Fishing and Natural Mortality of Bodie Bass Estimated Using a High-Reward Tag-Return Method

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Abstract. Hybrid Striped Bass, also officially known as Bodie Bass in North Carolina, are stocked by fisheries managers in reservoirs across North Carolina to create unique fishing opportunities for anglers. Their schooling behavior, lack of natural reproduction, and popularity with anglers make them vulnerable to overharvest in land-locked reservoirs. In Lake Norman, Bodie Bass have been stocked by the North Carolina Wildlife Resources Commission (Commission) since 2013 and quickly became a popular fishery. Following overharvest concerns, a tagging study was initiated to examine the impacts of fishing pressure on the population. A total of 1,462 Bodie Bass were caught and tagged with a high-reward tag between December 2015 and November 2018. Anglers who caught tagged Bodie Bass were asked to remove the tag, return it to the Commission, and disclose valuable information regarding harvest, release, method of capture, bait, and other details. A total of 931 tagged Bodie Bass were recaptured (64%). Based on returned tags and angler information, annual instantaneous fishing mortality (*F*) ranged from a minimum of 0.33 (95% CI = 0.26–0.41) in 2016 to a maximum of 0.42 (95% CI = 0.36–0.49) in 2018. Total instantaneous mortality (*Z*) estimates ranged from 0.53 (95% CI = 0.44–0.64) in 2016 to 0.65 (95% CI = 0.55–0.76) in 2018. Subsequent discrete annual mortality rates (*A*) ranged from 0.41 (95% CI = 0.36–0.47) in 2016 to 0.48 (95% CI = 0.42–0.53) in 2018, indicating that approximately 41–48% of the harvestable Bodie Bass population succumb to mortality annually. Seasonally, *F* was highest on average in spring, followed by winter, whereas fall and summer had low fishing mortality. Prior to this study, anglers voiced concerns about the overharvest of Bodie Bass at locations with thermal discharge, where Bodie Bass were known to congregate, and bank angling was popular. This project found that bank anglers recaptured Bodie Bass at these thermal discharge locations primarily during winter and the number of fish recaptured varied greatly, likely due to environmental conditions. Overall, boat anglers have a larger, more consistent, impact on the Bodie Bass population than bank anglers, natural and fishing mortality estimates indicate a substantial portion of the population is removed annually, and increased stocking rates and regulations to reduce Bodie Bass harvest are warranted.

Striped Bass *Morone saxatilis* and hybrid Striped Bass *M. chrysops X M. saxatilis*, or Bodie Bass as they are officially known in North Carolina, are often stocked by the North Carolina Wildlife Resources Commission (Commission) into inland freshwater reservoirs to create unique opportunities for anglers. Historically, Striped Bass were stocked into the largest reservoir in North Carolina, Lake Norman (Figures 1 and 2). However, due to the introduction of Alewife *Alosa pseudoharengus* in the early 2000s and limited suitable habitat during summer stratification, the frequency and severity of fish kills increased. As a result, the Commission began stocking Bodie Bass in Lake Norman in 2013 (McRae 2010; Abney et al. 2015). Their suspected differences in feeding behavior and higher thermal tolerance made Bodie Bass a more suitable option for this reservoir. Since their introduction into Lake Norman, there have been no major Bodie Bass fish kills in the reservoir (Roberts et al. 2025). Because these fish are unable to reproduce in reservoir systems, reservoir Bodie Bass populations are maintained through annual stockings. Bodie Bass populations are often managed by adjusting stocking rates and by establishing size and creel limits for harvest (Hightower and Pollock 2013).

The goal of stocking Bodie Bass in Lake Norman was to create a popular fishery and alleviate issues created by summertime Striped Bass fish kills; however, popular fisheries risk overharvest and often require adaptive management strategies based on mortality estimates. After the Bodie Bass stocking began, anglers expressed concern over perceived high angling pressure. Annual fishing mortality rates (F) were unknown for Bodie Bass in Lake Norman (or any other North Carolina reservoir) before this study. However, high annual fishing mortality rates of Striped Bass were found in Lake Gaston and Badin Lake (F>0.65; Hightower et al. 2001; Thompson et al. 2007), and it was suspected that fishing mortality rates could be high for this fishery as well. In addition, catch-and-release mortality on Bodie Bass is known to be high, especially in seasons with warmer water temperatures (Petersen and Bettoli 2013). Observations from Commission staff suggested that angling pressure was high for Bodie Bass near the thermal discharges of Marshall Steam Station in the winter and below Lookout Shoals dam in the spring. All of these concerns resulted in an increased stocking rate in 2016 to the current target rate of approximately 25 fish/ha (325,000 fingerlings). The actual number of fish stocked has varied annually based on hatchery operations (Appendix A). Additionally, the minimum size limit for Bodie Bass increased from 406 mm (TL, total length) to 508 mm in 2022 to reduce harvest and allow for additional growth. The increased stocking rate and restrictive regulations were implemented before the completion of this report but were based on preliminary results from this project. This study was needed to determine fishing mortality, the locations where fish were commonly captured, evaluate current management practices, and inform future management decisions.

Tag-return models are often used to estimate mortality rates of large, widely dispersed populations that are harvested (e.g., Bodie Bass in reservoirs; Brownie et al. 1985; Hightower and Pollock 2013). Hightower and Pollock (2013) indicated that calculating fishing and natural mortality is important to develop proper stocking and harvest regulations; however, distinguishing between fishing and natural mortality is often difficult (Thompson et al. 2007). When the tag-reporting rate is available, total mortality can be partitioned into fishing and natural mortality (Pollock et al. 1991; Hoenig et al. 1998b; Hightower and Pollock 2013). One approach for estimating the reporting rate is by using high-reward tags. When only high-reward tags are used, then the reporting rate is assumed to be 100% (Pollock et al. 2001; Bacheler et al.

2009; Hightower and Pollock 2013). As estimating tag loss is key to most tag return models, a subset of fish can be double-tagged, where the rate of double-tagged fish returned with only one tag is used to estimate the rate of tag loss (Hightower and Pollock 2013). Estimating fishing and natural mortality rates via tagged fish in large reservoir systems requires a study with a 3- to 5-year time span and a minimum of 300 tagged fish per year (Brownie et al. 1985; Pine et al. 2003). Tagged fish should be well mixed within the population because tagging fish only in aggregation areas (e.g., below dams and in thermal discharges) may cause overestimations of fishing mortality (Hoenig et al. 1998a). Hightower and Pollock (2013) outline the main assumptions for tag-return studies, including: (1) tagged fish represent the entire harvestable population not just certain congregations, (2) there is homogenous mortality over all fish considered in the model, (3) the fates of tagged fish are independent, and (4) tag returns are correctly reported by year or season.

This project was part of a comprehensive effort to better understand the population dynamics of Bodie Bass in Lake Norman and across North Carolina. The primary objective of this project was to estimate annual and seasonal fishing and natural mortality of Bodie Bass in Lake Norman using a tag-return model.

Methods

Study site. Lake Norman is an oligotrophic 13,152–ha reservoir impounded on the mainstem of the Catawba River in 1963 in the Piedmont region of North Carolina (DEQ 2023). Lake Norman is operated as a cooling impoundment for two Duke Energy Corporation power-generating facilities (Marshall Steam Station and McGuire Nuclear Station) and has historically received thermal discharge from those facilities. Much of the shoreline is heavily developed with piers, riprap, and bulkhead seawalls. Aquatic cover, such as woody debris and vegetation is relatively rare. Lake Norman contains several fish species of interest to anglers, including Largemouth Bass x Florida Bass hybrids *Micropterus nigricans* x *M. salmoides* (Page et al. 2023), Alabama Bass *M. henshalli*, Bodie Bass *M*. *chrysops* x *M*. *saxatilis,* Crappie *Pomoxis* spp., Blue Catfish *Ictalurus furcatus*, Channel Catfish *I. punctatus*, and Flathead Catfish *Pylodictus olivaris*. Lake Norman is currently stocked annually with approximately 325,000 Bodie Bass fingerlings, at a target rate of 25 fish/ha. Bodie Bass in Lake Norman are managed by the state-wide Striped Bass and Bodie Bass regulation, where 4 fish in combination over 508 mm may be possessed daily.

Tagging Program. To estimate the fishing and natural mortality for Lake Norman Bodie Bass, a tag-return study was conducted from December 2015 to November 2020. Before the start of the project, outreach efforts were initiated to ensure maximum angler participation. Anglers were notified of the tag-return program through signage, which was posted at all major boat ramps and local marinas. Information about the reward for returned tags was made available to local and state information outlets through a press release (i.e., newspapers, television, electronic media outlets). The tagging period occurred from December 2015 to November 2018, and tag returns occurred for the entirety of the project (December 2015 to November 2020). Anglers who recaptured tagged fish were asked to remove and mail the tag(s) to the Commission. Information about the fate of the fish (i.e., harvest versus release), capture location and date, bait used, and type of angling (boat versus bank) was collected via email or phone. Upon receiving tags, anglers were sent a $100 reward per tag. Anglers reported their recapture locations, and these locations were grouped into general recapture locations during analysis.

Tagging Procedure. Bodie Bass were collected by Commission staff and volunteers via hook and line and measured (TL, mm) and weighed (g). Fish were collected throughout the reservoir, rather than at a few centralized locations, to avoid tagging aggregations of fish. Fish measuring close to or greater than the legal minimum size limit of 406 mm (the regulation in place at the time this study was completed) were tagged with a Floy FM-95W Internal Anchor Tag (Floy Tag and Manufacturing Co., Seattle, Washington). Each tag was inserted by making an incision using a scalpel on the left side of the fish, approximately 25 mm posterior to the end of the pectoral fin. Approximately 20% of fish (or every fifth fish) were double tagged (i.e., had one tag inserted on each side) to estimate tag retention. All tags were printed with a unique number (except for double tags), reward amount, and contact information. To achieve adequate monthly sample sizes, a minimum goal of tagging 20 fish per month was attempted. Following tagging, fish recovered in tanks or net pens and were then released as close to the capture location as possible.

Statistical Analyses. To estimate annual and seasonal mortality, we analyzed tag-return data using the instantaneous-rate catch-and-release model developed by Jiang et al. (2007), as implemented in the *fishmethods* package in R (Nelson 2023). This likelihood-based model uses recapture data from both harvested and released fish and estimates instantaneous fishing mortality (*F*), tag-induced mortality (*FA*), and natural mortality (*M*) without requiring explicit age or growth data. The model structure accounts for tag loss, catch-and-release mortality, and variability in recapture timing across periods. Because all fish were tagged with high-reward anchor tags, the reporting rate was assumed to be perfect ($\lambda_h = \lambda_r = 1.0$) for both harvested and released individuals. Based upon returned double-tagged fish and the presence of one versus two tags (see below in **Results**, *Recaptures*) the tag retention rate was set to 0.9.

For the annual model, the hooking mortality rate was set to 0.17, which was an annual average derived from the seasonal mortality estimates from Petersen and Bettoli (2013) that corresponded with the water temperatures Bodie Bass utilized during the Roberts et al. (2025) study on Lake Norman. No studies have previously determined the hooking mortality rate of Bodie Bass in Lake Norman. The model was applied to tagging cohorts from 2016 to 2018, with recapture data extending through 2020. The model estimated annual instantaneous fishing mortality (*F*) and tag-induced mortality (*FA*) for each year from 2016 to 2020, along with constant natural mortality (*M*) via maximum likelihood. Total instantaneous mortality (*Z*) was extracted directly from the fitted model, allowing year-specific comparisons with uncertainty properly propagated from the estimated parameters. Annual discrete mortality rates (*A*) and associated 95% confidence intervals were calculated using the equation $A = 1–e^{-Z}$.

For the seasonal model, the hooking mortality rate was set to 0.04 for winter, 0.04 for spring, 0.4 for summer, and 0.2 for fall, and were approximations based on the Petersen and Bettoli (2013) estimates and approximate corresponding water temperatures determined during the Roberts et al. (2025) study. We estimated seasonal *F* for Bodie Bass in Lake Norman by fitting the 20-period version of the instantaneous-rate tag-return model (5 years X 4 seasons), representing 5 years of quarterly seasonal periods (winter = December, January, February; spring = March, April, May; summer = June, July; August, fall = September, October, November). This model produced maximum likelihood estimates of *F* for each of the 20 seasonal periods, which we present in full (Appendix B) as well as constant natural mortality (*M*) and tag-induced mortality (*FA*) rates. Because maximum likelihood estimates can become unstable when sample sizes are small within individual periods, we saved the fitted model as an RDS file and reloaded it for downstream analysis and plotting. From the saved model, we extracted period-specific estimates of *F* and their standard errors (*SE*), then calculated 95% confidence intervals on the log scale using the delta method (see below). We then summarized these estimates by averaging *F* across years within each season to obtain mean seasonal fishing mortality rates (i.e., one value each for winter, spring, summer, and fall), again using the log-scale delta method to compute confidence intervals for the seasonal means.

For both the annual and seasonal models, we applied the delta method to calculate confidence intervals for derived parameters such as total mortality (*Z*). The delta method is a widely used statistical approximation that estimates the variance of a function based on the variances of its input parameters. Because *Z* is not directly estimated but derived from model parameters (*F*, *FA*, and *M*), their associated uncertainty must be propagated accordingly. To ensure biologically meaningful and statistically valid confidence intervals, including keeping mortality rates strictly positive and between 0 and 1, we applied the delta method on the log scale. This transformation produces asymmetric confidence intervals, meaning the lower and upper bounds are not equally spaced around the estimate. This approach is especially important when mortality estimates are close to zero, because standard symmetric intervals based on normal assumptions can include negative values, which are not biologically realistic. Applying the transformation on the log scale helps keep all confidence limits positive and better reflects the actual shape of the uncertainty around these parameters. All analyses were conducted in R version 4.3.2 (R Core Team 2023).

Results

Tagged Fish. Between December 9, 2015, and November 29, 2018, 1,462 Bodie Bass were tagged with external Floy tags, and of those fish, 290 were double tagged. Tagged fish ranged in size from 400 to 697 mm (average = 449 mm; Figure 3) and weights ranged from 590 to 3,350 g (average = 1,160 g). Fish captured that were below the legal minimum length limit at the time of the study (406 mm) or were in poor condition were released without being tagged. Before releasing these untagged fish, they were measured and weighed periodically (Figure 3). In general, Bodie Bass exhibited below optimal body condition (average *Wr* = 84; Figure 4). The two largest fish collected had the lowest *Wr*, suggesting that larger fish may not be consuming enough prey to maintain optimal body condition (Figure 4). The number of fish tagged per year and season varied (Table 1; Figures 5 and 6). Although an effort was made to tag fish throughout the year, due to the nature of the fishery and catchability, more fish were tagged in winter (*n* = 568) and spring (*n* = 550) compared to summer (*n* = 78) and fall (*n* = 266; Figures 5 and 6). Tagged fish were released throughout the reservoir, with 130, 482, 525, and 325 fish released in the lower, middle, upper, and riverine sections of the reservoir, respectively (Figure 1).

Recaptures. High reward tags were returned by anglers from December 2015 to November 2020 (Figure 6). During the 5 years tags were accepted by the Commission, 64%, or a total of

931 tags, were returned (Table 1). A total of 185 of the 931 fish recaptured and reported were double tagged, where 165 of these fish had both tags present, 19 had only 1 tag present, and 1 fish had an unknown number of tags retained. This equates to approximately 10% tag loss, which was incorporated into the mortality estimates model. The number of fish recaptured varied by season and year, but generally, recaptures were highest in spring (*n* = 497) and winter (*n* = 317), compared to summer (*n* = 82) and fall (*n* = 35; Table 1; Figures 5 and 6). Recaptures were highest in 2018 (*n* = 363) and 2017 (*n* = 241), followed by 2019 (*n* = 172), 2016 (*n* = 92), and 2020 (*n* = 63; Table 1; Figure 6).

Of the 931 recaptured fish, 630 (68%) were harvested and 301 (32%) were released (Table 1). Bank anglers recaptured 307 fish (33%) and boat anglers recaptured 624 fish (67%; Figure 7). Of the fish caught by bank anglers, 10% were released and 90% were harvested, whereas boat anglers released 43% and harvested 57% of fish caught (Table 1; Figures 7 and 8). While the percentage of bank anglers that harvested Bodie Bass was higher than that of boat anglers, there were more total recaptures by boat anglers and thus, there was more harvest, overall, by boat anglers (Table 1). The average number of days a fish was "at large" was 253 and ranged from 0 days to 1,570 days for individual fish. Of the 931 fish recaptured, 605 were caught on a weekday (Monday–Friday) and 326 were caught on a weekend (Saturday, Sunday).

Location and Seasonality of Recaptures. There were a total of 11 and 43 general recapture locations for bank and boat anglers, respectively. Overall, bank anglers predominantly recaptured fish at Marshall Steam Station (*n* = 196; 64%), followed by the riverine portion of the lake (*n* = 71; 23%), McGuire Nuclear Station (*n* = 29; 9.5%), and the remaining 3.5% (*n* = 8) of fish were captured at various other locations throughout the reservoir (Figure 2). One fish did not have a recapture location listed. Due to the mobility of boat anglers, many more locations were given for fish recaptured by boat anglers. The most frequently reported recapture location for boat anglers was the riverine section of the lake (*n* = 236; 38%). The next highest recapture locations were Stumpy Creek (*n* = 50; 8%), Navigation Marker 20 (*n* = 42; 6.7%), and Highway 150 (*n* = 36; 5.8%; Figure 2). For boat anglers, all these locations were at or upstream of Highway 150, indicating high angling success in the upper and riverine sections of Lake Norman. The remaining fish were captured throughout the lake at lower frequencies.

The number of recaptures varied seasonally for boat and bank anglers. The majority of recaptures from bank anglers occurred during winter (*n* = 174; 64%; December, January, and February), followed by spring (*n* = 82; 27%; March, April, and May; Figure 6). In the winter months, 171 of the 174 fish were caught at the Marshall Steam Station (*n* = 154) or the McGuire Nuclear Station thermal discharge area (*n* = 17). Most recaptures from boat anglers occurred during spring months (*n* = 415; 67%; Figure 7) and most frequently occurred in the riverine section of the lake (*n* = 156; 64%). The second most common season for boat anglers to catch fish was winter (*n* = 121; 19%) and the two most frequent locations for recaptures in winter were Navigation Marker 20 and Marshall Steam Station. Harvest from boat anglers was highest during April and May and highest for bank anglers during January and February.

Annual Mortality Estimates. Annual estimates of instantaneous fishing mortality (*F*), tag-induced mortality (*FA*), natural mortality (*M*), and total mortality (*Z*), as well as discrete annual mortality rates (*A*), were obtained for Bodie Bass in Lake Norman from 2016 to 2020 (Table 2). Fishing mortality (*F*) ranged from a minimum of 0.33 (95% CI = 0.26–0.41) in 2016 to a maximum of 0.42 (95% CI = 0.36–0.49) in 2018. The precision of these estimates was highest in the earlier years (e.g., 2017: 95% CI = 0.33–0.45), and decreased over time, with the widest confidence interval observed in 2020 (95% CI = 0.18–0.63), likely reflecting the reduced number of marked fish available for recapture in the later years of the study (Table 2; Figure 9).

Tag-induced mortality (*FA*) increased from 0.09 (95% CI = 0.05–0.13) in 2016 to a maximum of 0.28 (95% CI = 0.20–0.39) in 2019, before declining to 0.22 (95% CI = 0.12–0.43) in 2020 (Table 2). Natural mortality (*M*) was estimated as a constant value across all years at 0.19 based on a model structure that did not support year-specific *M* estimation. Total instantaneous annual mortality (*Z*), representing the combined effect of fishing, tags, and natural sources, increased steadily from 0.53 (95% CI = 0.44–0.64) in 2016 to 0.65 (95% CI = 0.55–0.76) in 2018, then declined slightly to 0.57 (95% CI = 0.36–0.90) by 2020. Confidence intervals for total mortality were relatively narrow in the early years (2016–2018) and widened toward the end of the study (2019 and 2020; Table 2). This pattern of increasing uncertainty reflects both the model structure and a general decrease in the number of recaptures over time. Discrete annual mortality rates (*A*) ranged from 0.41 (95% CI = 0.36–0.47) in 2016 to 0.48 (95% CI = 0.42–0.53) in 2018.

Seasonal Mortality Estimates. Fishing mortality (*F*) estimates varied across the 20 seasonal periods (5 years × 4 seasons; Appendix B; Figure 10). During the early years of the study (2016 and 2017), fishing mortality was highest during winter seasons (e.g., winter 2017: *F* = 0.32, 95% CI = 0.26–0.39). During the later years of the study (2018 to 2020), fishing mortality was higher during the spring (e.g., spring 2020: *F* = 0.30, 95% CI = 0.19–0.47; Appendix B; Figure 10). However, individual *F* estimates in later seasons were less stable due to limited tag-return data, leading to greater uncertainty. Constant seasonal natural mortality (*M*) was estimated to be 0.067. Constant seasonal tag-induced mortality (*FA*) was estimated to be 0.062.

Using the multivariate delta method, we determined one aggregated estimate for each season. Winter and spring exhibited the highest seasonal fishing mortality, with mean aggregated *F* values of 0.186 (95% CI = 0.096–0.362) and 0.234 (95% CI = 0.185–0.296), respectively. Summer and fall had lower aggregated *F* values where *F* = 0.057 (95% CI = 0.044–0.073) in the summer and *F* = 0.019 (95% CI = 0.011–0.033) in the fall (Table 3; Figure 11).

Creel Data. Tags were returned by approximately 550 unique anglers. The number of tags returned by each angler ranged from 1 to 12, with an average of 1.7 tags returned per angler. Notably, 379 anglers returned 1 tag, 88 anglers returned 2 tags, and 2 anglers returned 12 tags. Remaining anglers returned various numbers of tags.

While anglers were not asked where they lived, an address was requested so the reward could be mailed. Using these addresses, 902 tags were returned by in-state North Carolina anglers (97%) and 25 were returned by out-of-state anglers (3%). The remaining four returned tags did not have an associated address recorded. Of the 902 recaptured fish caught by in-state anglers, 618 (68.5%) were harvested and 284 (31.5%) were released. Out-of-state anglers harvested 40% (*n* = 10) and released 60% (*n* = 15) of the Bodie Bass recaptured.

Anglers reported whether natural or artificial baits were used to recapture Bodie Bass. Specific details regarding their baits were gathered whenever possible. Natural bait information was collected for 581 recaptured fish (65%), and artificial bait information was collected for 313 recaptured fish (35%). Natural baits were classified as either live fish (minnows, shad, sunfish, etc.), cut bait, chicken, mussels, worms, or shrimp. The most reported natural baits were live fish (*n* = 323; 56%) and mussels (*n* = 222; 38%). When using natural baits, anglers harvested 433

Bodie Bass and released 147. Artificial baits were classified into many more categories due to the variety of lures available to anglers. The most reported artificial baits were hard baits (n = 71), soft plastics (n = 57), and swimbaits (n = 57). When using artificial baits anglers harvested 166 Bodie Bass and released 146. Mussels were the preferred bait for bank anglers, whereas boat anglers most frequently used live fish.

Discussion

This is the first study to evaluate fishing and natural mortality of Bodie Bass in reservoirs using a tag-return model. Based on the results from this study, harvest and catch-and-release practices have significant impacts on this Bodie Bass population and highlight the importance of this fishery to anglers. Seasonally, fishing mortality is highest in winter and spring. Both bank and boat anglers target Bodie Bass at Lake Norman, but boat anglers have the distinct advantage of targeting the species across the entirety of the lake, rather than at several distinct bank locations, and recaptured more Bodie Bass overall. Bank anglers were more likely to harvest a fish, compared to boat anglers; however, the overall number of fish harvested was still higher for boat anglers. This indicates that concerns regarding bank angler harvest may not be warranted. In addition to mortality from harvest, catch-and-release mortality by both bank and boat anglers must be considered when examining mortality factors. At this time, no studies have examined catch-and-release mortality on Lake Norman Bodie Bass; however, Petersen and Bettoli (2013) found almost 40% mortality in summer in a Tennessee reservoir. Due to the seasonality of angling effort for this fishery, catch-and-release mortality on Lake Norman may contribute significantly to total mortality during spring and summer when water temperatures are warming. Additional studies examining seasonal catch-and-release mortality could be conducted on Lake Norman to confirm this.

Annual instantaneous fishing mortality (F) estimates ranged from 0.33 to 0.42 (Table 2), which is less than the range estimated by a telemetry study on Striped Bass in nearby Badin Lake (F = 0.65 to 0.77; Thompson et al. 2007). Another telemetry study on Lake Gaston Striped Bass estimated annual fishing mortality rates of F = 0.74 (SE = 0.13) in 1997 and F = 0.34 (SE = 0.18) in 1998 (Hightower et al. 2001). Estimates from 1998 closely align with estimates of fishing mortality in this study and demonstrate that there can be a wide variation in fishing mortality across years and within reservoirs. Annual instantaneous natural mortality (M) has been estimated in Striped Bass populations in North Carolina and has ranged from M = 0.10 (SE = 0.01) in Badin Lake (Thompson et al. 2007) to M = 0.16 (SE = 0.04) in Lake Gaston (Hightower et al. 2001). This project estimated annual instantaneous natural mortality to be 0.19 which is slightly higher than estimates for these Striped Bass populations but not biologically unreasonable. Estimates of natural mortality for other Bodie Bass populations appear to be extremely limited. Schultz and Dodd (2008) determined instantaneous total annual mortality for Bodie Bass in an urban lake in Iowa to be Z = 0.37 and Hoffman et al. (2013) found Z = 0.32 (SE = 0.05) in an Indiana lake, which are both lower than our estimated range for Z (0.53–0.65; Table 2).

Fishing mortality varied seasonally, which was expected due to fish behavior and the anglers' ability to catch fish during various seasons. In spring, anglers can capitalize on upstream migrations made by Bodie Bass to spawn (Roberts et al. 2025). While this spawning activity does not likely lead to any actual offspring produced, migration into riverine waters allows anglers to target these congregations. The success of this approach was seen in this study as the average spring fishing mortality (*F* = 0.234; 95% CI 0.185–0.296) was higher than any other season. Winter had the next highest average seasonal fishing mortality (*F* = 0.186; 95% CI 0.096–0.362), and this was primarily due to the bank angling activity at thermal discharge locations (Marshall Steam Station and McGuire Nuclear Station) where Bodie Bass were likely seeking warmer waters to have a metabolic advantage and find forage fish. Over 98% of winter bank angler recaptured fish were caught from these locations (89% at Marshall Steam Station and 9% McGuire Nuclear Station). The thermal discharge areas were also top locations for boat anglers to recapture Bodie Bass in winter. Fishing mortality was low in both summer (*F* = 0.057; 95% CI 0.044–0.073) and fall (*F* = 0.019; 95% CI 0.011–0.033) and this was likely due to a reduction in people fishing (only 82 tags were returned in summer and 35 in fall), fish not aggregating in thermal discharge and riverine areas where capture probabilities appear higher, and the movement of Bodie Bass into cooler, deeper habitat when water is warmer (Roberts et al. 2025).

Seasonal fishing mortality varied by year as well. There was an abnormally high number of tags returned by boat anglers fishing in the riverine portion of the reservoir in the spring of 2018 (Figure 8) and subsequently that period had the highest spring estimate of fishing mortality (*F* = 0.3; SE = 0.028; Appendix B). Success in recapturing tagged Bodie Bass during this season and in the riverine section of the lake, was likely due to generally dry conditions in early spring (March to mid-April), followed by heavy rain in the second half of April. From April 15 to 30, 2018, over five inches of rain fell in the general area surrounding Lake Norman (NOAA, National Weather Service 2025). The number of recaptured fish during this time steadily increased, and high catch rates continued through May 2018. In addition to heavy rainfall, which likely encouraged Bodie Bass to migrate into the riverine section of the reservoir, a high number of Bodie Bass were tagged in the previous winter. A total of 260 fish were tagged from December 1, 2017, to February 28, 2018 (Figure 6). Of these fish, 73 were recaptured in spring 2018 and represented over 40% of the fish captured during that season (Figure 6; Figure 8). This indicates that tagging large numbers of fish in a season may impact the number of recaptured fish in subsequent seasons. When feasible, tagging lower numbers of fish, consistently through all seasons is advised. If possible, future projects should examine multiple capture methods to capture fish across seasons and habitats.

Winter fishing mortality varied interannually across the duration of the study. During the first three years of this project (2016–2018), bank anglers had higher recapture success than boat anglers during the winter season. This trend changed during the last two years of the project, when bank angling success in winter declined (Figure 8). Bank anglers recaptured 28, 72, 64, 28, and 0 Bodie Bass at thermal discharge areas in the winter seasons of 2016, 2017, 2018, 2019, and 2020, respectively. These recaptures primarily occurred at Marshall Steam Station. The decline in bank angler recaptures is possibly due to a shift in habitat use, for both Bodie Bass and the forage fish they are seeking, because of changes in the Marshall Steam Station operations, weather patterns, and ultimate fluctuations in water temperature. For example, the mean water temperature of the discharge canal at Marshall Steam Station was the colder during December 2018, January 2019, and February 2019 (Duke Energy 2021) when compared to the other winter months in our study, and this corresponded with the period when bank angler recaptures decreased. Around this time, Marshall Steam Station reduced operations, resulting in a reduction in thermal discharge (Nick Wahl, Duke Energy, personal communication). The results from this study suggest that while the fish were utilizing the thermal discharge areas from 2016–2018, reduced water temperature, reduction of thermal discharge, or some other unknown factor, led to a decrease in Bodie Bass inhabiting these areas in 2019 and 2020. The study by Roberts et al. (2025) demonstrated that Bodie Bass did not utilize the thermal discharge areas after this study to a high degree, as ≤ 1% of Bodie Bass detections occurred at either Marshall Steam Station or McGuire Nuclear Station throughout the course of their study. Duke Energy plans to retire all four of its coal units at Marshall Steam Station by the early 2030s (Duke Energy 2022), which indicates thermal discharge may not draw in large numbers of Bodie Bass in a consistent manner. During this study, bank anglers primarily caught fish at Marshall Steam Station, in the riverine section of the lake, and at McGuire Nuclear Station. In recent years, anecdotal reports indicate that anglers are catching Bodie Bass at Marshall Steam Station during colder time periods (Sergeant Josh Hudson, Commission, personal communication), but it is unclear if angling has been as successful as it was during the first three years of this project. If bank anglers see reduced angling success at thermal discharge areas, then they are left with very few locations to capture Bodie Bass. Future bank fishing locations should be considered to allow for the utilization of the Bodie Bass resource by a more diverse group of anglers.

The preliminary and final results of this project supported changes in management practices for this fishery. This project determined that fish spent an average of 253 days, less than 1 year, in Lake Norman before being recaptured. Some fish were even recaptured on the same day they were tagged. This quick turnaround between tagging and recapture fueled the desire to stock more fish in the early years of this project and led to additional fish being stocked in 2016. Currently, the Commission has a goal of stocking Lake Norman with 25 Bodie Bass/ha. While necessary, the varying stocking rates that occurred during this project may have impacted this study, and future studies would likely benefit from a constant stocking rate. In addition to this change in stocking rate, anglers requested a higher minimum length limit to allow fish to remain in the lake, growing, for a longer period of time. Thus, the Commission increased the minimum length limit from 406 mm to 508 mm in August of 2022. Commission fishery surveys on Lake Norman Bodie Bass in 2013, 2014, and 2023 showed that fish reached 406 mm by age 1 (Dorsey 2015) and approached the new harvestable size of 508 mm by age 2 (Joubert 2024). The 2023 survey also demonstrated that the fishery was well established and fish as large as 621 mm were captured (Joubert 2024). To date, there has been positive angler feedback from the increase in the minimum length limit (Lawrence Dorsey, Commission, personal communication).

The type of bait an angler used, and whether a fish was released or harvested allowed us to gain knowledge about angler behavior. Natural baits were the most common type of bait or lure used to capture Bodie Bass by bank or boat anglers. It was also more common for an angler to harvest a Bodie Bass when using a natural bait, possibly indicating that if anglers make the effort to have natural baits, their intention is to harvest fish. Boat anglers primarily used live fish, which were most likely caught using a cast net from a boat, and bank anglers primarily used frozen mussels, which can be found at local grocery stores.

When using artificial baits, it was approximately a 50–50 split between whether a fish would be harvested or released, indicating that for these anglers, harvest may not be a top priority. While sample sizes were low, our results 11 indicated that out of state anglers were less likely to harvest fish when recapture occurred. It is unknown why this occurred, but it could be due to the lack of knowledge regarding the project and uncertainty concerning the legality of harvesting the fish, the possibility that anglers did not want to travel long distances with fish carcasses, or they simply were not fishing with harvest as the primary goal. Future tagging programs could consider asking anglers questions regarding their motivation for fishing.

There was no set maximum number of tags an angler could return, and it was possible for anglers to turn fishing for tagged Bodie Bass into a "job". Pollock et al. (2001) warns that anglers may "fish for tags" if it is profitable but explains that this is often not the case if tagged fish are dispersed throughout the reservoir system, as was done in this project to the greatest extent possible. While approximately 30% of anglers returned more than 1 tag and 2 anglers returned 12 tags total, it does not appear that any anglers drastically increased their fishing pressure to capitalize on this tagging project. Future tagging projects could consider conducting a creel survey concurrently to confirm that fishing pressure was not skewed. Additionally, at the time of data collection, researchers could ask what motivation anglers have for targeting the species in question. For future projects that utilize a monetary reward for returned tags, inflation should be kept in mind when determining reward amounts. While $100 was the reward amount used for this study, it is likely that this amount will need to be increased in future studies to continue to assume a 100% return rate.

Communication with anglers was essential for this project's success. These open lines of communication are an excellent way to build trust between managers and anglers utilizing fishery resources. Future projects could build upon the relationships formed during this project and contact information could be used to further engage anglers. In future studies, we recommend asking anglers if it is ok for them to be contacted again regarding the fishery in question and/or for other fishery matters. This communication could allow for the formation of citizen science projects and/or creel data collection. While this project was widely advertised via press releases, public notices, signage, and other methods at the start of the project, we suggest additional communication and routine sign maintenance throughout the course of future projects. This will ensure all anglers are informed of ongoing projects. While anglers did return tags throughout the course of this project, the number of returned tags decreased in the last two years (Figure 6). This was likely due to dwindling sample sizes and no additional fish being tagged but could also indicate a lack of awareness or understanding of the project and tag return logistics.

Overall, anglers harvested 43% of the tagged Bodie Bass in this project and additionally impacted the population via catch-and-release mortality. Total mortality estimates support the management decision to stock more Bodie Bass and highlight the importance of annual stocking for the continuation of the Bodie Bass population at Lake Norman. An angler survey was completed in 2023, and results indicate that Lake Norman is the most fished lake for Bodie Bass (or Striped Bass) in the state, again indicating the popularity of the fishery (Jewell et al. 2024). Over the course of this five-year study, anglers returned tags and provided the Commission with valuable insights into the fishery. Using results from this study the Commission has made several changes to the management strategies implemented at Lake Norman to improve the Bodie Bass fishery.

Management Recommendations

1. Maintain the current stocking rate of 25 fish/ha (325,000 fingerlings) annually.
2. Continue to regulate Bodie Bass harvest using a 4-fish per day creel (in combination with Striped Bass) and a 20-inch minimum size limit.
3. Monitor the population using gill nets every 2 to 3 years to assess population metrics such as growth, relative weight, and size distribution.
4. Combine multiple recent surveys to assess mortality using a catch-curve analysis and compare mortality results to the results of this study. This will help determine the feasibility and accuracy of utilizing catch-curve analyses for future management efforts of this population.
5. Maintain bank fishing opportunities and explore the possibility of adding new bank fishing locations in areas where Bodie Bass habitat exists.

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TABLE 1. Number of Bodie Bass tagged and recaptured in Lake Norman by year, the number of recaptured fish by bank and boat anglers, and the number of fish harvested or released by bank and boat anglers.

		Recaptures			Bank		Boat		Total	
Year	Tagged	Total	Bank	Boat	Harvested	Released	Harvested	Released	Harvested	Released
2016	331	92	42	50	40	2	33	17	73	19
2017	525	241	104	137	97	7	76	61	173	68
2018	606	363	106	257	91	15	154	103	245	118
2019	–	172	47	125	39	8	62	63	101	71
2020	–	63	8	55	8	0	30	25	38	25
Total	**1,462**	**931**	**307**	**624**	**275**	**32**	**355**	**269**	**630**	**301**
%Total	–	**64%**	**33%**	**67%**	**90%**	**10%**	**57%**	**43%**	**68%**	**32%**

TABLE 2. Estimates for instantaneous annual fishing mortality (*F*), annual tag-induced mortality (*FA*), and annual total mortality (Z), as well as the discrete estimate for total annual mortality (*A*) for each year. The 95% confidence intervals are in parentheses. Annual natural mortality (*M*) was held constant and was estimated to be 0.19.

	F	*FA*	*Z*	*A*
2016	0.33 (0.26–0.41)	0.09 (0.05–0.13)	0.53 (0.44–0.64)	0.41 (0.36–0.47)
2017	0.38 (0.33–0.45)	0.15 (0.12–0.19)	0.60 (0.51–0.70)	0.45 (0.40–0.50)
2018	0.42 (0.36–0.49)	0.20 (0.17–0.25)	0.65 (0.55–0.76)	0.48 (0.42–0.53)
2019	0.40 (0.29–0.55)	0.28 (0.20–0.39)	0.64 (0.49–0.84)	0.47 (0.39–0.57)
2020	0.34 (0.18–0.63)	0.22 (0.12–0.43)	0.57 (0.36–0.90)	0.43 (0.30–0.59)

TABLE 3. Average seasonal fishing mortality (*F*) and 95% confidence intervals for Bodie Bass in Lake Norman. Seasonal natural mortality (*M*) was held constant and was estimated at 0.067 per season. Tag-induced mortality (*FA*) was held constant and was estimated at 0.062 per season.

	Fishing Mortality (*F*)	
Season	Average	95% CI
Winter	0.186	0.096–0.362
Spring	0.234	0.185–0.296
Summer	0.057	0.044–0.073
Fall	0.019	0.011–0.033

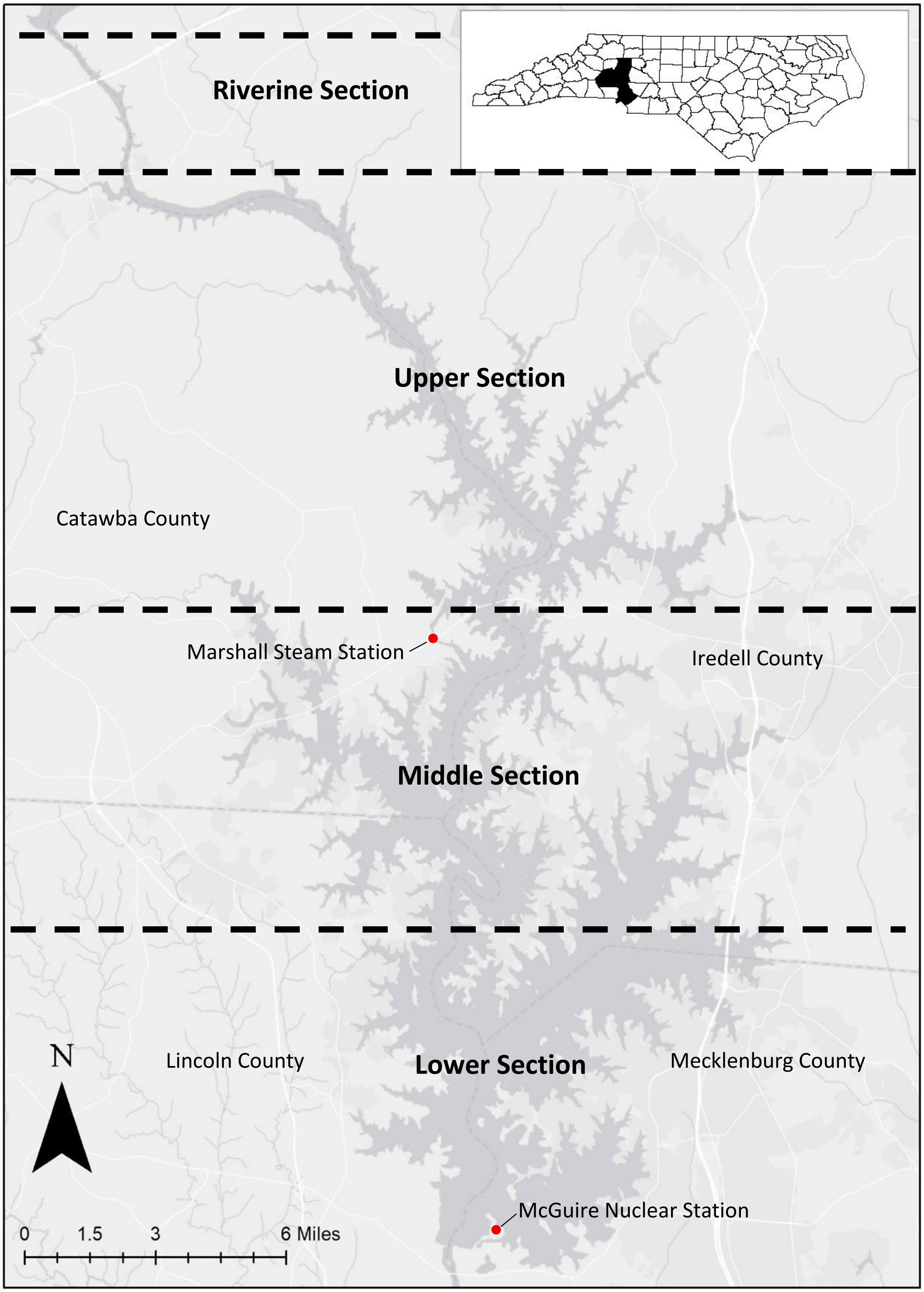

FIGURE 1. Map of Lake Norman showing the four sections where tagged fish were initially released.

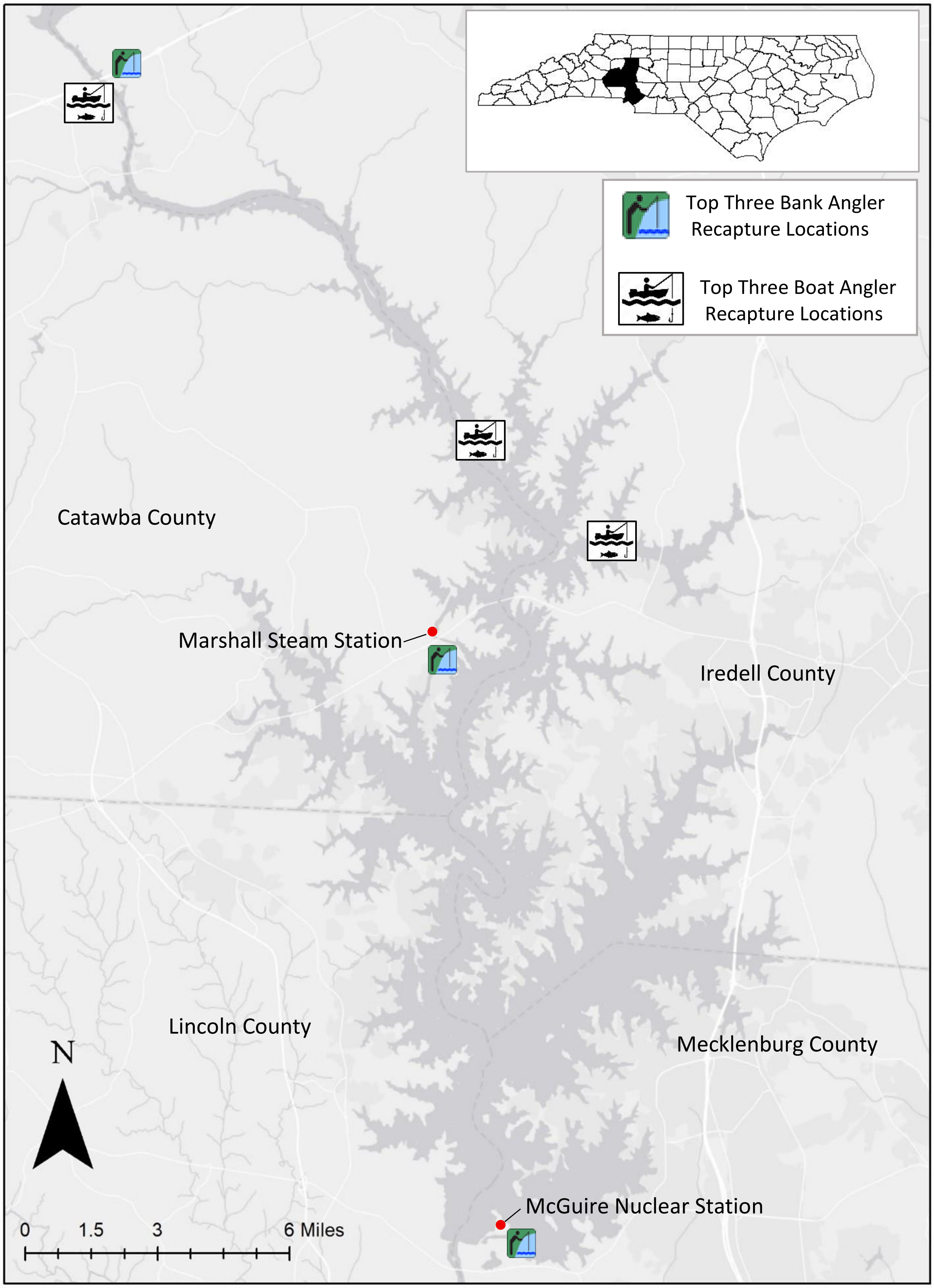

FIGURE 2. Map of Lake Norman showing locations where recaptured fish were most commonly caught.

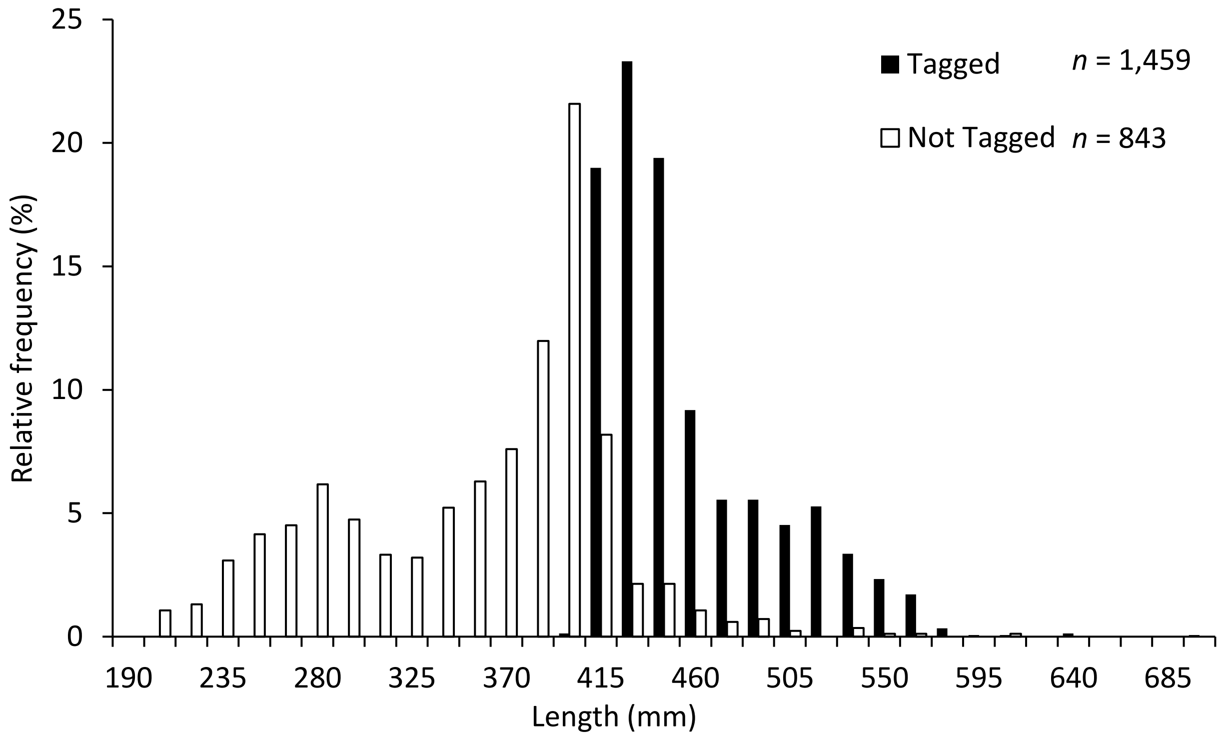

FIGURE 3. Length frequency distribution of Bodie Bass collected at Lake Norman. Solid bars represent fish > 406 mm that were tagged. Length was not recorded for three tagged Bodie Bass.

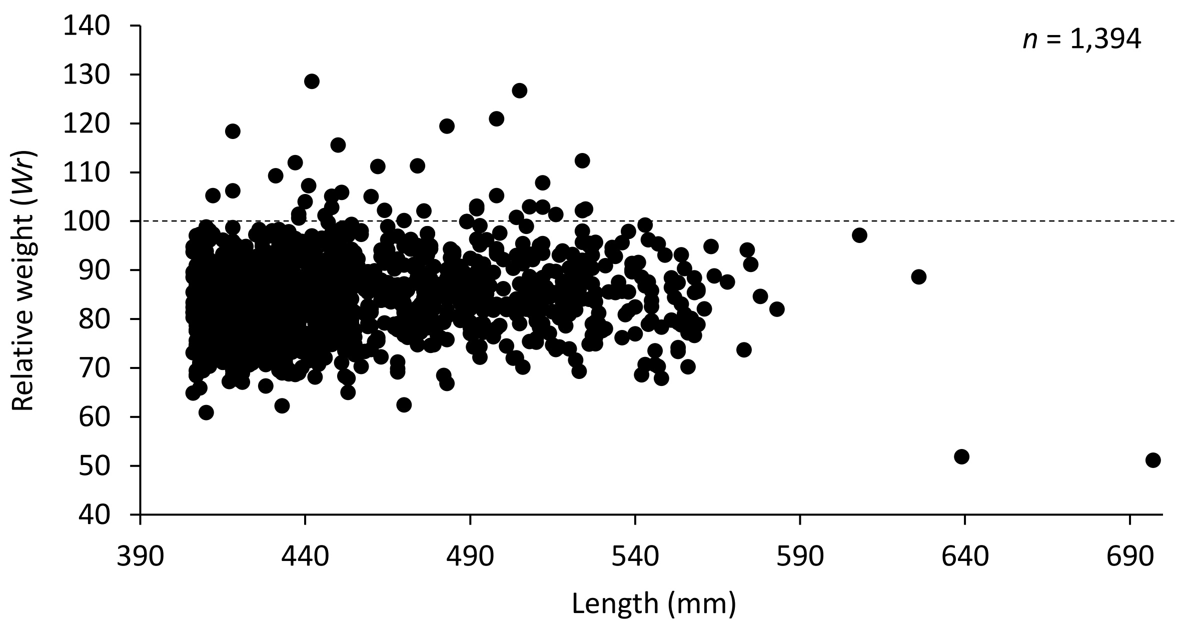

FIGURE 4. Relationship between total length and relative weight of tagged Bodie Bass at the time of collection and prior to tagging. The dashed line represents an ideal body condition where *Wr* = 100. Weight was not recorded for 68 Bodie Bass.

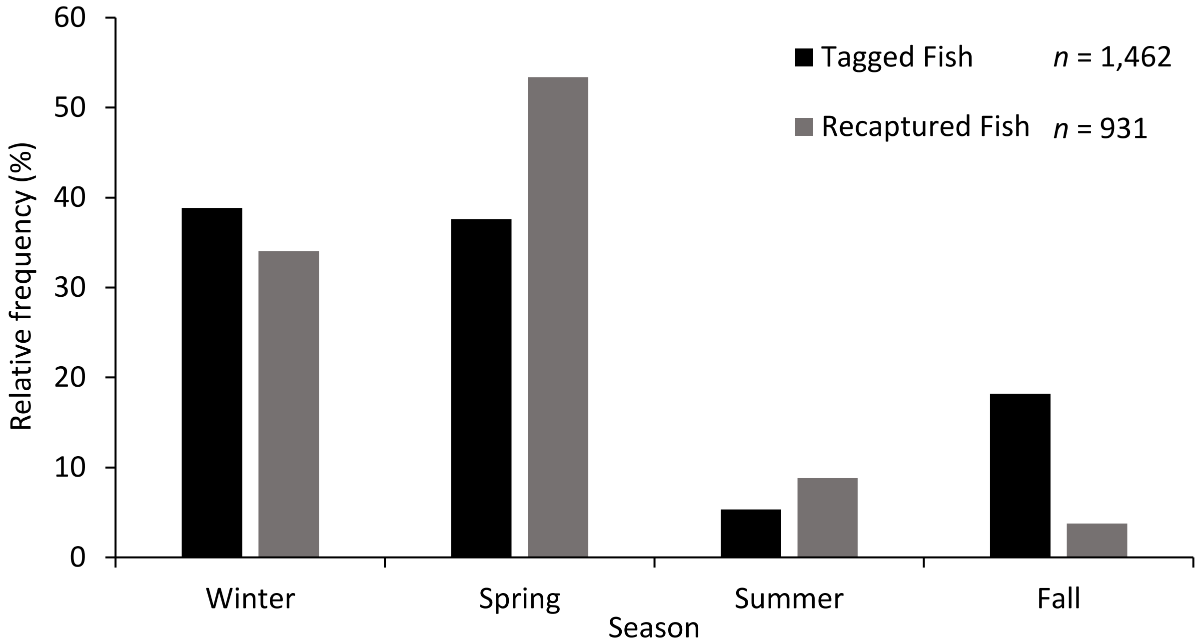

FIGURE 5. Percentage of Bodie Bass tagged and recaptured by season throughout the project.

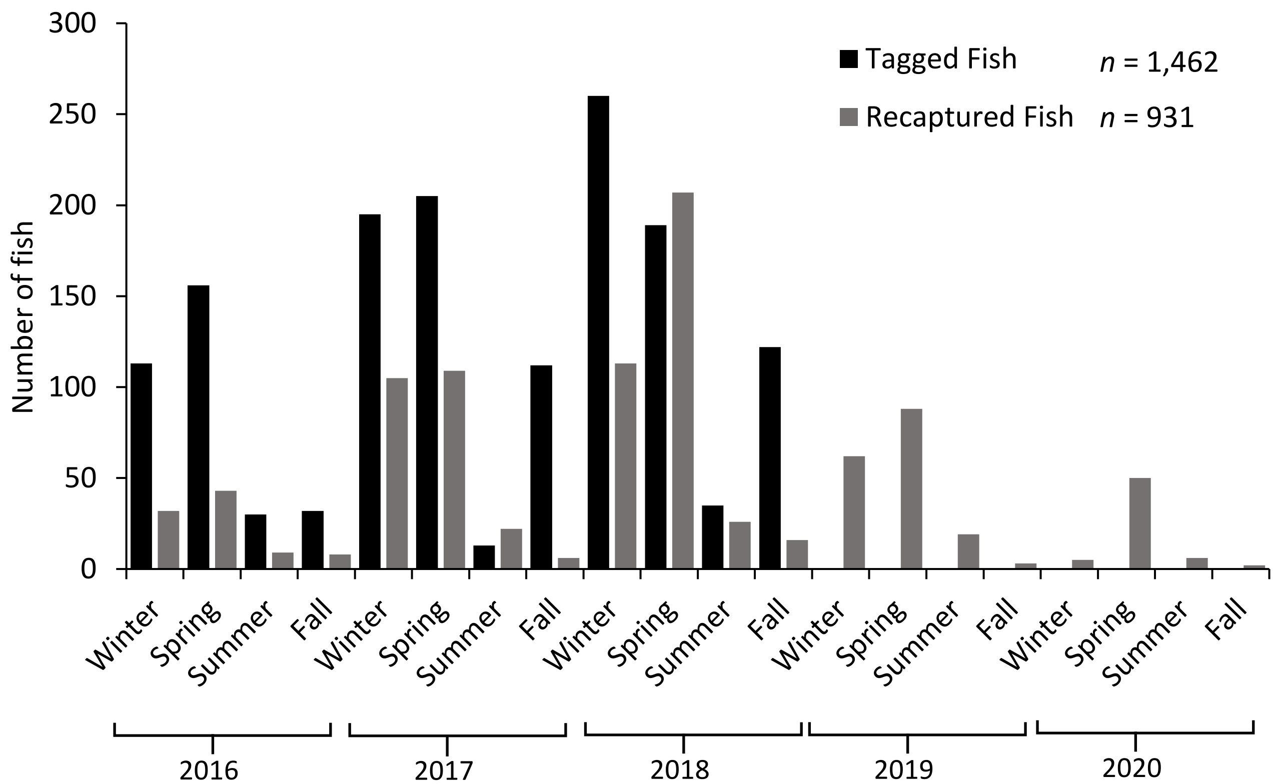

FIGURE 6. The number of Bodie Bass tagged, and the number of Bodie Bass recaptured by season throughout each year of the project for both bank and boat anglers.

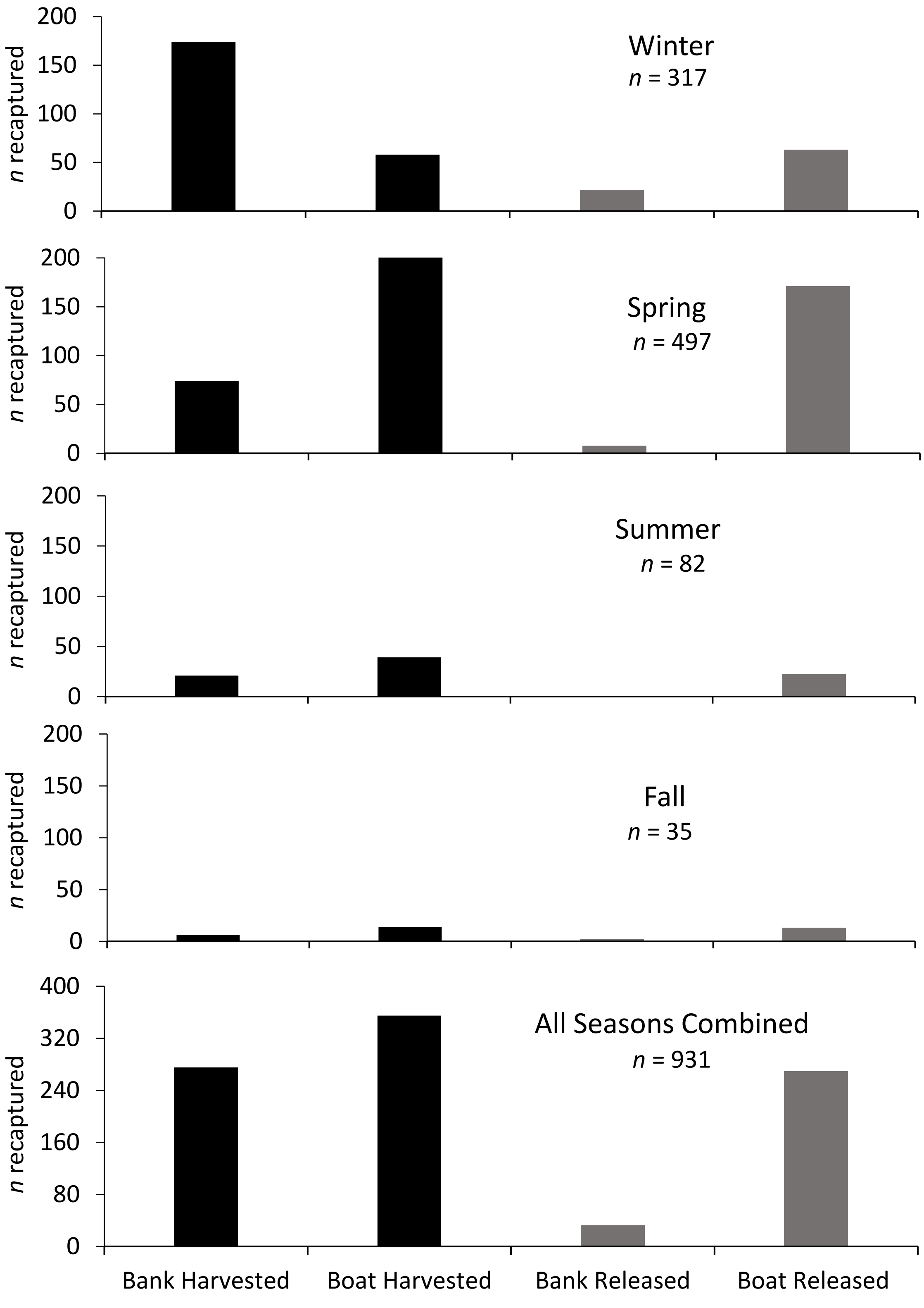

FIGURE 7. Number of Bodie Bass harvested and released from bank anglers or boat anglers, by season and with seasons combined. Black bars represent harvested fish and gray bars represent released fish.

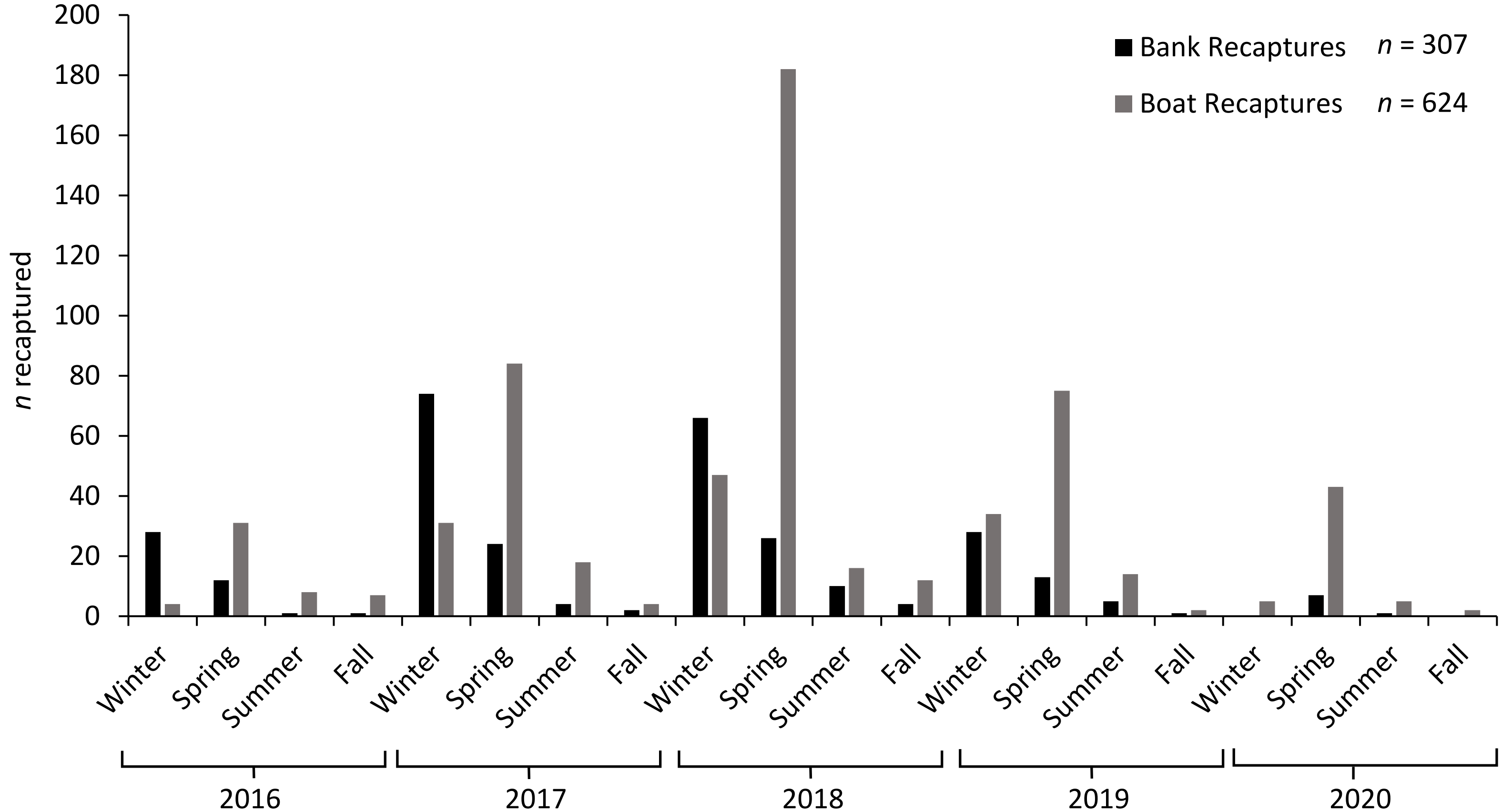

FIGURE 8. The number of Bodie Bass recaptured by bank and boat anglers during each season at Lake Norman.

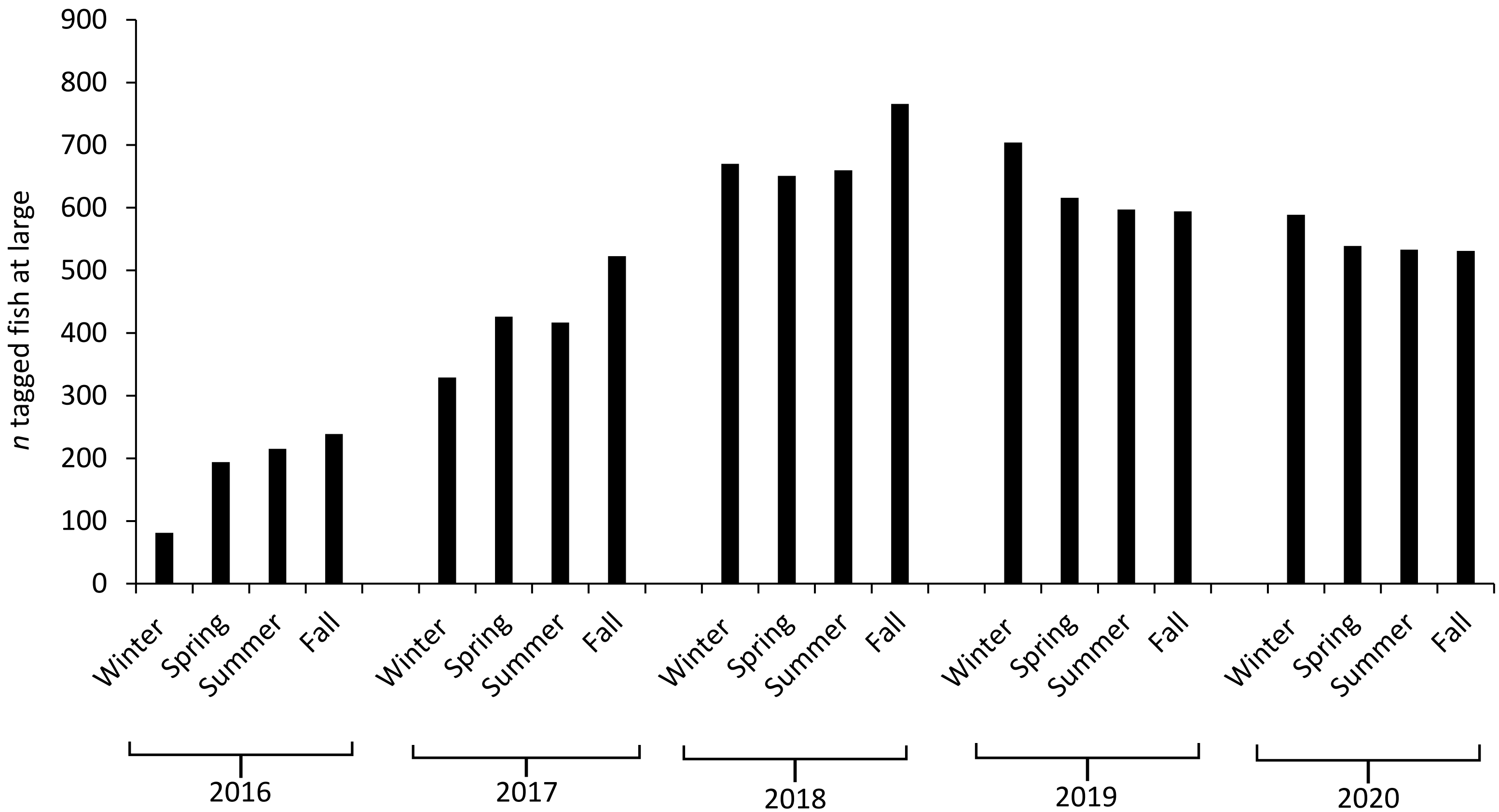

FIGURE 9. Total number of tagged Bodie Bass estimated to be at large at the end of each season (*n* tagged fish at large) based upon the number of fish tagged and recaptured. No additional fish were tagged following the fall of 2018.

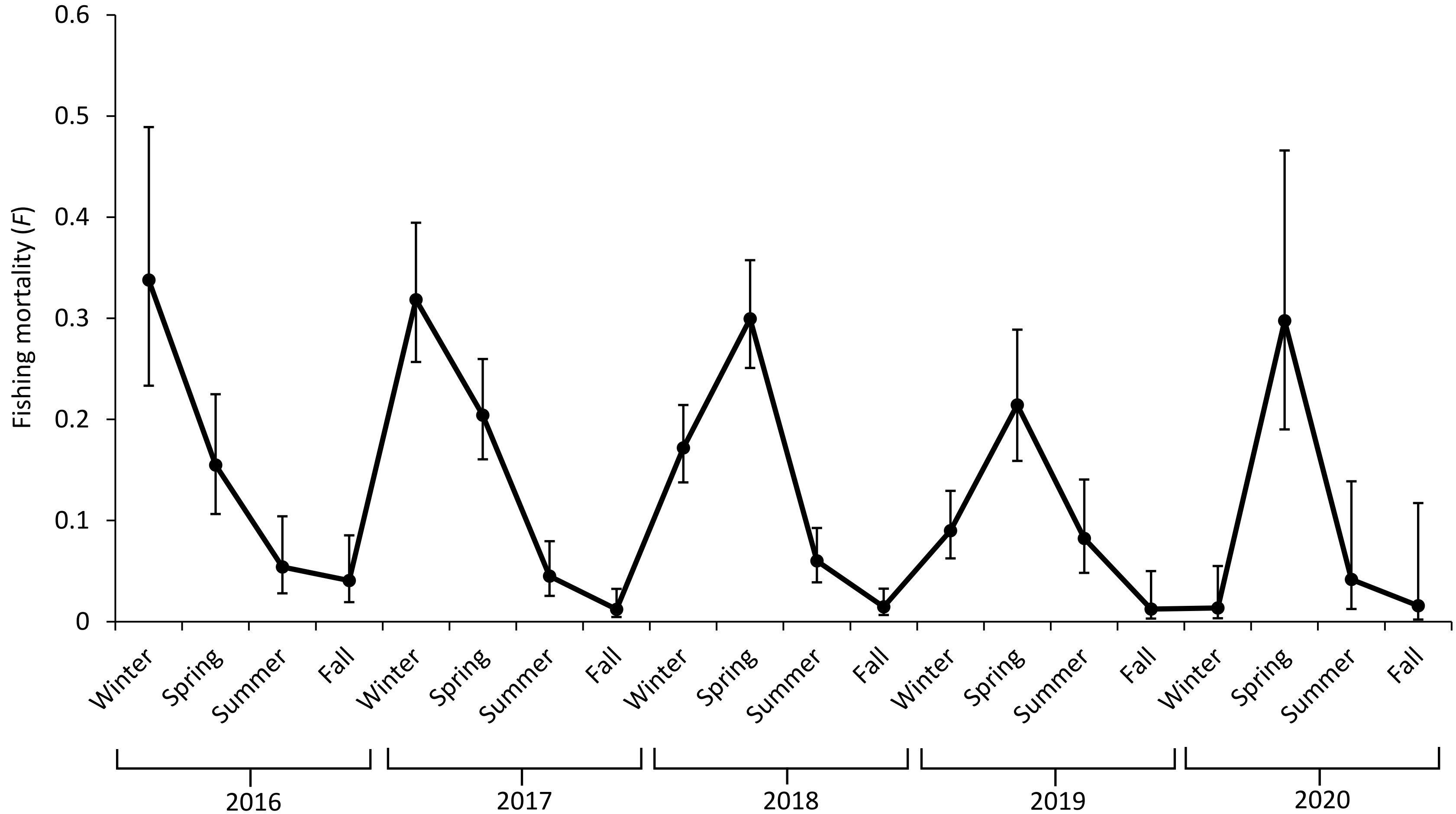

FIGURE 10. Seasonal estimates of instantaneous fishing mortality (*F*) for Bodie Bass in Lake Norman from 2016 to 2020. Each point represents a single seasonal period (winter, spring, summer, fall). Error bars indicate 95% confidence intervals.

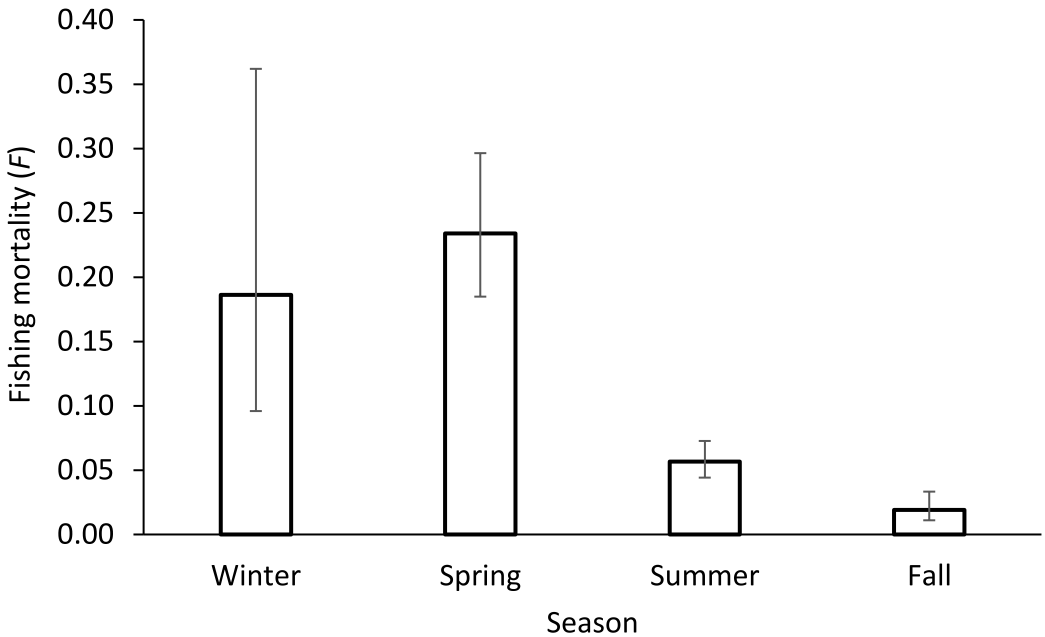

FIGURE 11. Mean seasonal fishing mortality (*F*) and error bars showing 95% confidence intervals.

Appendix A. Stocking History

TABLE A1. Number of Bodie Bass Stocked into Lake Norman from 2013 to 2019.

Year	Number Stocked
2013	162,500
2014	162,500
2015	162,500
2016	268,270
2017	306,042
2018	180,167
2019	280,654
Total	1,522,633

Appendix B. Fishing Mortality Estimates

Table B.1. Fishing mortality (F) and 95% confidence intervals (CI) for each season from 2016 to 2020.

		Fishing Mortality (*F*)	
Year	Season	Average	95% CI
2016	Winter	0.34	0.23–0.49
	Spring	0.15	0.11–0.22
	Summer	0.05	0.03–0.10
	Fall	0.04	0.02–0.09
2017	Winter	0.32	0.26–0.39
	Spring	0.20	0.16–0.26
	Summer	0.05	0.03–0.08
	Fall	0.01	0.00–0.03
2018	Winter	0.17	0.14–0.21
	Spring	0.30	0.25–0.36
	Summer	0.06	0.04–0.09
	Fall	0.01	0.01–0.03
2019	Winter	0.09	0.06–0.13
	Spring	0.21	0.16–0.29
	Summer	0.08	0.05–0.14
	Fall	0.01	0.00–0.05
2020	Winter	0.01	0.00–0.06
	Spring	0.30	0.19–0.47
	Summer	0.04	0.01–0.14
	Fall	0.02	0.00–0.12