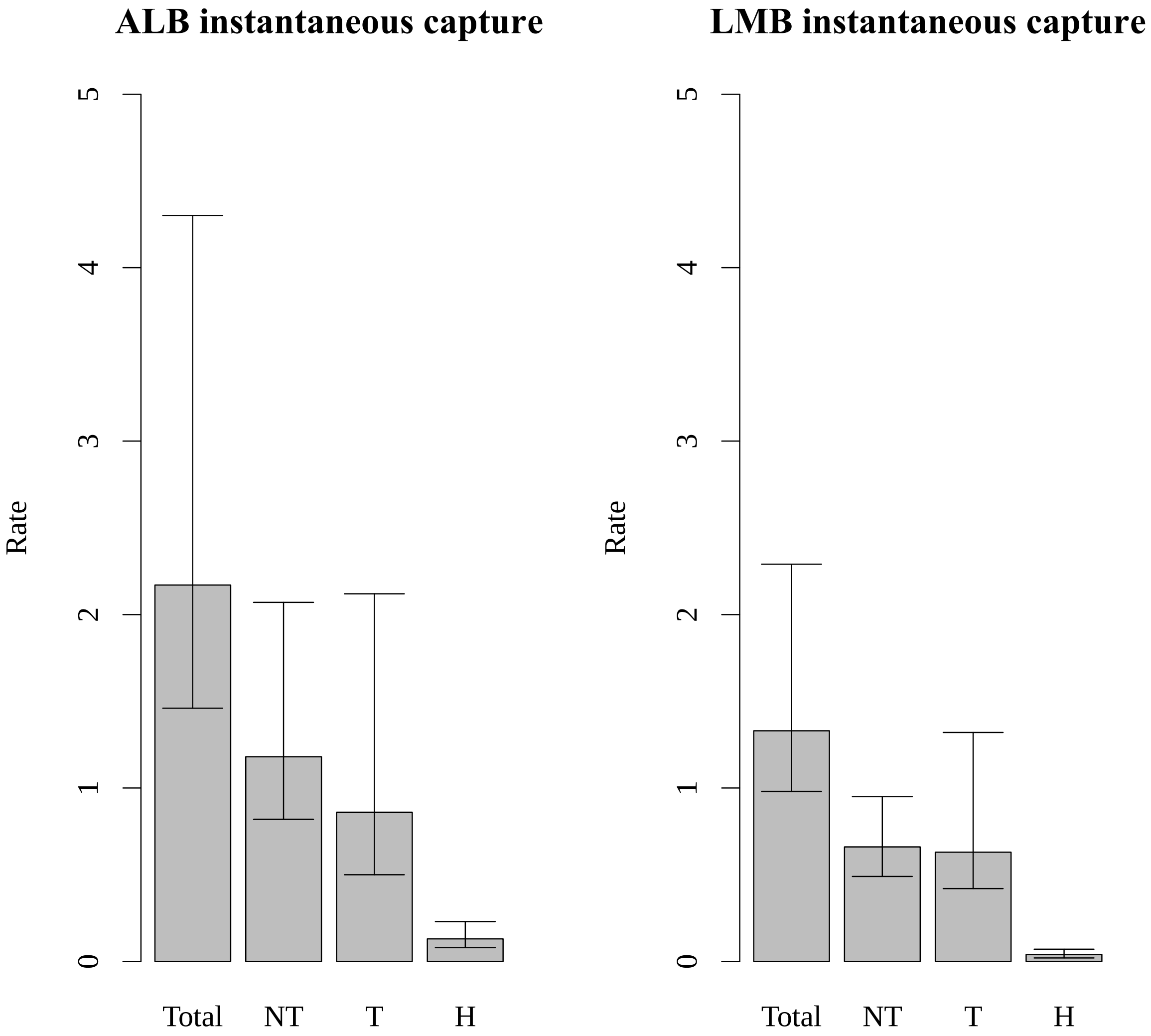

Figure 7. Instantaneous annual total, non-tournament catch-and-release, tournament, and harvest capture rates (+/- 95%CI) of Alabama Bass (left panel) and Largemouth Bass (right panel) at Neely Henry Reservoir.

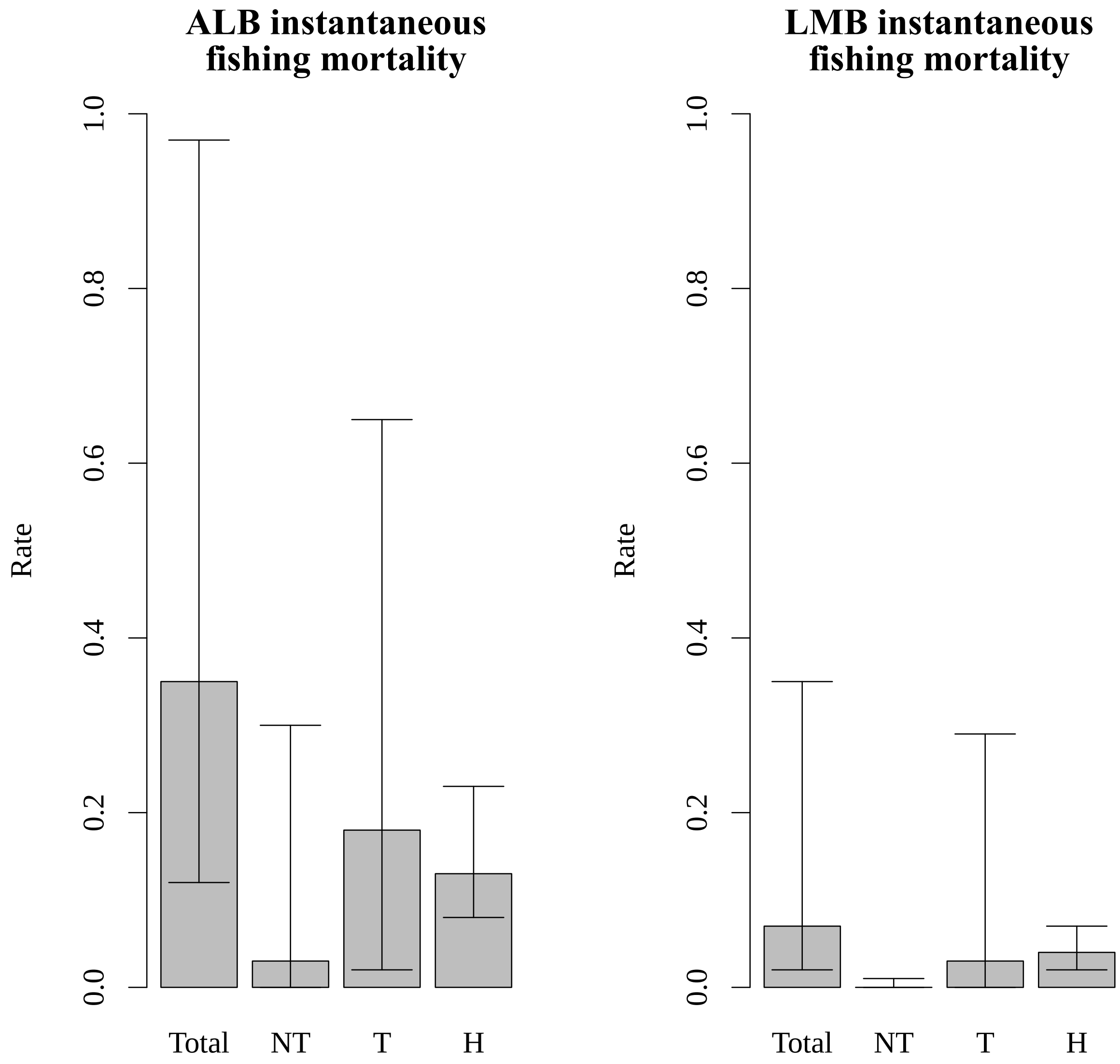

Figure 8. Instantaneous annual total fishing, non-tournament catch-and-release, tournament, and harvest mortality rates (+/- 95%CI) of Alabama Bass (left panel) and Largemouth Bass (right panel) at Neely Henry Reservoir.

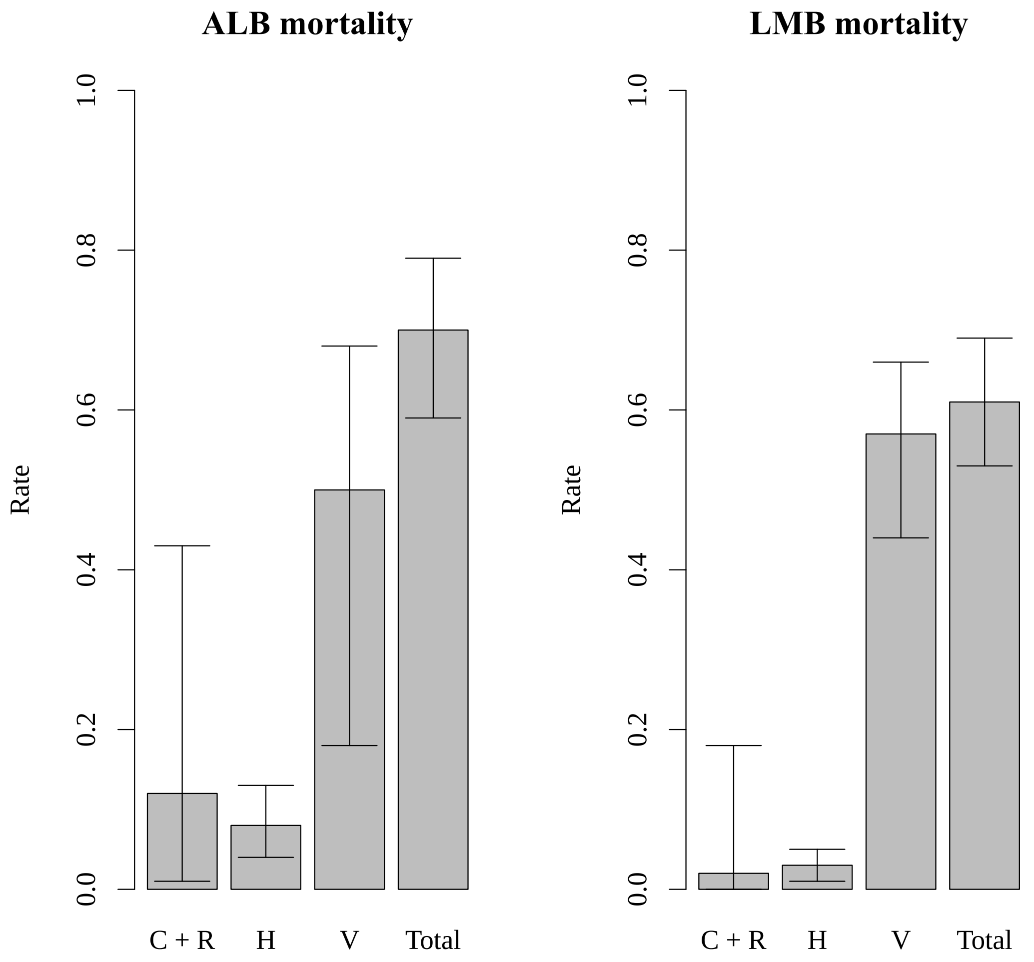

Figure 9. Annual finite catch-and-release fishing, harvest, natural, and total mortality rates (+/- 95%CI) of Alabama Bass (left panel) and Largemouth Bass (right panel) at Neely Henry Reservoir**.**

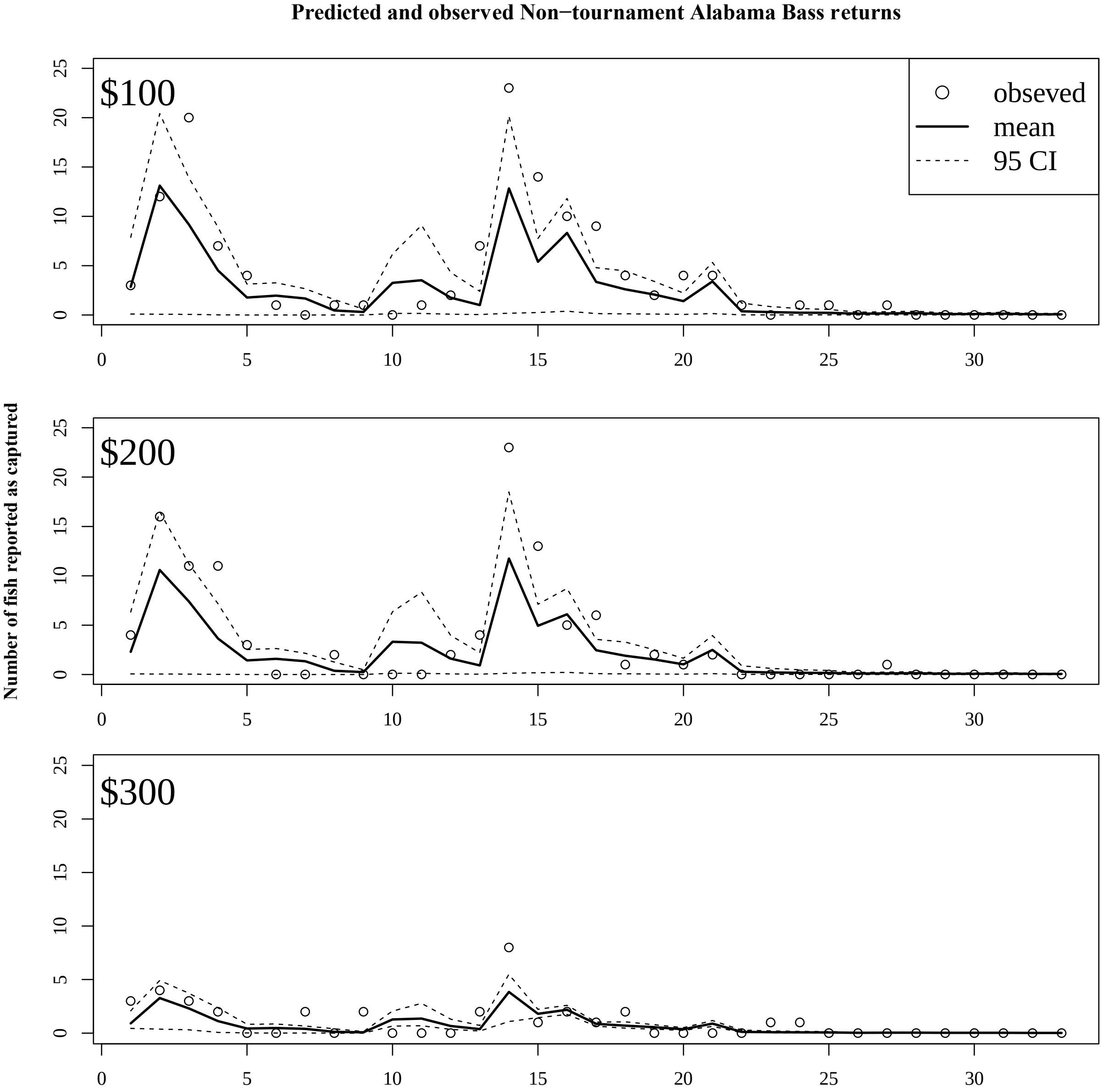

Figure 10. Posterior mean (solid line), 95% credible intervals (dahsed lines), and observed non-tournament angler tag returns for Alabama Bass for $100 (top panel), $200 (middle), and $300 (lower) reward tags.

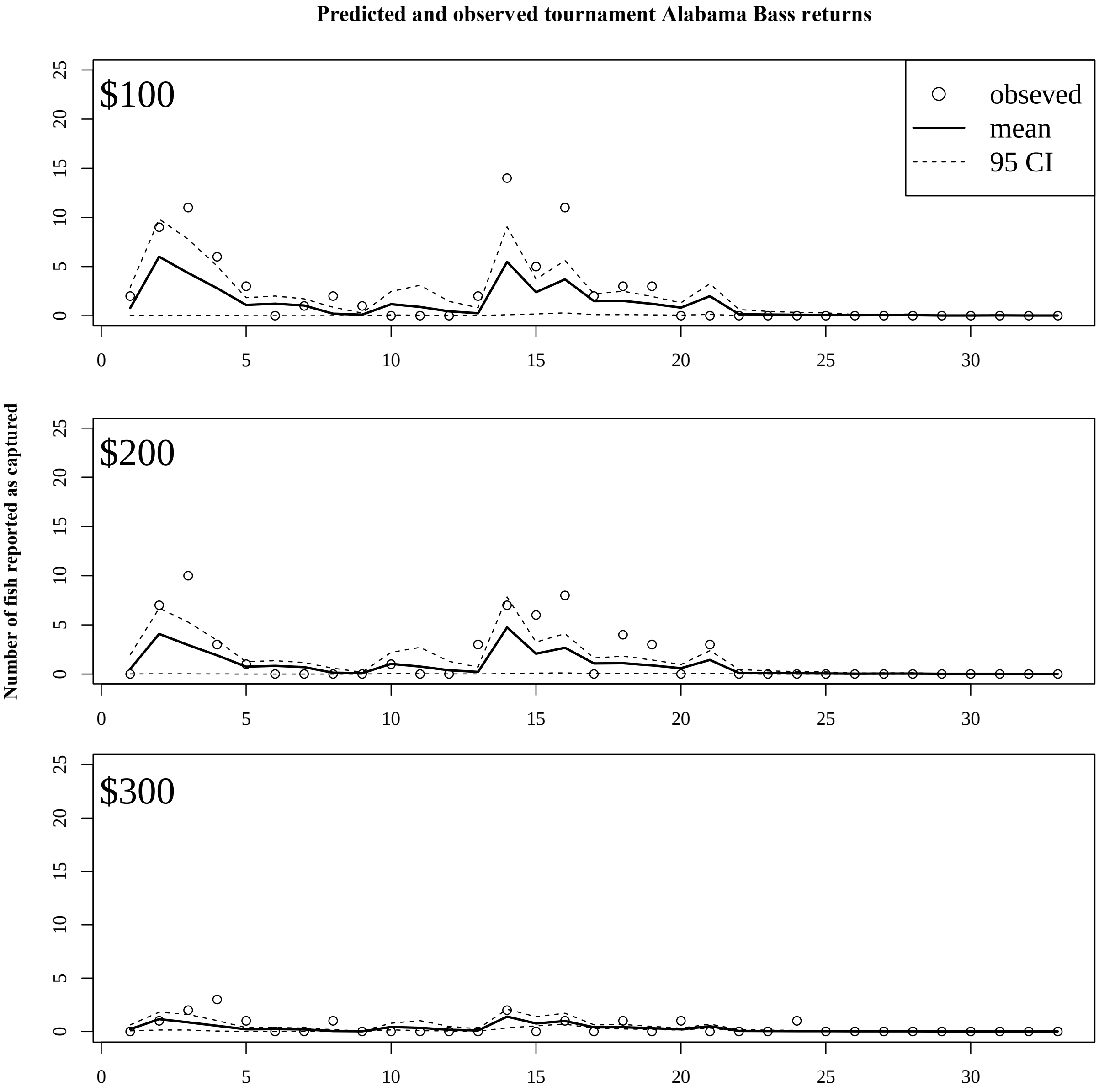

Figure 11. Posterior mean (solid line), 95% credible intervals (dahsed lines), and observed tournament angler tag returns for Alabama Bass for $100 (top panel), $200 (middle), and $300 (lower) reward tags.

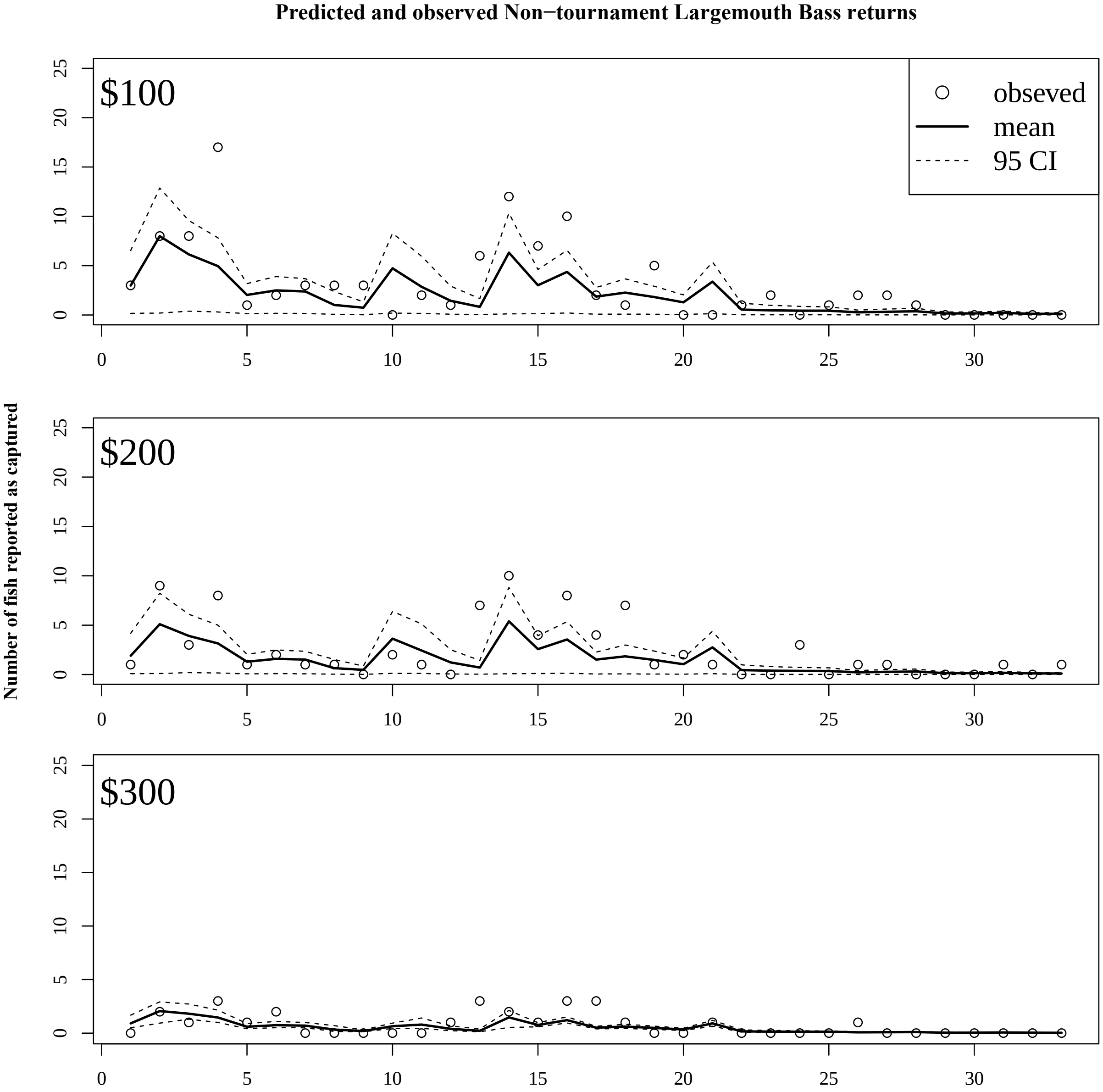

Figure 12. Posterior mean (solid line), 95% credible intervals (dahsed lines), and observed non-tournament angler tag returns for Largemouth Bass for $100 (top panel), $200 (middle), and $300 (lower) reward tags.

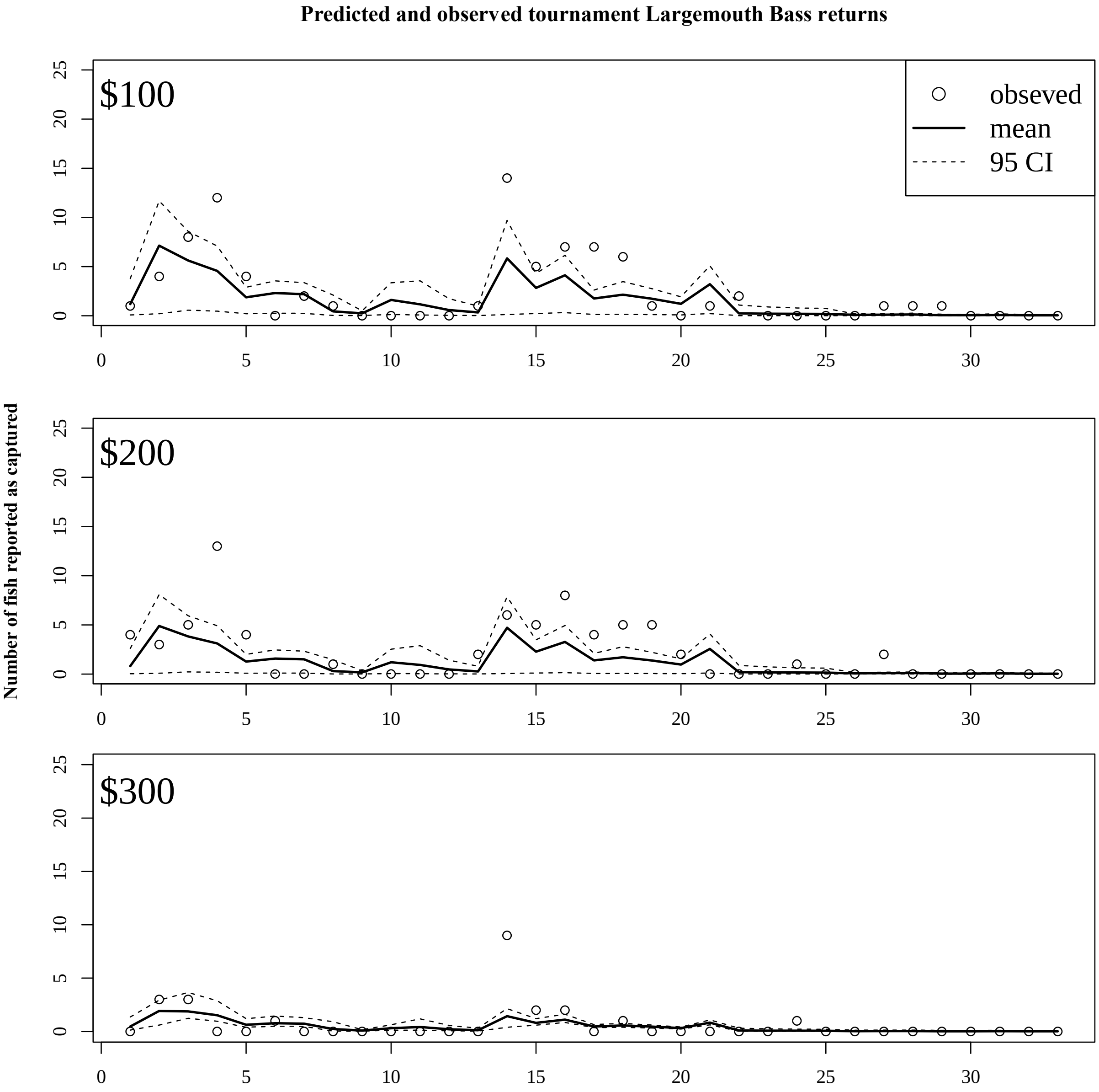

Figure 13. Posterior mean (solid line), 95% credible intervals (dahsed lines), and observed tournament angler tag returns for Largemouth Bass for $100 (top panel), $200 (middle), and $300 (lower) reward tags.

Appendix A: Function to marginalize over latent states of fish. probInit represents the probability of tagging mortality and tag shedding, probTrans is the biological state transition matrix, and probObs is the observed state transition matrix.

```
dHMM <- nimbleFunction(
     run = function(x = double(1),
                  probInit = double(1), # vector of initial states
                  probObs = double(3), #observation matrix
                  probTrans = double(3), # transition matrix
                  len = double(0, default = 0), # number of sampling occasions
                  log = integer(0, default = 0)) {
       alpha <- probInit[1:15]
       for (t in 2:len) {
         alpha[1:15] <- (alpha[1:15] %*% probTrans[t-1,1:15,1:15]) * probObs[t,1:15,x[t]]
       }
       logL <- log(sum(alpha[1:15]))
       returnType(double(0))
       if (log) return(logL)
       return(exp(logL))
     }
   )
```

Appendix B: Function to generate random deviates for dHMM function

```
rHMM <- nimbleFunction(
  run = function(n = integer(),
                 probInit = double(1),
                 probObs = double(3),
                 probTrans = double(3),
                 len = double(0, default = 0)) {
    returnType(double(1))
    z <- numeric(len)
    z[1] <- rcat(n = 1, prob = probInit[1:15]) # all individuals alive at t = 0
    y <- z
    y[1] <- 1 # all individuals are detected at t = 0
    for (t in 2:len){
      # state at t given state at t-1
      z[t] <- rcat(n = 1, prob = probTrans[t-1,z[t-1],1:15])
      # observation at t given state at t
      y[t] <- rcat(n = 1, prob = probObs[t,z[t],1:17])
    }
    return(y)
  })
```

Appendix C: Additional tables

Table C-1. Angler capture $u'_{\square}$, non-tournament catch-and-release u'_{NT}, tournament capture u'_{T} rate for Alabama Bass and harvest $u_{h}^{\square}$. Results come from model averaging.

	$u'_{\square}$	u'_{NT}	u'_{T}	$u_{h}^{\square}$
mean	1.26	0.69	0.5	0.08
sd	0.44	0.2	0.25	0.02
median	1.1	0.63	0.4	0.07
2.5%	0.8	0.45	0.28	0.04
97.5%	2.44	1.19	1.21	0.13

Table C-2. Angler capture $u'_{\square}$, non-tournament catch-and-release u'_{NT}, tournament capture u'_{T} rate for Largemouth Bass and harvest $u_{h}^{\square}$. Results come from model averaging.

	$u'_{\square}$	u'_{NT}	u'_{T}	$u_{h}^{\square}$
mean	0.86	0.43	0.41	0.03
sd	0.2	0.07	0.14	0.01
median	0.8	0.41	0.36	0.03
2.5%	0.63	0.32	0.27	0.01
97.5%	1.4	0.6	0.81	0.05

Table C-3. Non-tournament catch-and-release u_{NT}, tournament capture u_{T} rate for Alabama Bass and harvest u_{h} exploitation. Results come from model averaging.

	u_{NT}	u_{T}	u_{h}
mean	0.02	0.1	0.08
sd	0.04	0.1	0.02
median	0	0.07	0.07
2.5%	0	0.01	0.04
97.5%	0.17	0.37	0.13

Table C-4. Non-tournament catch-and-release $u_{NT}^{}$, tournament capture $u_{T}^{}$ rate for Largemouth Bass and harvest $u_{h}^{}$ exploitation. Results come from model averaging.

	$u_{NT}^{}$	$u_{T}^{}$	$u_{h}^{}$
mean	0	0.02	0.03
sd	0	0.04	0.01
median	0	0	0.03
2.5%	0	0	0.01
97.5%	0.01	0.17	0.05

Table C-5. Instantaneous angler capture $F'_{\square}$, non-tournament catch-and-release F'_{NT}, tournament capture F'_{T} rate for Alabama Bass and harvest $F_{h}^{\square}$. Results come from model averaging.

	$F'_{\square}$	F'_{NT}	F'_{T}	$F_{h}^{\square}.$
mean	2.17	1.18	0.86	0.13
sd	0.77	0.34	0.43	0.04
median	1.86	1.06	0.68	0.12
2.5%	1.46	0.82	0.5	0.08
97.5%	4.3	2.07	2.12	0.23

Table C-6. Instantaneous angler capture $F'_{\square}$, non-tournament catch-and-release F'_{NT}, tournament capture F'_{T} rate for Largemouth Bass and harvest $F_{h}^{\square}$. Results come from model averaging.

	$F'_{\square}$	F'_{NT}	F'_{T}	$F_{h}^{\square}$.
mean	1.33	0.66	0.63	0.04
sd	0.32	0.11	0.22	0.01
median	1.23	0.64	0.55	0.04
2.5%	0.98	0.49	0.42	0.02
97.5%	2.29	0.95	1.32	0.07

Table C-7. Instantaneous fishing F, non-tournament catch-and-release F_{NT}, tournament F_{T} and harvest F_{h} mortality rates for Alabama Bass. Results come from model averaging.

	F	F_{NT}	F_{T}	F_{h}.
mean	0.35	0.03	0.18	0.13
sd	0.24	0.08	0.17	0.04
median	0.26	0	0.12	0.12
2.5%	0.12	0	0.02	0.08
97.5%	0.97	0.3	0.65	0.23

Table C-8. Instantaneous fishing $F_{\square}^{\square}$, non-tournament catch-and-release $F_{NT}^{\square}$, tournament $F_{T}^{\square}$ and harvest $F_{h}^{\square}$mortality rates for Largemouth Bass. Results come from model averaging.

	$F_{\square}^{\square}$	$F_{NT}^{\square}$	$F_{T}^{\square}$	$F_{h}^{\square}.$
mean	0.07	0	0.03	0.04
sd	0.07	0.01	0.07	0.01
median	0.05	0	0	0.04
2.5%	0.02	0	0	0.02
97.5%	0.35	0.01	0.29	0.07

Table C-9. Angler capture $u'_{\square}$, non-tournament catch-and-release u'_{NT}, tournament capture u'_{T} rate for Largemouth Bass and harvest $u_{h}^{\square}$. Results come from model averaging.

	$u'_{\square}$	u'_{NT}	u'_{T}	$u_{h}^{\square}$
mean	0.86	0.43	0.41	0.03
sd	0.2	0.07	0.14	0.01
median	0.8	0.41	0.36	0.03
2.5%	0.63	0.32	0.27	0.01
97.5%	1.4	0.6	0.81	0.05

Table C-10. Non-tournament catch-and-release u_{NT}, tournament capture u_{T} rate for Alabama Bass and harvest u_{h} exploitation. Results come from model averaging.

	u_{NT}	u_{T}	u_{h}
mean	0.02	0.1	0.08
sd	0.04	0.1	0.02
median	0	0.07	0.07
2.5%	0	0.01	0.04
97.5%	0.17	0.37	0.13

Table C-11. Non-tournament catch-and-release u_{NT}, tournament capture u_{T} rate for Largemouth Bass and harvest u_{h} exploitation. Results come from model averaging.

	u_{NT}	u_{T}	u_{h}
mean	0	0.02	0.03
sd	0	0.04	0.01
median	0	0	0.03
2.5%	0	0	0.01
97.5%	0.01	0.17	0.05

Table C-12. Instantaneous angler capture $F'_{\square}$, non-tournament catch-and-release F'_{NT}, tournament capture F'_T rate for Alabama Bass and harvest $F_h^{\square}$. Results come from model averaging.

	$F'_{\square}$	F'_{NT}	F'_T	$F_h^{\square}.$
mean	2.17	1.18	0.86	0.13
sd	0.77	0.34	0.43	0.04
median	1.86	1.06	0.68	0.12
2.5%	1.46	0.82	0.5	0.08
97.5%	4.3	2.07	2.12	0.23

Table C-13. Instantaneous angler capture $F'_{\square}$, non-tournament catch-and-release F'_{NT}, tournament capture F'_{T} rate for Largemouth Bass and harvest $F_{h}^{\square}$. Results come from model averaging.

	$F'_{\square}$	F'_{NT}	F'_{T}	$F_{h}^{\square}.$
mean	1.33	0.66	0.63	0.04
sd	0.32	0.11	0.22	0.01
median	1.23	0.64	0.55	0.04
2.5%	0.98	0.49	0.42	0.02
97.5%	2.29	0.95	1.32	0.07

Table C-14. Instantaneous fishing $F_{\square}^{\square}$, non-tournament catch-and-release $F_{NT}^{\square}$, tournament $F_{T}^{\square}$ and harvest $F_{h}^{\square}$mortality rates for Alabama Bass. Results come from model averaging.

	$F_{\square}^{\square}$	$F_{NT}^{\square}$	$F_{T}^{\square}$	$F_{h}^{\square}$.
mean	0.35	0.03	0.18	0.13
sd	0.24	0.08	0.17	0.04
median	0.26	0	0.12	0.12
2.5%	0.12	0	0.02	0.08
97.5%	0.97	0.3	0.65	0.23

Table C-15. Instantaneous fishing $F_{\square}^{\square}$, non-tournament catch-and-release $F_{NT}^{\square}$, tournament $F_{T}^{\square}$ and harvest $F_{h}^{\square}$mortality rates for Largemouth Bass. Results come from model averaging.

	$F_{\square}^{\square}$	$F_{NT}^{\square}$	$F_{T}^{\square}$	$F_{h}^{\square}.$
mean	0.07	0	0.03	0.04
sd	0.07	0.01	0.07	0.01
median	0.05	0	0	0.04
2.5%	0.02	0	0	0.02
97.5%	0.35	0.01	0.29	0.07

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