Striped Bass Exploitation in Tailwater Habitats of East-Central Oklahoma

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Striped Bass Exploitation in Tailwater Habitats of East-central Oklahoma

Photo Credit: A. Vaisvil

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EXECUTIVE SUMMARY

Striped Bass (*Morone saxatilis*) is naturally anadromous, but a few land-locked populations have been documented that are self-sustaining, including fish in the Arkansas River, Oklahoma. This rare population is the source of brood stock for the Oklahoma Department of Wildlife Conservation hatcheries and is an important sportfish stock. Striped Bass often congregate in tailwater habitats, where anecdotal observations indicate anglers can harvest numerous fish daily. This suggests potential usefulness of evaluation of the sustainability of harvest in these locations. It is unknown what portion of fish from the Arkansas River population use tailwater habitats or the timing and duration of use. The objectives of this study were to: 1) determine size structure, abundance, and total mortality rate of Striped Bass in the tailwaters of Tenkiller Lake and Lake Eufaula; 2) determine the extent and timing of immigration and emigration of Striped Bass in tailwater habitats to determine the potential for overharvest when they congregate in tailwater areas; 3) estimate delayed hooking mortality of Striped Bass in spring and summer; and 4) using the above data and modeling simulations, determine the potential for growth overfishing of Striped Bass in the tailwater reaches. We sampled 2,730 Striped Bass using boat electrofishing and tagged with passive integrated transponder (PIT) tags to estimate demographic data using a capture-recapture model. A subset of these Striped Bass was tagged with angler reward tags (internal anchor tags, n = 681) and dual technology acoustic-radio telemetry tags (n = 111) to estimate exploitation and track movements, respectively. Anglers returned 116 tags from 2020 to 2022; and our angler reporting rate was estimated to be 14.3%. Annual harvest mortality is minimally 7% (unadjusted for reporting rate) but could be as high as 42% (i.e., adjusting for compliance; but this exceeds the measured total mortality rate (34.3%) so true exploitation is probably 7–34.3%). Our abundance estimates for Striped Bass varied seasonally (ranging from 782 to 38,597 seasonally) and had a high level of uncertainty likely due to relatively low recapture rates. Additionally, our results indicated that Striped Bass exhibited a strong fidelity to their respective habitats within seasons, with fidelity probabilities ranging from 0.98 to 1.00. Movement among segments was common among seasons, indicating these localized populations mix with a larger population annually. Striped Bass were primarily in tailwater habitats during summer. Delayed hooking mortality data were collected in summer 2022. Due to habitat conditions that year, angling catch rates were low. Twenty-nine Striped Bass were tagged, and only eight Striped Bass remained tagged long enough to be tracked at

least one day. The total time tracked for these eight fish was between one and three days. There were no confirmed mortalities, treatment, or control. Because of the low sample size, literature values for delayed hooking mortality were also used to supplement field data in the models. The yield-per-recruit model indicated exploitation at 30% or higher leads to recruitment overfishing. A 600 mm minimum TL regulation and 25–30% exploitation rate achieve maximum yield (954 kg/1,000 recruits). Maximum yield related to an average size at harvest of 718-mm TL; thus, growth overfishing occurs for any regulation where average size of harvest is smaller than 718 mm (which the model predicted would occur for any minimum length < 600, and for minimum length = 600 if exploitation was > 30%, it never occurred with minimum length requirements ≥ 650). Increasing the minimum length regulation improves size structure, but a maximum length regulation had minimal effect unless it was implemented at a sufficiently small size (i.e., ≤ 700 mm). Although catch-and-release mortality can be relatively high at times in the literature, according to our model, it appears to have a small effect on size structure, except when exploitation rates are > 50% and a restrictive maximum size regulation (≤ 800 mm) is used. The current population appears sustainable, especially considering the annual mixing dynamics and apparently large population (though we see a lot of uncertainty in the population estimates). However, modeling indicates that if enhancing size structure is an agency priority, then implementing more restrictive regulations could be advantageous.

OBJECTIVES

1. Determine size structure, abundance, total mortality, and angling mortality of Striped Bass in the tailwaters of Tenkiller Lake and the Canadian River below Lake Eufaula.
2. Determine the extent and timing of immigration and emigration of Striped Bass in tailwater habitats to determine the potential for overharvest when they congregate in tailwater areas.
3. Estimate delayed hooking mortality of Striped Bass in spring and summer.
4. Using the above data and modeling simulations, determine the potential for growth overfishing of Striped Bass in the above tailwater reaches.

STUDY AREA

Our study area includes one reservoir (Robert S. Kerr Reservoir), a highly channelized river (Arkansas River), two tailwaters (Canadian and lower Illinois rivers), and several smaller tributary streams. Our sampling primarily focused on the Arkansas River downstream of Webbers Falls Lock and Dam and above Robert S. Kerr Lock and Dam. We also sampled the tailwater sections of the Canadian and lower Illinois rivers below Eufaula and Tenkiller reservoirs, respectively (Figure 1). The connected waterways in this complex are characterized by unique geographical and environmental features. The presence of multiple dams and corresponding influences on flow patterns present significant challenges for fish populations and managers. At present, Oklahoma's Striped Bass fishery permits a daily harvest of five fish per angler with no length limits. Of course, anglers and fishing guides often have their own goals associated with the Striped Bass fishery. While anglers seek recreational experiences and diverse motivations, guides aim to provide successful fishing trips tailored to their clients' desires, often centered around catching trophy-sized fish. Questions about the long-term sustainability of the Striped Bass population and its size structure, especially trophy-sized individuals, were primary concerns associated with the development of our study.

The Robert S. Kerr river-reservoir complex is situated within the lower Boston Mountains, Arkansas River Floodplain, and the Arkansas Valley Plains ecoregions (Woods 2005). This region has a varied landscape, featuring plains, hills, floodplains, terraces, and scattered mountains. Land cover types range from pastures on gentle sloping uplands to croplands in bottomlands, with forests predominantly found on steep slopes. Other land uses in the area include poultry farming, coal mining, and natural gas production (NRCS 2012). Due to high water demand in the Arkansas River basin, more than 50 reservoirs have been constructed in the drainage (Limbird 1993), including those on the Canadian and Illinois rivers. These dams have resulted in highly variable summer flows, affecting the physicochemical conditions in tailwater reaches (Dolliver 1984).

Dam operations in the Arkansas River are multipurpose, with navigation, hydroelectric power generation, and flood control as primary objectives. The river is extensively channelized and has 15 dams. Over the past decade, the average annual discharge in the Arkansas River was 725 m^3/s. However, immediately prior to fieldwork commencing for this study, extensive flooding in 2019 caused significant sediment deposition of approximately 1,150,000 m^3, leading to the United States Army Corps of Engineers dredging the navigation channel to restore its functionality (Morgan 2020).

The two tailwater river systems, the lower Illinois River and the Canadian River, differ in ecoregion and physicochemical characteristics. The lower Illinois River, downriver of Tenkiller Dam, is situated in the lower Boston Mountains ecoregion. The Illinois River catchment primarily features limestone and sandstone lithologies, with spring-fed headwater streams (Felley and Hill 1983). Over the past decade, the average annual discharge in the lower Illinois River was 57 m^3/s (U.S. Geological Survey stream gage OK-07198000, https://waterdata.usgs.gov/monitoring-location/07198000/#parameterCode=00065&period=P7D&showMedian=true). The Canadian River, downriver of Eufaula Reservoir, is located within the Arkansas Valley ecoregion. Historically, the Canadian River was a free flowing, braided, sand bed stream with adaptable channel morphology. From 2010 to 2020, the average annual discharge of the Canadian River was 134 m^3/s (U.S. Geological Survey stream gage OK-07245000, https://waterdata.usgs.gov/monitoring-location/07245000/#parameterCode=00060&period=P7D&showMedian=true).

Objective 1. Determine size structure, abundance, total mortality, and angling mortality of Striped Bass in the tailwaters of Tenkiller Lake and the Canadian River below Lake Eufaula.

BACKGROUND

Assessing population dynamics, including factors such as birth rate, natural mortality, and angling mortality, is important for determining sustainable harvest regulations (Zabel et al. 2003). Striped Bass, a popular sportfish in Oklahoma, is highly sought by anglers (Jager 2014). In the lower Arkansas River basin, particularly during periods of moderate to high discharge, Striped Bass congregate in impoundment tailwaters, such as the lower Illinois River below Tenkiller Dam and the Canadian River below Eufaula Dam (Wilkerson and Fisher 1997). The presence of these large congregations makes tailwater habitats attractive to anglers, resulting in a perception of high catch rates of Striped Bass (i.e., many anglers can harvest a limit when they fish). However, the perceived high harvest levels in these areas raise concerns about overharvesting, potential changes in size structure, and impacts on reproductive output of the Striped Bass population. These factors can ultimately lead to population declines. To evaluate the sustainability of Striped Bass populations and assess if the current fishing regulations are adequate, it is essential to examine the demographics of adult fish in tailwater habitats.

METHODS

Electrofishing

To gather data on the size structure of Striped Bass, we used boat-mounted electrofishing in the lower Illinois and Canadian rivers, with most of the sampling taking place from April to September in each year (2019–2022). Striped Bass collected by electrofishing were measured (mm, TL) and fitted with passive integrated transponder (PIT) tags (more details in the PIT Tag section). We also weighed a subsample of these fish. Angler reward tags were also installed on a subset of fish to estimate exploitation rates (more details in Reward Tag section). Additionally, a subset of fish was equipped with telemetry transmitters to track their movement patterns (more details in the Telemetry section). An open-population capture-recapture approach was used to estimate population abundance, with recaptures of PIT-tagged fish serving as the basis for analyses (further details in the PIT Tag section). Three hundred seventy-five Striped Bass were sacrificed, and otoliths removed for aging (259 from the lower Illinois, 88 from the Canadian, and 29 from the Arkansas rivers). A subsample of these fish was sexed and examined for the presence of mature gonads (n = 152). Target length bins when sampling were 30 mm and ranged from 60 mm to 1079 mm.

PIT Tagging

We tagged 2,730 Striped Bass using 23-mm half duplex (HDX) PIT tags, which were inserted laterally below the soft dorsal fin, within the musculature. As a secondary identification mark, two or three dorsal fin spines were clipped. These secondary marks aided in estimating tag retention (which we estimated at 89.8%). The recaptures of PIT-tagged fish were used to estimate various parameters, including apparent survival (phi), capture probability (p), the probability that an individual will never be captured again (chi), and the number of individuals captured at a given time divided by the probability of capture at that time (pop).

A Bayesian Cormack-Jolly-Seber (CJS) model using the rstan package (Stan Development Team 2023) was used to account for heterogeneity in apparent survival and capture probability over time. The analyses were conducted using the rstan package in R 4.2.2 (R Core Team 2022). To represent the different seasons of the year, separate capture occasions were defined for the cool water (October–May) and warm water (June–September) periods of each year (2019–2022). The first capture occasion corresponded to the 'warm' portion in 2019. This resulted in seven capture occasions.

Reward Tags

To estimate exploitation rates, internal anchor tags were inserted into the abdomen of 681 Striped Bass that ranged in length from 375 to 1063 mm, TL to ensure representation across the size range typically available to anglers in the Robert S. Kerr river-reservoir complex. Between May 2020 and August 2022, Striped Bass were sampled via boat electrofishing and tagged with internal anchor tags (FM-84, Floy Tag, Seattle, WA). These tags were printed with an ID number, the phrase "up to $100 reward," and a URL (http://tinyurl.com/fishreward), which provided anglers with additional instructions on how to claim rewards. As a means of estimating tag loss, PIT tags were used as secondary tags alongside the internal anchor tags (see PIT Tag section). The retention rate of internal anchor tags was adjusted based on observed losses with the secondary tags, following the modification from Dunning et al. (1987). A monthly reward system was implemented where returned tags were entered into a raffle. Nineteen rewards of $20 each and one reward of $100 were drawn each month. Anglers who accessed the reward tag website specified on the tags were directed to a Google Form. The form requested the fish tag number, date caught, start and stop fishing dates, TL, presence of additional tags, catch location, tagged striped bass kept or released, number of striped bass caught and kept during this trip, bait type, and fishing method (shore or boat). Anglers were required to send the cut tag to Oklahoma State University (OSU) to be eligible for the reward raffle. A reward of $100 is generally considered sufficient to ensure a reporting rate of 100% (Latour et al. 2001; Bacheler et al. 2009). In this study, anglers were informed about the reward tag study by roaming creel clerks who distributed reward tags as a promotional activity, as well as a social media post by the

Oklahoma Department of Wildlife Conservation (ODWC). Anglers were informed that they could claim a reward using the tag by following the directions provided on the tag's web address. The same procedure was to be followed if they caught a fish with a tag attached. The proportion of tags distributed by roaming creel clerks was used to estimate the return rate of reward tags (Maceina et al. 1998). The reward tag study was conducted over a two-year period, from June 2020 to October 2022 with tags deployed as needed to keep the number of tags at large around 500.

Objective 2. Determine the extent and timing of immigration and emigration of Striped Bass in tailwater habitats to determine the potential for overharvest when they congregate in tailwater areas.

BACKGROUND

Telemetry methods were used to study the movement patterns of Striped Bass from the Arkansas River population, specifically their use of tailwater habitats throughout the year and the duration of their residency in the tailwaters. Understanding the movement patterns of fish is important to effective population management (Cooke et el. 2013). In the case of landlocked Striped Bass, it is known that they migrate to spawning tributaries during the spring season (Jackson and Hightower 2001). However, the behavior of individuals after spawning varies, with some dispersing to different locations and others remaining in the spawning tributaries. The specific factors influencing this behavior include fish size and the post-spawn water quality (Schaffler et al. 2001). By tracking the movement of individual fish using telemetry transmitters, this study aimed to determine what proportion of the population uses tailwater habitats and for how long they remain in these habitats.

METHODS

Telemetry

We tagged Striped Bass with telemetry transmitters (MM-series CART, Lotek Wireless, Ontario, Canada) that used both acoustic and radio technology. This dual-technology tagging approach was necessary due to the turbulent and noisy environments of the Canadian and lower Illinois rivers, which rendered acoustic signals ineffective, and the high conductivity and deep habitat in the mainstem Arkansas River, which reduced the efficacy of radio telemetry. The transmitters we used weighed less than 2% of the fish's body weight (Jepsen et al. 2005). We tagged 111 Striped Bass ranging from 400 to 1080-mm TL to ensure representation across the size range typically encountered by anglers in the lower Arkansas River basin. Paired passive acoustic telemetry receivers (SUR, Sonotronics, Tucson, AZ) were strategically placed in the Arkansas River near the confluences of the Canadian and lower Illinois rivers, and at the entrance to the Robert S. Kerr Reservoir (Figure 2). These paired receivers not only detected fish in the area but also provided information on the direction of travel when a fish left the area, based on which receiver in the pair was the last to detect the fish. Additionally, paired passive radio telemetry receivers (SRX-800D; Lotek Wireless, Newmarket, ON) were deployed near the Eufaula (Canadian River) and Tenkiller (lower Illinois River) dams, as well as at the confluences of each river with the Arkansas River. These radio receivers were positioned to maximize detection probability across the entire river channel. Data from the telemetry receivers were downloaded monthly from June 2020 to October 2022. Prior to analysis, false detections and single-hit data were discarded (Clements et al. 2005). To further track the movement of the tagged fish, manual tracking was conducted monthly, and the UTM coordinates of the detected fish were recorded. The manual tracking in each tracking period encompassed the Arkansas River from Webbers Falls Lock and Dam to Robert S. Kerr Lock and Dam, including the Canadian and lower Illinois tributaries. Additionally, during 2022, the river segments from Webbers Falls Lock and Dam to Muskogee, Oklahoma, including the Neosho River to Ft. Gibson Dam and the Verdigris River to Choteau Lock and Dam, were tracked once to search for Striped Bass that had migrated out of the study area.

Data from both passive and active telemetry were used to develop a Bayesian multistate capture-recapture model in R using the rstan package (Stan Development Team 2023) in R 4.2.2

(R Core Team 2022). The model aimed to estimate apparent survival (phi), capture probability (p), and movement probability (psi) from one location to another. The study area was divided into four states: alive at A (Arkansas River/Robert S. Kerr Reservoir), alive at B (lower Illinois River), alive at C (Canadian River), and dead/emigrated. Separate capture occasions were defined for winter (January–March), spring (April–June), summer (July–September), and autumn (October–December) each year (2020, 2021, 2022), enabling the analyses of seasonal movement. This resulted in ten capture occasions, commencing in spring 2020 and concluding in autumn 2022. Fish found in multiple states within the same season were excluded from the analyses.

A Bayesian multistate capture-recapture model using the rstan package (Stan 2022) in R 4.2.2 (R Core Team 2022) was constructed using telemetry data from both passive arrays and active telemetry. This model aimed to estimate true survival (s), fidelity probability (f), recovery probability (r), and capture probability (p). The four states in this model were defined as: alive in the study area, alive outside the study area, recently dead and recovered, or recently dead but not yet recovered. Recently dead and recovered included all mortalities that were subsequently recovered (determined to be mortalities or physically recovered) whereas recently dead but not yet recovered included all fish where mortality was not physically confirmed by tag recovery. Similar to the previous model, separate capture occasions were defined for each season and year, resulting in ten total capture occasions.

Objective 3. Estimate delayed hooking mortality of Striped Bass in spring and summer.

BACKGROUND

Fishing regulations often rely on the assumption of high survival for released fish. However, if overharvest is occurring in tailwater habitats, more restrictive bag limits may be necessary to ensure the sustainability of the population, but this management change would only be effective if released fish survive. Therefore, it is important to understand the extent of delayed hooking mortality to inform appropriate management strategies. Previous studies have examined delayed hooking mortality in Striped Bass, but conflicting results and variations in habitat among different study areas make it challenging to predict the mortality rates associated with catch-and-release angling in the Arkansas River catchment. Published studies have reported delayed hooking mortality rates ranging from 0% to 74% (Wilde et al. 2000; Stockwell et al. 2002; Millard et al. 2003; Millard et al. 2005; Bettinger et al. 2005). Factors such as bait type (natural versus artificial lures) and water temperature have been suggested as potential contributors to the observed variation in mortality rates (Wilde et al. 2000). Two approaches were taken to better understand delayed hooking mortality of Striped Bass. This involved conducting a field study to gather firsthand data and insights. However, recognizing the challenges associated with such studies, a literature review was then undertaken to compile and analyze existing research findings.

METHODS

Delayed Hooking Mortality

To estimate delayed hooking mortality rates of Striped Bass in the study area, several approaches were attempted and refined over the course of the study:

1. Net Pen Trials: In summer 2021, net pens (15 m x 15 m x 4.5 m) were deployed in the lower Illinois River. Two separate trials were conducted to transport angled Striped Bass to the anchored net pens. However, the flowing water in the river caused the net pens to come apart despite trying different frame configurations. Smaller net pens (3 m x 1.5 m) were also tested but proved challenging to maintain in moving water. Additionally, certain areas with no water movement in the river were determined to be unsuitable as elevated temperatures in these locations would induce thermal stress not representative of natural conditions.
2. Experimental Pond Trials: In autumn 2021, experimental ponds were considered for delayed hooking mortality trials. However, after consulting experts familiar with transporting and confining Striped Bass in ponds, it was determined that this method would inflict significant hauling stress on the fish and was therefore not viable for the study. In addition, conducting the study during cooler months when transport and confinement stress would have been lower was not of interest. Summer transportation and confinement in ponds was not attempted with Striped Bass.
3. Telemetry Transmitter Attachment: In 2022, a final approach was attempted to estimate delayed hooking mortality rates using telemetry transmitters attached using dissolving

suture material (3/0 plain gut, Sutamed Corp., Fort Meyers, FL, USA), following the approach of Bettoli and Osborn (1998). Transmitters were attached to floats to make them barely buoyant, and the transmitter/float assembly was attached to fish with a single suture through the dorsal musculature just posterior to the dorsal spine. This approach was tested in a pilot study in aquaculture ponds in autumn 2021 using Common Carp *Cyprinus carpio* and Largemouth Bass *Micropterus salmoides* and worked well. Control fish collected by electrofishing were also fitted with transmitters for comparison. The Striped Bass with transmitter/float assemblies attached were tracked continuously for the first 30 minutes and then were relocated daily until the suture material dissolved and the tags were released from the fish. Due to habitat conditions during the summer of 2022 (i.e., low flows, high turbidity), angling catch rates were inadequate, so only 29 Striped Bass were tagged, and only eight treatment Striped Bass remained tagged long enough to be tracked at least one day.

4. Literature Review: A comprehensive search was conducted across various online databases, including Google Scholar, and relevant fisheries and conservation journals. The search used a combination of keywords and phrases related to "striped bass," "catch-and-release," and "mortality." Identified articles were screened based on predefined inclusion and exclusion criteria. Included studies had to focus explicitly on catch-and-release mortality of striped bass in recreational fishing scenarios. Studies that evaluated mortality rates, factors affecting mortality, release techniques, and post-release behavior were prioritized. Review articles, opinion pieces, and studies involving species other than Striped Bass were excluded. We then summarized the information found in the resulting studies to provide as much information as was available about the range of post-release mortality and the factors that are most significant in altering this source of mortality.

Objective 4. Using the above data and modeling simulations, determine the potential for growth overfishing of Striped Bass in the study system.

BACKGROUND

Preventing overfishing is an important fisheries management objective. Overfishing can manifest in two ways: growth overfishing and recruitment overfishing. Growth overfishing occurs when fish are caught before they have the chance to reach their maximum size, leading to a decline in the overall size distribution and total yield of the population. Although the population may still be able to sustain itself through reproduction, the size structure will be compromised, and maximum yield cannot be achieved (Diekert 2012). On the other hand, recruitment overfishing arises when excessive harvesting of mature fish depletes the brood stock, making it insufficient to support population growth through reproduction, leading to population decline, and possible extirpation if harvest is not reduced. In the case of Striped Bass within the Robert S. Kerr Reservoir portion of the Arkansas River population, assessment of the potential for growth and recruitment overfishing may support fisheries management. This evaluation may be used to predict the effect various regulations have on the sustainability and size structure of the Striped Bass population. To accomplish this, a model was developed, using measured data on mortality (both from angling and natural causes) and length at age of Striped Bass within the study area. By integrating these data, the model estimated the population dynamics of Striped Bass under different fishing mortality rates to assess the effect of different fishing strategies on the abundance, size structure, and yield of the population to aid managers in evaluating the regulation options most likely to produce their desired outcome for the fishery.

METHODS

Population Modelling

To assess the population dynamics and potential for growth or recruitment overfishing in the Striped Bass population, several analyses were conducted. First, aged fish were used to create an age-length key. This key was then used to assign ages to all fish collected by electrofishing using a semi-random approach (Isermann and Knight 2005) using the alkIndivAge function in the FSA package in R (Ogle et al. 2023). These fish with assigned ages were then used to fit a von Bertalanffy growth curve (Beverton 1954; Beverton and Holt 1957). This information was used to determine the mean TL and the standard deviation of TL at each age group. Additionally, a Chapman Robson catch curve analysis was used to estimate the total mortality rate of the population using fish age three and older (age 2 and younger fish did not appear fully recruited to sampling by the electrofisher; Chapman and Robson 1960; Hoenig et al. 1983; Smith et al. 2012). Including older fish in the population made little difference in survival rates and thus, were included in the analysis. Fishing mortality was estimated from reward tag returns to provide an estimate of current exploitation and was used to calculate the natural mortality rate (total mortality–fishing mortality = natural mortality). Length-weight data (n = 833) were taken from electrofished Striped Bass collected from August 2019 to July 2021. The earliest fish were collected in April and the latest in November. This subsample was also used to develop a linear regression equation describing the log of weight given the log of TL. Although the length-weight relationship likely varied seasonally, we needed to derive an equation to predict yield for the entire year, so pooling across seasons was the most appropriate approach.

A discrete age-specific yield-per-recruit model was created using the above demographic parameters from field sampling data. Growth overfishing was identified as the point where the average size at harvest falls below the size at which maximum yield per recruit is achieved, as defined by Allen and Hightower (2010). The basic model estimated cohort abundance using the equation:

$$N_{a,t} = N_{a-1,t-1} * (1- (v + u*V_h + d*u_{rel}* V_h + (u + d)*u_{rel}*(V_c - V_h))) \quad (1)$$

where $N_{a,t}$ is the number of individuals in age class "*a*" at time "*t*", $N_{a-1,t-1}$ is the number of individuals in the cohort during the previous time step, v is the annualized natural mortality rate, u is the annualize fishing mortality rate (exploitation), V_h is vulnerability to harvest (the proportion of the year class that is large enough to be harvest (i.e., ≥ minimum length requirement being evaluated) given the year class' mean and standard deviation of length), d is the annualized discard rate (rate at which fish in the general population experience catch and release angling), u_{rel} is the mortality rate of fish that are caught and released, and V_c is the vulnerability to angling (the proportion of fish in the cohort over 225mm TL [assumed to be the minimum size of fish typically caught by anglers]). This approach assumes all sources of mortality are additive. Thus, total mortality was the sum of natural mortality (v), the exploitation rate (u) multiplied by the vulnerability of fish to harvest (i.e., over the minimum length requirement), then two terms related to catch-and-release mortality. The first catch-and-release mortality term ($d*u_{rel}* V_h$) applies the catch-and-release mortality rate to fish that could have been harvested, but the angler chose not to (true catch-and-release mortality). The second catch-and-release mortality term ($(u + d)*u_{rel}*(V_c - V_h)$) applies the catch-and-release mortality rate to fish that were large enough to be caught (were $\geq$ 255 mm TL), but too small to be legally harvested (i.e., < minimum length requirement or > the maximum length requirement; the proportion of fish in this condition is the difference between V_c and V_h because we never tested minimum length requirements under the 225 mm threshold for being vulnerable to Striped Bass angling gear). This second catch-and-release mortality term assumed anglers who harvested fish caught sub-legal length fish at the same rate as all other sizes (as described by u) and that catch-and-release-only anglers are an additional (additive) fishing pressure on sub-legal length fish at a rate of d percent of the population.

The above equation was then parameterized with a combination of field-measured values and systematically varied parameters. Natural mortality (v) was set at 24% based on our field data. We then systematically varied u and u_{rel} to determine the effect of using different exploitation rates (i.e. as could be accomplished with changes in bag limits; we tested values from 5–75% exploitation) and post-release mortality rates (varied from 0–100%). We assumed d (rate of catch-and-release angling in the population) was a function of the exploitation rate (i.e., if exploitation rate increased, it implied the amount of catch-and-release angling would increase proportionately) by setting the value of d to u * 0.34 (i.e., catch and release was always 34% of the exploitation rate), to produce a conservatively high release rate that could account for possible future harvest restrictions that force higher release rates (current observed release rates were 0–22%, depending on year and assumed angler compliance rate [c-u, Table 1]). Vulnerability coefficients (proportion of fish large enough for legal harvest) were derived by assuming the variation in length at age was normally distributed and calculating the portion of the normal curve describing length at age that was either over the minimum length and under the maximum length for V_h, or over the minimum size vulnerable to angling for V_c).

The above model was then used to estimate abundance in all age classes for a cohort of 1000 age-0 individuals as they grew over the next 30 years in an unfished condition (i.e., with no fishing mortality; u and d set to zero). The number of individuals in each age class was converted to age-specific biomass by multiplying it by the mean weight of the age class (using the length-weight regression and von Bertalanffy-generated mean length at age for the cohort; Beverton 1954, Beverton and Holt 1957). The resulting biomass values were summed across age classes to arrive at the total biomass of standing stock of the population in the unfished condition. A similar procedure was then used to estimate abundance and biomass of cohorts over a 45-year period (long enough for the population to reach equilibrium) when fishing mortality was inflicted on the population at various rates (u varied from 5%–90% in 5% steps, which also altered d [d=u*0.3]). From the final year of simulation, we calculated total standing biomass, yield (harvested biomass), mean size of harvested fish, population PSD (proportional stock density) categories (PSD, PSD-P, and PSD-M; Gabelhouse 1984; Anderson and Neumann 1996), and estimated a spawning potential ratio (SPR; Goodyear 1993). To calculate SPR, we first calculated cohort-specific fecundity using the length-based fecundity equation given by Olsen and Rulifson (1992), but with the assumption that only age-2+ fish were mature. The number of fish in each age class was then multiplied by these age-specific fecundity values and the products summed to produce an estimate of total population egg production (population fecundity). We calculated total population fecundity in this way for the unfished condition as well as all modeled harvest scenarios. We then calculated SPR for a given modeled scenario as the egg production from that scenario divided by egg production in the unfished condition. We then assumed SPR values > 0.20 indicated sustainable conditions and that any scenario that produced SPR < 0.20 indicated recruitment overfishing (Goodyear 1993).

We built two types of models, a minimum length regulation model and a model combining a minimum length and a maximum length regulation model (effectively a harvest slot model, which would be somewhat similar to a minimum length regulation with a “1 fish over” or similar type bag restriction on larger fish). We also considered building a traditional slot limit model (protected slot), but traditional slot limits are designed to function by reducing abundance of smaller fish (below the protected slot) in order to increase growth rate. As such, this type of model would not be useful without an equation that accurately describes the relationship between cohort abundance and growth rate, which was not available. Thus, rather than build a model that is highly speculative (uses a hypothetical density-growth function), we opted not to build the model. For the minimum length model, we systematically varied the minimum length regulation from 250 mm (our assumed minimum catch size simulating no harvest regulation) to 1050 mm (approximately the largest mean length at age observed in the population) in 50-mm increments. The second model, which combined a minimum length and maximum length regulations, was tested to evaluate the benefit of restricting harvest on large fish. An extensive creel survey would be needed to model the effect of a specific harvest limitation (i.e., 1 fish over some size), so we instead model the maximum length model (no fish harvested over the maximum length size) to show the maximum benefit such a regulation could have under the best-case scenario (no harvest at all). Additional data about the frequency with which anglers harvest multiple large fish could be studied in the future to then refine this model to test the effects of allowing some degree of restricted harvest of large fish if this base model suggests it is worthwhile. In the second model, we used a 400-mm TL minimum length regulation (which matches the anecdotally observed minimum harvest sizes for most anglers) in all cases, then systematically varied the maximum size that could be harvested from 500 mm to 1,000-mm TL.

RESULTS

Data collected by the state are available on request. Please see the statement in the Acknowledgments.

Objective 1. Determine size structure, abundance, total mortality, and angling mortality of Striped Bass in the tailwaters of Tenkiller Lake and Canadian River arm of Lake Eufaula and surrounding rivers (lower Illinois, Arkansas, and Canadian).

Annual exploitation rates peaked in summer 2020 at 70% with the assumption of 14.3% compliance and 16% under the assumption of 100% compliance (Table 1). For the entire study, the catch and release rate was 4% with the assumption of 14.3% compliance and 12% under the assumption of 100% compliance (c-u, Table 1). If a substantial number of fishing events go unreported, it becomes challenging to accurately assess the true extent of angling pressure on the population. This could lead to inaccurate estimations of fishing mortality. Between August 2019 and August 2022, we PIT tagged 2,730 Striped Bass. We successfully recaptured 250 individuals, accounting for approximately 8.4% of the tagged population (Table 2). PIT tag loss was observed in 11.6% (29/250) of the recaptured fish, and only Striped Bass retaining tags were included in subsequent analyses. From June 2020 to August 2022, we tagged 681 Striped Bass with reward tags and 116 reward tags were returned by anglers in the lower Illinois and Canadian rivers (Table 3). Tag loss was 1.1% (1/90) for recaptured reward-tagged fish. Angler reporting rate (compliance) was estimated at 14.3% (2/14). The low angler reporting rate suggests that there could be a higher level of fishing pressure on Striped Bass than what is currently documented (Table 4). Anglers reported using live bait 67% of the time and artificial lures 33% of the time (n=57). In addition, anglers reported fishing from shore 42% of the time as opposed to a boat 58% of the time (n=53).

Proportional size distribution of Striped Bass sampled in the lower Illinois and Canadian rivers were dominated by quality sized fish (Table 5). The size structure we observed is somewhat smaller than what was collected by the Oklahoma Department of Wildlife and Conservation (ODWC) from 2010 to 2012 (Table 6; Figure 3, 4) (Data are available by request to Kurk Kuklinski, kurt.kuklinski@odwc.ok.gov). Notably, the proportion of preferred size Striped Bass was more than two times the size of our sample, though it is worth noting this also implies the 2010–2012 size structure was not in equilibrium (i.e., did not have more small/young fish than big/old fish). In addition, we did not capture any trophy sized fish but two trophy-sized fish were caught in the 2010–2012 sample. It is possible that the smaller sample size (n=633) for the ODWC sample compared to our sample (n=2,730) contributed to the disproportionate proportion of large fish being found in the ODWC sample (i.e., large fish were a greater proportion of the total in the smaller sample size). Nevertheless, these data suggest a possibility that the overall size structure of the population has decreased. The lack of stock sized fish could reflect sampling bias of the electrofisher, that these smaller fish are not located in the tailwaters, or a combination of the two. Age and growth data indicated that Striped Bass grew rapidly until approximately 750 mm, where growth began to slow down as fish mature (Figure 5). The Von Bertalanffy growth equation was:

$$TL = 1087.9(1 - \mathrm{e}^{-0.219(\mathrm{age}+0.187)})$$

Where TL is total length (mm) and age is the age of fish in years. Mean length and weight-at-age (Table 7) was comparable to other populations of landlocked Striped Bass (see Bulak et al. 1995; Shepherd and Maceina 2009). Total instantaneous mortality was estimated from Chapman-Robson catch-curve analysis as 42% over the course of the study, which corresponds to an annualized total mortality of 34%, suggesting that the current total mortality rate is sustainable

(Figure 6). After adjusting for tag loss and natural mortality, catch rates estimated from tag-returns was 11%, which included annual harvest of 7% (exploitation), and an annual catch-and-release rate of 4% assuming 100% compliance and total catch rate was 54%, which included annual harvest of 42% (exploitation, but this exceeded the measured total mortality of 34%, so is likely no higher than 34%) and a catch-and-release rate of 12% if a compliance rate of 14.3% is used. These rates appear to reflect sustainable levels of exploitation even if low reporting rates suggest the actual value is higher because the total mortality rate (34%) sets an upper bound for exploitation, and our model suggests harvest would be sustainable even if exploitation was as high as the current total mortality rate.

The survival-focused mark-recapture model indicated a true survival probability of 0.97 (0.95–0.98; 95% credible interval) for Striped Bass with telemetry transmitters (Figure 7). True survival indicates the probability of survival from one capture occasion to the next. This would equate to a 73.7% annual survival rate or a 26.3% annual mortality rate.

Abundance estimates of fish across the two tailwater habitats in the study varied seasonally and ranged from 782 in winter to 38,597 in summer, but with a relatively high degree of uncertainty (Table 8; Figure 8) due to the relatively low recapture rate of the population (9.2%). Although this reflects a lot of uncertainty between time periods (likely due to movement of fish into and out of the system annually), the data suggest a population in the thousands to tens of thousands of individuals in the lower Illinois and Canadian rivers. Much of the uncertainty is also likely due to the number of smaller fish that were captured (< 400 mm). These individuals were rarely recaptured (relative to the expected proportion in the population), which resulted in a larger population estimate. The abundance of smaller Striped Bass is unknown, but low recaptures likely reflect a large and mobile number of small fish (see Objective 2). However, larger Striped Bass tended to remain within their respective habitats during the seasonal sample period (fidelity probability was 0.98–1.00).

Objective 2. Determine the extent and timing of immigration and emigration of Striped Bass in tailwater habitats to determine the potential for overharvest when they congregate in tailwater areas.

We tagged 111 Striped Bass with telemetry transmitters and tracked them in the lower Illinois and Canadian rivers (Table 9). Passive receiver detections (Figure 9B) showed higher detection rates during autumn and spring, which correlated with the movement of Striped Bass into (spring) or out of (autumn) tailwater habitats. Particularly noteworthy was the increased susceptibility of Striped Bass to exploitation during the summer season when water temperatures exceeded approximately 25°C (Table 3; Figure 9C). This period coincided with their movements into tailwater habitats (Figure 9B) and higher rates of reward tag returns (Figure 9A), most of which came from tailwater habitats (Table 1).

To gain further insights into the dynamics of the Striped Bass populations, we employed the movement-based multistate capture-recapture model using 91 individual capture histories. The resulting model estimated movement probabilities between the three main study area segments (Figure 10). Striped Bass mostly used the main stem Arkansas River from October to May, during periods of cooler water. Some movement was seen out of the tailwaters during the warmer months (June–September), but most fish stayed in a given tailwater for an entire warmwater season. Striped Bass had a 0.77 mean probability of moving from the Canadian River to the lower Illinois River over the course of the study, the highest movement probability for Canadian River fish. Mean movement probability from the lower Illinois River to the Canadian River was 0.26 (Figure 10). Overall, these findings indicate that the Robert S Kerr river-reservoir complex is home to one population of Striped Bass, which partitions into sub populations during the summer when fish are vulnerable to exploitation.

Objective 3. Estimate delayed hooking mortality of Striped Bass in spring and summer.

Angling rates dissipated soon after they increased in July 2022, so only 45 (34 treatment, 11 control) Striped Bass were tagged, and only eight of the treatment fish remained tagged long enough to be tracked at least one day. The total time tracked for these eight fish was between one and three days. There were no confirmed mortalities from these fish (treatment or control). However, many of the fish that lost tags within a day of tagging were tagged in the upstream reaches of the lower Illinois River when the dissolved oxygen was low, and those fish did not regain equilibrium in the short time we were able to follow them before they were tangled in woody debris and lost their tags, so measurable mortality may have occurred in some of the fish that could not be tracked. We were unable to get additional replicates because U.S. Army Corps of Engineers would not allow us to fish at the dam on the Canadian River, and where we could fish in the middle and upper reaches of the lower Illinois River, woody debris was abundant, which caused transmitters to snag on wood and come off within the first few hours of tracking. The only viable option for releasing and tracking fish was to either angle near the confluence or moving fish angled in other locations to the confluence for release. In addition, the U.S. Army Corps of Engineers was performing maintenance on Tenkiller Dam throughout the summer, which limited water releases and hindered our ability to move upriver (and likely explaining the lower-than-usual angling rates this year). We found fish captured when dissolved oxygen was less than 4 mg/L in the lower Illinois River did not recover within thirty minutes of being tracked. These were not confirmed to be mortalities because the tags separated from the fish before the fish died, and we then lost track of the fish once the tag was detached, but it is possible that mortality rates of these fish would be high given their slow recovery.

To supplement the small amount of data collected for delayed hooking mortality, a literature review was conducted to evaluate what is currently known about delayed hooking mortality of Striped Bass in other locations. Delayed hooking mortality studies of Striped Bass have identified several key factors that can reduce the survival of released fish. These factors include high water temperature (Harrell 1988; Nelson 1998; Bettoli and Osborne 1998; Millard et al. 2005), the use of live bait relative to artificial lures (Nelson 1998; Millard et al. 2003), hooking in the esophagus or gut instead of near the mandibles (Millard et al. 2003), high air temperature (Bettoli and Osborne 1998), type of hook (Nelson 1998), summer relative to spring, fall, and winter (Hysmith et al. 1994; Bettinger et al. 2005), and prolonged handling time (Bettoli and Osborne 1998). Overall, it appears that two main factors contributing to catch-and-release mortality are physical injury and physiological stress (Muoneke and Childress 1994), the effects of which we will detail below.

The first, and most important factor affecting hooking mortality is the anatomical location of the hook wound. Fish hooked in sensitive areas, such as the gills, esophagus, or stomach are more likely to suffer injuries and have a higher risk of mortality (Muoneke and Childress 1994; Millard et al. 2003; 2005). Deep hooking, especially when fish swallow hooks, increases the likelihood of injury and death (Diodati and Richards 1996; Nelson 1998). The use of non-offset circle hooks has been suggested as a less lethal option for anglers, as they result in more jaw-hooked fish and reduce damage to vital organs (MD DNR 2010; DNREC 2011).

Second, environmental factors, particularly water temperature, play a significant role in hooking mortality as they affect physiological stress. As water temperatures rise above the optimal range for Striped Bass, stress levels increase, and the potential for post-release mortality rises (Harrell 1988; Hysmith et al. 1994; Tomasso et al. 1996; Nelson 1998; Wilde et al. 2000; Millard et al. 2003; Lockwood 2012). Warm water temperatures, especially exceeding 21°C, are associated with higher stress-induced mortality in Striped Bass (Lockwood 2012; Millard et al. 2005; Nelson 1998). Air temperature at the time of catch and release is also an important factor, especially during hot weather when there are significant temperature differences between water and air (Bettoli and Osborne 1998; Lockwood 2012). Summer mortality can be as high as 83% (Bettinger et al. 2005), and it was higher than other times of the year in all studies that have observed Striped Bass catch-and-release mortality during summer (Bettinger and Wilde 2012). Large fish, low salinity, and high-water temperatures are all associated with increased summer mortality rates for Striped Bass (RMC 1990; Lukacovic and Uphoff 1997). Striped Bass caught in freshwater ecosystems are more susceptible to stress-induced mortality compared to those in marine waters due to potential osmoregulatory dysfunction (Diodati and Richards 1996).

Several other factors also affect post-hooking mortality rates. Fish caught on natural or live baits are more likely to be deep hooked, increasing the risk of injury and mortality (Hysmith et al. 1994; Harrell 1998; Wilde et al. 2000; Millard et al. 2003). Angling with artificial baits generally results in fewer injuries, but large lures with multiple treble hooks can cause harm to fish, particularly if they hook the fish in sensitive areas (Harrell 1998). Prolonged fights during angling can lead to fish exhaustion and the accumulation of lactic acid in the tissues, causing acidosis and physiological imbalance (Tomasso et al. 1996; Nelson 1998). Shortening the fight time and handling fish carefully can reduce stress and increase post-release survival chances (Cooke and Suski 2005). Mishandling fish during landing, handling, and release can further exacerbate stress and lead to increased post-release mortality (Hysmith et al. 1994; Diodati and Richards 1996; Nelson 1998; Millard et al. 2003; Lukacovic and Uphoff 2007). The longer a fish is kept out of the water, especially after a prolonged fight, the lower its chances of survival (Cooke and Suski 2005). Overall, the Canadian and lower Illinois rivers represent a high-risk fishery for Striped Bass catch-and-release mortality, as these are freshwaters where the majority of exploitation happens in the summer (with high temperature and periods of low oxygen concentration), live bait is commonly used, and large fish are often the target. The warm water temperatures of the Canadian River during the summer are especially problematic given the associated thermal stress. The above literature review suggests the use of circle hooks, restricting the use of live bait, and education of anglers about proper handling of fish are options to reduce the chances of catch-and-release mortality of Striped Bass.

Objective 4. Using the above data and modeling simulations, determine the potential for growth overfishing of Striped Bass in the tailwater reaches of the study system.

Based on the minimum length model, it appears recruitment overfishing was unlikely to occur in this fishery, at least until exploitation increases to at least 30% and even then, exploitation could be prevented by implementing a modest minimum length regulation (Table 10) or a conservative maximum length regulation (Table 11). As is typical, growth overfishing was much more likely. The average length of fish harvest under these conditions was 728 mm with 25% exploitation and 718 mm with 30% exploitation (Tables 12–13). Thus, by definition, growth overfishing occurs for all harvest regulations where the average size at harvest was < 718 mm, which occurred for any minimum length tested < 600 mm if exploitation was above 10%, and for exploitation <10%, it still required a minimum length regulation of at least 500 mm (Tables 12–13). Maximum yield (954 kg/1,000 recruits) was realized with a 600 mm TL minimum length regulation and 25–30% exploitation rate (same yield found for both exploitation rates; Table 14).

Overall size structure (PSDs) is probably more important than the measure of where growth overfishing occurs, given maximizing yield is not currently a management objective for this fishery. As would be expected, all PSD values were maximized with higher minimum length regulations, more conservative maximum length regulations (i.e., restricting harvest of all fish over a relatively smaller size) and lower exploitation rates. Current PSD values (Table 5) are somewhat higher than what are predicted by our model (Tables 15–17) given our expected exploitation rate between 7% and 34%, suggesting either faster growth of some older cohorts or the presence of strong, older year classes that do not match the model's assumption of constant growth and recruitment. The model predicts that PSD and PSD-P values could be improved by 5 units or more (probably the minimum change that would be noticed by an angler) only with a large increase in the minimum length regulation (i.e., minimum lengths ≥ 700 mm TL for PSD or ≥ 850 mm TL for PSD-P), and more modest length regulations would not have large effects (Tables 15–16). Values for PSD-M were low enough under all reasonable harvest strategies that a 5-unit increase was not possible (Table 17). PSD values would decline by ≤ 5 units if exploitation increased more than 10% the current conditions (7–34%) unless a minimum length of at least 600 or a maximum length protecting fish over 650 were used, and exploitation appears to be more important than the size at harvest with respect to determining population size structure (Tables 15–17).

The maximum length regulation model provides an opportunity to evaluate the best-case scenario for maximizing size structure through restrictions on the number of large fish harvested. The maximum length regulation model was tested assuming anglers self-impose a 400-mm minimum length regulation, so its results are only directly compared with the 400 mm rows of the minimum length model tables. Almost no change in PSD values were observed (relative to a 400 mm minimum length requirement with no maximum size enforced) when maximum size limits of ≥ 900 mm were used (Tables 18–20). PSD and PSD-P values did increase if a fairly low maximum size was used (e.g., ≤ 650 mm or so; Tables 18–19). This was true across most reasonable exploitation levels, but the amount the PSD values improved from such a restrictive maximum size were greater when exploitation was higher. Again, PSD-M values were low enough at all harvest scenarios that a 5-unit change was not achievable at low exploitation levels, but could be realized once exploitation levels were ≥ 0.25 if very restrictive maximum length regulations were used (i.e., maximum length ≤ 600 mm; Table 20).

For both models, post-release mortality had a minimal effect on size structure if exploitation was at current levels, despite assuming a 34% catch-and-release angling rate (maximum observed rate even under an assumption of low angler compliance for returning tags was only 12%). Even with 100% post-release mortality, PSD values for modest to small minimum length requirements (i.e., minimum lengths < 650 mm) only changed 3–5 PSD units (Table 21). In the minimum length model, only truly large minimum length requirements (> 640 mm) had PSD values that were more than 5 units different when post-release mortality rates were changed from 0% to 100% (but PSD changed by 11 units for the largest minimum lengths modeled). In the maximum length regulation model, results of post-release mortality were similarly small with meaningful changes from the current PSD values only occurring with large changes in post-release mortality rates and moderate to highly restrictive maximum sizes (i.e., PSD values with maximum sizes limits $\leq$ 800 mm and post-release mortality < 35% had meaningfully higher values than those observed with larger maximum length limits and/or post-release mortality rates from 50–100%; Table 22).

CONCLUSIONS

Our data indicate that the Robert S. Kerr Striped Bass fishery is sustainable under the current management practices and exploitation rates. Given the high mobility and low recapture rate of the Striped Bass population in the study area, our data indicate that the population replenishes from the Arkansas River, and mixing occurs in the tailwaters throughout most seasons except summer. Consequently, our data indicate that managing the Robert S. Kerr river-reservoir complex as a single population makes biological sense.

Despite the apparent sustainability of the current fishery conditions, our findings also indicate there are ways to improve the overall size structure of the population if that is a goal of the management agency. Implementing a minimum length regulation of at least 600-mm TL could improve the overall size structure of the population and increase yield. Additionally, our models indicate maintaining moderate exploitation rates may support maintenance of the desired size structure and prevent overexploitation. Keeping exploitation rates below 25–30% may maintain large size structure and maximize yield in the fishery; however, lower exploitation could be used to increase PSD values. The exploitation rates (7%) we show may be underestimated given low reward tag returns, but the true value must be below the total mortality rate (26.3% as estimated from recaptures and 34.3% as estimated from a catch curve), which is currently sustainable given the catch curve estimate of total mortality is accurate. However, reducing a bag limit or making other changes that result in fewer fish being harvested (e.g., high minimum length or conservative maximum length regulations) could improve size structure (but would slightly decrease yield), according to our model. For example, a minimum length regulation of over 800 mm TL could meaningfully improve the proportion of quality and preferred size fish, although this may result in a predominantly catch-and-release fishery.

Alternatively, a slot-based regulation system could be considered, which would offer multiple advantages. First, a slot limit might be able to further increase growth of younger fish by reducing competition. Second, it would protect the mid-size fish as they continue to grow at the high rate induced by harvest below the slot. These mid-size fish are less likely to experience catch-and-release mortality than the larger fish. Finally, a slot limit would also allow some harvest of larger fish to satisfy trophy-oriented anglers. We were unable to accurately model slot limit effects because there are no data available to parameterize the relationship between fish abundance and growth rate for the species. However, a slot limit might be hypothesized to provide greater growth potential, and increased size structure compared to the other modeled regulations.

The literature suggests that the summertime conditions in these tailwater fisheries represent a high catch-and-release mortality risk. A conservative management approach would assume that catch-and-release mortality is moderate to high at certain times, especially among the largest fish in the population. Therefore, length regulations protecting large fish are likely to be hindered by catch-and-release mortality. Educating anglers about responsible fishing practices can help minimize adverse effects of catch-and-release mortality that are likely to occur at high temperatures and/or under low-oxygen conditions. However, the only method to ensure catch-and-release mortality would not harm the fishery would be a seasonal closure. However, we show catch and release mortality is unlikely to result in recruitment overfishing, and its effects on size structure are not as large as the effects of minimum or maximum length regulations. If the agency has concerns related to the ethics of releasing fish with high mortality, then requiring take during certain periods may be needed.

It is important to acknowledge uncertainties in modelled abundance, catch rates, mortality rates, and movement probabilities. Periodic reassessment and monitoring can provide more confidence in management decisions. In summary, the fishery appears to be sustainable in its current state, but our data indicate the following enhancements might be made depending on the management goals:

1. Minimum length regulation of at least 6000-mm TL would be most likely to maximize yield from the fishery and is likely to improve size structure.
2. Consider > 800-mm maximum length regulation or slot-based regulations protecting 600–800 mm as possible ways to maximize size structure.

3. High catch-and-release mortality risk likely exists in summer, especially for larger fish. Thus, population and ethical concerns may need to be addressed during the warm summers and depending on dam operations (i.e., should catch and release be allowed or should periodic closures occur during these critical periods).
4. Monitoring and maintaining water temperature and oxygen at acceptable levels through altered dam operation, when possible, may reduce the risk of catch-and-release mortality.
5. Striped Bass in tailwaters along the Arkansas River may be managed as a single population.
6. Educating anglers about optimal fish handling methods may minimize catch-and-release mortality.
7. Awareness of uncertainties and periodic reassessment of the population may improve information available for management assessment.

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Table 1. Annual instantaneous harvest rate (F), discrete annual harvest rate (u), instantaneous annual catch rate (C), and discrete annual catch rate (c) for the Striped Bass fishery in the Lower Illinois and Canadian River tributaries of the Arkansas River from June 2020–June 2022. The values are based on reward tag returns and have been adjusted for natural mortality and tag loss. Values associated with complete angler compliance and the 14.3% compliance found from tag handouts are included. Data from June 2022 – August 2022 were not included as it was not a complete year and rates varied seasonally (but monthly values were provided in Table 3).

Compliance	Year	F	u	C	c
100%	2020	0.09	0.08	0.17	0.16
	2021	0.06	0.06	0.07	0.06
	Average	0.08	0.07	0.12	0.11
14.3%	2020	0.64	0.48	1.20	0.70
	2021	0.44	0.35	0.46	0.37
	Average	0.54	0.42	0.83	0.54

Table 2. Summary statistics describing PIT tagged Striped Bass collected from August 2019–August 2022 from the Canadian River below Eufaula Dam and the lower Illinois River below Tenkiller Dam, Oklahoma. Number of tagged fish by year and river, number of recaptured fish by year and river, cumulative number of tagged fish, and mean and maximum total length by year and river are included.

Year	Segment	Number of fish tagged	Number of fish recaptured	Number of tagged fish at large	Mean Length (mm)	Maximum Length (mm)
2019	Canadian	26	0	26	685	906
2019	Illinois	125	3	125	661	1004
2020	Canadian	644	19	670	650	995
2020	Illinois	712	46	837	633	1070
2021	Canadian	448	37	1,118	663	1042
2021	Illinois	237	36	1,074	606	1032
2022	Canadian	460	35	1,578	569	988
2022	Illinois	276	58	1,350	626	990

Table 3. Summary statistics for Striped Bass tagged with reward tags from June 2020–August 2022 from the Canadian River below Eufaula Dam and the lower Illinois River below Tenkiller Dam, Oklahoma. Number of tagged fish by year and river, number of tags returned by year and river, and mean and maximum total length by year and river are included.

Year	Segment	Number of Fish Tagged	Tags Returned	Mean Length (mm)	Maximum Length (mm)
2020	Canadian	235	13	712	995
2020	Illinois	240	51	685	1063
2020	Arkansas	0	3	-	-
2021	Canadian	8	5	742	965
2021	Illinois	54	20	726	1032
2021	Arkansas	0	6	-	-
2022	Canadian	30	1	741	982
2022	Illinois	54	15	675	892
2022	Arkansas	0	1	-	-

Table 4. Monthly tags at large, instantaneous harvest rate (F), discrete monthly harvest rate (u), instantaneous monthly catch rate (C), and discrete monthly catch rate (c) for the Striped Bass fishery in the Lower Illinois and Canadian River tributaries of the Arkansas River from June 2020–August 2022. Tags at Large were the number of tags released in the segment to date adjusted for tags returned, natural mortality, and tag loss. Values associated with complete angler compliance and the 14.3% compliance found from tag handouts are included.

Compliance	Month	Year	Tags at large	F	u	C	c
100%	6	2020	260	0.0116	0.0116	0.0539	0.0554
	7	2020	431	0.0354	0.0348	0.0673	0.0697
	8	2020	416	0.0218	0.0216	0.0336	0.0342
	9	2020	431	0.0117	0.0116	0.0116	0.0117
	10	2020	430	0.0023	0.0023	0.0023	0.0023
	12	2020	429	0.0023	0.0023	0.0023	0.0023
	3	2021	428	0.0000	0.0000	0.0023	0.0023
	4	2021	432	0.0046	0.0046	0.0046	0.0046
	5	2021	434	0.0093	0.0092	0.0092	0.0093
	6	2021	446	0.0158	0.0157	0.0202	0.0204
	7	2021	445	0.0136	0.0135	0.0135	0.0136
	8	2021	443	0.0045	0.0045	0.0045	0.0045
	9	2021	498	0.0121	0.0120	0.0120	0.0121
	6	2022	504	0.0000	0.0000	0.0119	0.0120
	7	2022	541	0.0056	0.0055	0.0055	0.0056
	8	2022	574	0.0123	0.0122	0.0157	0.0158
	9	2022	571	0.0018	0.0018	0.0053	0.0053
	10	2022	569	0.0018	0.0018	0.0035	0.0035
14.3%	6	2020	260	0.0843	0.0809	0.3774	0.4738
	7	2020	431	0.2792	0.2436	0.4710	0.6368
	8	2020	416	0.1640	0.1512	0.2352	0.2682
	9	2020	431	0.0846	0.0811	0.0811	0.0846
	10	2020	430	0.0164	0.0163	0.0163	0.0164
	12	2020	429	0.0164	0.0163	0.0163	0.0164

3	2021	428	0.0000	0.0000	0.0163	0.0165
4	2021	432	0.0329	0.0324	0.0324	0.0329
5	2021	434	0.0667	0.0645	0.0645	0.0667
6	2021	446	0.1164	0.1099	0.1413	0.1523
7	2021	445	0.0992	0.0944	0.0944	0.0992
8	2021	443	0.0321	0.0316	0.0316	0.0321
9	2021	498	0.0880	0.0842	0.0842	0.0880
6	2022	504	0.0000	0.0000	0.0832	0.0869
7	2022	541	0.0395	0.0388	0.0388	0.0395
8	2022	574	0.0892	0.0853	0.1097	0.1162
9	2022	571	0.0123	0.0123	0.0368	0.0375
10	2022	569	0.0124	0.0123	0.0246	0.0249

Table 5. Proportional stock density (PSD) and incremental PSD values for Striped Bass sampled from the lower Illinois and Canadian rivers, Oklahoma from June 2020–August 2022. Also given are lower (95% LCI) and upper (95% UCI) bounds for 95% confidence intervals. PSD category abbreviations are S = stock size, Q = quality size, P = preferred size, M = memorable size. No fish over trophy size was observed.

	Estimate	95% LCI	95% UCI
PSD-Q	78	76	80
PSD-P	25	23	27
PSD-M	10	8	11
PSD S-Q	22	20	24
PSD Q-P	53	51	56
PSD P-M	15	13	17
PSD M-T	10	8	11

Table 6. Proportional stock density (PSD) and incremental PSD values for Striped Bass sampled from the lower Illinois and Canadian rivers, Oklahoma sampled by ODWC from 2010–2012. Also given are lower (95% LCI) and upper (95% UCI) bounds for 95% confidence intervals. PSD category abbreviations are S = stock size, Q = quality size, P = preferred size, M = memorable size. No fish over trophy size were observed.

	Estimate	95% LCI	95% UCI
PSD-Q	89	85	93
PSD-P	48	42	54
PSD-M	13	9	17
PSD S-Q	11	7	15
PSD Q-P	41	35	47
PSD P-M	35	29	41
PSD M-T	13	9	17

Table 7. Age, number of fish predicted to be in each age class from the 2,730 total fish sampled during the project, mean length at age and standard deviation, minimum length at age, median length at age, maximum length at age, predicted mean weight at age and the associated confidence interval for Striped Bass sampled from the Arkansas River between Robert S. Kerr Reservoir and Webber's Falls Lock and Dam, including the lower Illinois River and Canadian River tailwaters from 2019-2022.

Age	# Fish	Mean length (mm)	Standard deviation	Minimum	Median	Maximum	Mean weight (kg)	Upper CI 95%	Lower CI 95%
0	25	131	68	60	105	259	0.0	0.0	0.0
1	133	247	57	126	254	355	0.2	0.1	0.2
2	769	454	64	63	459	629	1.1	0.8	1.5
3	594	566	56	331	574	689	2.2	1.6	3.1
4	641	652	59	323	662	839	3.4	2.4	4.7
5	503	754	63	630	745	898	5.3	3.8	7.5
6	289	781	96	571	792	1018	6.0	4.3	8.3
7	59	867	25	810	876	896	8.3	5.9	11.6
8	48	921	33	850	923	982	10.0	7.1	14.0
9	92	922	71	789	925	1045	10.0	7.1	14.0
10	114	861	164	510	922	1045	8.1	5.8	11.3
11	7	1005	11	990	1010	1016	13.1	9.4	18.4
12	4	1068	10	1058	1067	1080	15.8	11.3	22.2
14	3	1011	9	1000	1014	1018	13.3	9.5	18.7
17	3	1031	8	1023	1032	1038	14.2	10.1	19.9

Table 8. Posterior distribution mean, standard error, standard deviation, and credible intervals from a Cormack Jolly Seber model of recaptures of Striped Bass from Arkansas River between Robert S. Kerr Reservoir and Webber's Falls Lock and dam, including the lower Illinois River and Canadian River tailwaters during 2019-2022. Parameters include apparent survival probability (phi), capture probability (p), the probability that if an individual is alive at time t that it will never be captured again (chi), and the population size estimate (pop). The bracketed numbers refer to the capture occasion.

Parameter	Mean	SE	SD	2.5%	25%	50%	75%	97.5%
phi[1]	0.65	0.00	0.21	0.26	0.50	0.67	0.83	0.98
phi[2]	0.85	0.00	0.11	0.58	0.78	0.88	0.94	0.99
phi[3]	0.68	0.00	0.14	0.43	0.58	0.67	0.78	0.96
phi[4]	0.58	0.00	0.15	0.34	0.47	0.56	0.67	0.91
phi[5]	0.54	0.00	0.23	0.18	0.35	0.52	0.72	0.97
phi[6]	0.42	0.00	0.25	0.09	0.21	0.36	0.60	0.95
p[1]	0.50	0.00	0.28	0.03	0.26	0.50	0.75	0.97
p[2]	0.08	0.00	0.06	0.01	0.04	0.07	0.11	0.24
p[3]	0.04	0.00	0.02	0.01	0.03	0.03	0.05	0.08
p[4]	0.02	0.00	0.01	0.01	0.01	0.02	0.02	0.03
p[5]	0.08	0.00	0.02	0.05	0.07	0.08	0.09	0.12
p[6]	0.01	0.00	0.01	0.00	0.01	0.01	0.02	0.04
p[7]	0.41	0.00	0.25	0.08	0.20	0.35	0.60	0.95
chi[1]	0.90	0.00	0.03	0.83	0.88	0.91	0.93	0.96
chi[2]	0.92	0.00	0.01	0.89	0.91	0.92	0.93	0.95
chi[3]	0.94	0.00	0.01	0.93	0.93	0.94	0.94	0.95
chi[4]	0.92	0.00	0.02	0.89	0.91	0.93	0.93	0.95
chi[5]	0.94	0.00	0.01	0.92	0.93	0.94	0.94	0.95
chi[6]	0.87	0.00	0.07	0.69	0.84	0.89	0.92	0.95

pop[2]	3114	49	3341	649	1441	2234	3593	10717
pop[3]	38958	271	20177	15433	25638	33971	46145	91014
pop[4]	14468	71	4893	7251	10965	13641	17129	26339
pop[5]	8932	27	2166	5443	7377	8695	10178	13814
pop[6]	774	7	473	195	442	668	989	1978
pop[7]	3032	33	2316	841	1341	2265	3942	9428

Table 9. Summary statistics for telemetry tagged Striped Bass captured and implanted with tags from June 2020–June 2022 from the Canadian River below Eufaula Dam and the lower Illinois River below Tenkiller Dam, Oklahoma. Number of tagged fish by year and river, number of cumulative tagged fish by year and river, and minimum, mean, and maximum total length by year and river are included.

Year	Segment	Number of fish tagged	Number of tagged fish at large	Minimum length (mm)	Mean length (mm)	Maximum length (mm)
2020	Canadian	12	12	446	599	849
2020	Illinois	42	42	410	776	1080
2021	Canadian	25	37	557	776	1049
2021	Illinois	27	69	400	753	1000
2022	Illinois	5	74	599	699	815

Table 10. Spawning potential ratio (SPR) for Striped Bass under various exploitation rates (u) and minimum size regulations (mm) from a yield per recruit model evaluating harvest in the Arkansas River system near the confluence of the Canadian and lower Illinois

rivers. Values of SPR < 0.2 indicate recruitment overfishing and are shaded grey whereas higher values are shaded from orange (near 0.2) to green (highest values).

	Exploitation (u)										
Minimum length regulation (mm)	0.05	0.1	0.15	0.2	0.25	0.3	0.35	0.4	0.45	0.5	0.55
250	0.71	0.52	0.39	0.29	0.22	0.17	0.13	0.10	0.07	0.05	0.04
300	0.72	0.54	0.41	0.32	0.25	0.19	0.15	0.12	0.09	0.07	0.05
350	0.73	0.56	0.43	0.34	0.27	0.22	0.18	0.14	0.11	0.09	0.07
400	0.75	0.58	0.46	0.38	0.31	0.26	0.21	0.18	0.15	0.13	0.11
450	0.77	0.61	0.50	0.42	0.35	0.30	0.26	0.23	0.20	0.18	0.16
500	0.78	0.64	0.53	0.45	0.39	0.35	0.31	0.28	0.25	0.23	0.21
550	0.80	0.66	0.56	0.49	0.43	0.39	0.35	0.32	0.29	0.27	0.25
600	0.81	0.69	0.59	0.52	0.47	0.43	0.39	0.36	0.33	0.31	0.29
650	0.83	0.71	0.63	0.56	0.51	0.47	0.44	0.41	0.38	0.36	0.34
700	0.85	0.74	0.66	0.60	0.55	0.51	0.48	0.45	0.43	0.41	0.39
750	0.86	0.77	0.70	0.64	0.59	0.56	0.52	0.50	0.47	0.45	0.43
800	0.88	0.79	0.73	0.68	0.63	0.60	0.56	0.54	0.51	0.49	0.47
850	0.89	0.81	0.75	0.70	0.66	0.63	0.60	0.57	0.54	0.52	0.50
900	0.91	0.84	0.78	0.73	0.69	0.66	0.63	0.60	0.57	0.55	0.53
950	0.92	0.86	0.81	0.77	0.73	0.70	0.66	0.64	0.61	0.58	0.56
1000	0.93	0.88	0.83	0.79	0.75	0.72	0.69	0.66	0.63	0.61	0.58
1050	0.94	0.90	0.85	0.81	0.78	0.74	0.71	0.68	0.65	0.62	0.60

Table 11. Spawning potential ratio (SPR) for Striped Bass under various exploitation rates (u) and maximum size regulations (mm) from a yield per recruit model evaluating harvest in the Arkansas River system near the confluence of the Canadian and lower Illinois rivers. The model assumed that harvest did not occur on fish < 400 mm (either due to a minimum length requirement or voluntary

behavior of anglers). Values of SPR < 0.2 indicate recruitment overfishing and are shaded gray, whereas higher values are shaded from yellow (near 0.2) to green (highest values).

	Exploitation (u)										
Maximum length regulation (mm)	0.05	0.1	0.15	0.2	0.25	0.3	0.35	0.4	0.45	0.5	0.55
500	0.91	0.83	0.76	0.69	0.63	0.57	0.51	0.46	0.42	0.37	0.33
550	0.90	0.80	0.71	0.64	0.56	0.50	0.44	0.38	0.34	0.29	0.25
600	0.88	0.77	0.67	0.58	0.50	0.43	0.37	0.32	0.27	0.23	0.19
650	0.86	0.74	0.63	0.53	0.45	0.38	0.32	0.26	0.22	0.18	0.15
700	0.84	0.70	0.59	0.49	0.41	0.34	0.28	0.23	0.19	0.15	0.12
750	0.82	0.68	0.55	0.45	0.37	0.30	0.25	0.21	0.17	0.14	0.12
800	0.81	0.65	0.53	0.43	0.35	0.28	0.23	0.19	0.16	0.13	0.11
850	0.80	0.63	0.51	0.41	0.33	0.27	0.23	0.19	0.16	0.13	0.11
900	0.78	0.62	0.49	0.40	0.32	0.27	0.22	0.18	0.15	0.13	0.11
950	0.77	0.60	0.48	0.38	0.31	0.26	0.22	0.18	0.15	0.13	0.11
1000	0.76	0.59	0.47	0.38	0.31	0.26	0.22	0.18	0.15	0.13	0.11
1050	0.75	0.59	0.47	0.38	0.31	0.26	0.22	0.18	0.15	0.13	0.11

Table 12. Mean TL of fish harvested per 1000 recruits for Striped Bass under various exploitation rates (u) and minimum size regulations (mm) from a yield per recruit model evaluating harvest in the Arkansas River system near the confluence of the Canadian and lower Illinois rivers. Harvest scenarios where SPR < 0.2 (indicating recruitment overfishing) are shaded gray. Other shaded cells indicate sustainable conditions and shading ranges from red (lowest mean TL) to green (highest mean TL).

	Exploitation (u)										
Minimum length regulation (mm)	0.05	0.1	0.15	0.2	0.25	0.3	0.35	0.4	0.45	0.5	0.55
250	578	542	511	485	463	444	428	414	401	390	380
300	610	576	547	523	502	485	469	455	443	433	423
350	638	605	578	555	536	519	504	491	479	469	460
400	669	639	613	592	574	558	545	533	522	513	505
450	704	677	654	634	618	603	591	580	571	562	555
500	735	710	689	671	656	643	632	622	613	606	599
550	764	741	722	706	692	680	670	661	653	647	641
600	793	773	755	741	728	718	708	700	693	687	682
650	826	807	791	778	767	758	750	743	737	731	726
700	860	844	830	819	809	801	794	788	782	777	773
750	894	881	869	860	851	844	838	833	828	824	820
800	927	916	907	900	893	888	883	879	875	872	869
850	955	946	939	933	928	923	920	917	915	913	911
900	983	976	970	965	961	957	954	952	950	948	947
950	1025	1022	1019	1016	1013	1011	1009	1007	1006	1004	1002
1000	1051	1051	1051	1051	1052	1052	1053	1054	1054	1055	1055
1050	1093	1095	1098	1100	1102	1105	1107	1108	1110	1111	1112

Table 13. Mean TL of fish harvested per 1000 recruits for Striped Bass under various exploitation rates (u) and maximum size regulations (mm) from a yield per recruit model evaluating harvest in the Arkansas River system near the confluence of the Canadian and lower Illinois rivers. Harvest scenarios where SPR < 0.2 (indicating recruitment overfishing) are shaded gray. Other shaded cells indicate sustainable conditions and shading ranges from red (lowest mean TL) to green (largest mean TL).

	Exploitation (u)										
Maximum length regulation (mm)	0.05	0.1	0.15	0.2	0.25	0.3	0.35	0.4	0.45	0.5	0.55
500	473	473	472	471	470	469	469	468	467	466	465
550	491	490	488	487	486	484	483	481	480	478	476
600	510	508	506	504	501	499	497	495	492	490	487
650	531	528	524	521	517	514	510	506	503	499	495
700	553	548	543	537	532	527	521	516	511	505	500
750	574	567	559	552	545	537	530	523	516	509	502
800	592	583	573	564	554	545	536	527	519	511	504
850	606	595	583	572	561	550	540	530	521	512	504
900	623	608	593	579	566	554	542	531	522	513	504
950	641	622	603	587	571	557	544	532	522	513	505
1000	649	628	608	589	573	558	544	533	522	513	505
1050	662	635	612	591	574	558	545	533	522	513	505

Table 14. Yield (total harvest, kg/1000 recruits) for Striped Bass under various exploitation rates (u) and minimum size regulations (mm) from a yield per recruit model evaluating harvest in the Arkansas River system near the confluence of the Canadian and lower Illinois rivers. Harvest scenarios where SPR < 0.2 (indicating recruitment overfishing) are shaded gray. Other shaded cells indicate sustainable conditions and shading ranges from red (lowest modeled yield) to green (highest yield).

Exploitation (u)

Minimum length regulation (mm)	0.05	0.1	0.15	0.2	0.25	0.3	0.35	0.4	0.45	0.5	0.55
250	511	702	750	734	690	635	579	525	475	430	390
300	518	722	785	781	746	699	648	598	551	508	468
350	521	737	812	819	793	753	707	661	617	575	537
400	523	750	838	857	842	811	773	732	692	654	617
450	522	761	863	896	893	872	842	807	772	737	704
500	518	765	878	922	929	915	892	863	831	800	769
550	509	760	881	933	948	942	923	899	871	842	813
600	495	747	874	933	954	954	941	921	896	869	842
650	474	721	850	915	942	947	938	921	900	875	849
700	443	680	808	875	906	915	910	896	877	854	829
750	404	625	748	814	845	856	853	841	824	803	780
800	361	562	674	736	766	777	774	763	747	727	705
850	321	501	603	659	687	696	693	682	665	646	624
900	266	418	505	553	578	586	585	576	562	545	527
950	188	295	356	390	406	411	408	401	391	378	364
1000	144	224	268	290	298	299	294	285	274	262	250
1050	64	102	124	137	143	146	146	144	141	137	132

Table 15. Proportional size distribution of quality-size fish (PSD) from a yield per recruit model for Striped Bass in the Arkansas River system near the confluence of the Canadian and lower Illinois rivers under different exploitation rates (u) and minimum length requirements. Harvest scenarios where SPR < 0.2 (indicating recruitment overfishing) are shaded gray. Other shaded cells indicate sustainable conditions and shading ranges from red (lowest PSD) to green (largest PSD).

Exploitation (u)

Minimum length regulation (mm)	0.05	0.1	0.15	0.2	0.25	0.3	0.35	0.4	0.45	0.5	0.55
250	50	45	41	36	32	28	25	21	18	15	12
300	50	45	41	37	33	29	26	22	19	16	13
350	50	45	41	37	33	30	27	24	21	18	16
400	50	46	42	38	35	32	29	26	24	22	20
450	50	46	43	39	36	34	31	29	27	25	24
500	50	47	43	40	38	35	33	31	29	28	27
550	51	47	44	41	39	37	35	33	32	30	29
600	51	48	45	42	40	38	37	35	34	33	32
650	51	48	46	44	42	40	38	37	36	35	34
700	51	49	47	45	43	42	40	39	38	37	36
750	52	50	48	46	45	43	42	41	40	39	39
800	52	50	49	47	46	45	44	43	42	41	41
850	52	51	49	48	47	46	45	44	44	43	42
900	53	51	50	49	48	47	46	46	45	44	44
950	53	52	51	50	49	49	48	47	47	46	45
1000	53	52	52	51	50	49	49	48	48	47	46
1050	54	53	52	51	51	50	50	49	48	48	47

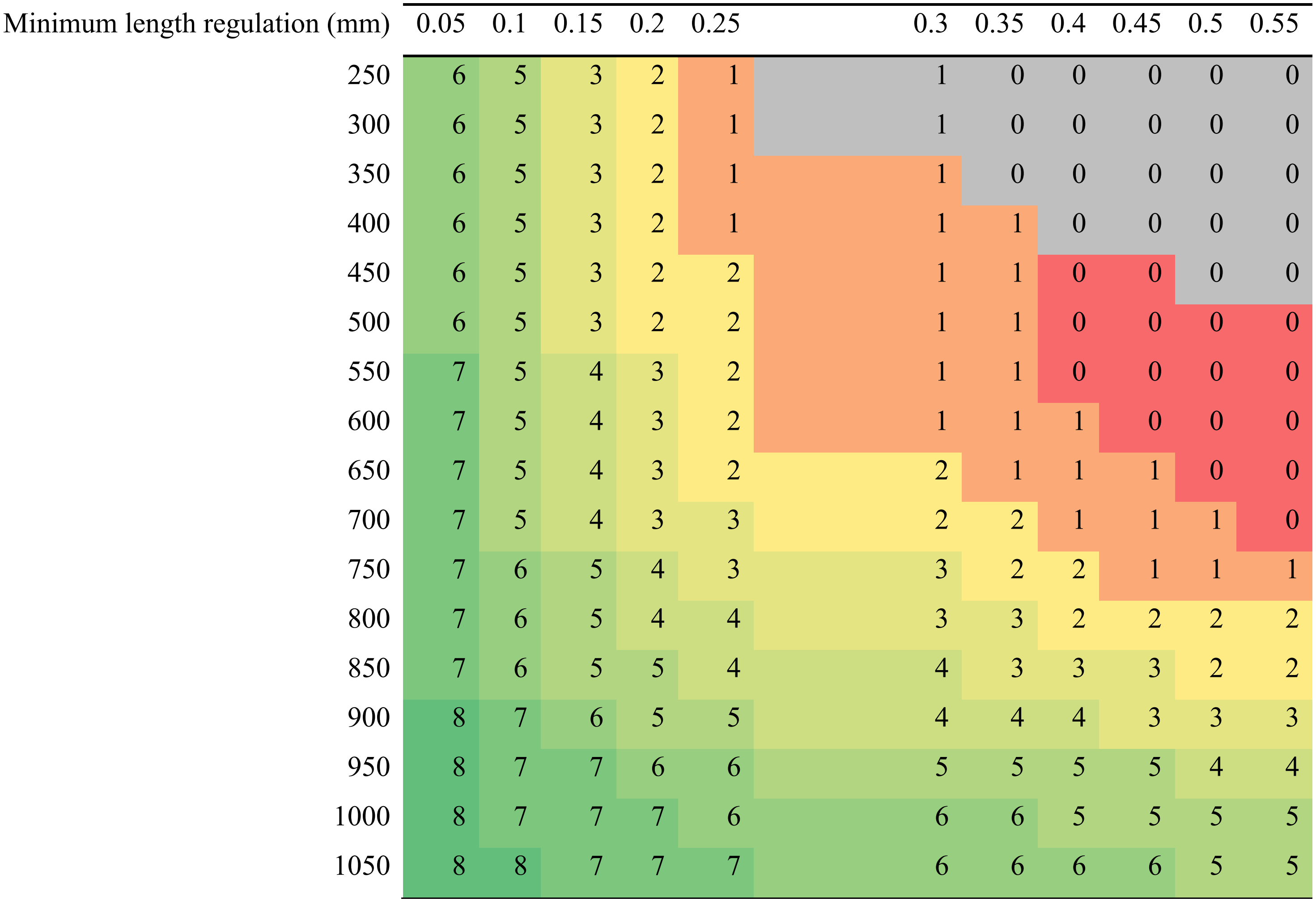
Table 16. Proportional size distribution of preferred-size fish (PSD-P) from a yield per recruit model for Striped Bass in the Arkansas River system near the confluence of the Canadian and lower Illinois rivers under different exploitation rates (u) and minimum length requirements. Harvest scenarios where SPR < 0.2 (indicating recruitment overfishing) are shaded gray. Other shaded cells indicate sustainable conditions and shading ranges from red (lowest PSD-P) to green (largest PSD-P).

Exploitation (u)

Minimum length regulation (mm)	0.05	0.1	0.15	0.2	0.25	0.3	0.35	0.4	0.45	0.5	0.55
250	19	15	11	8	6	4	3	2	1	1	0
300	19	15	11	8	6	4	3	2	1	1	0
350	19	15	11	9	6	4	3	2	1	1	0
400	19	15	12	9	6	5	3	2	1	1	1
450	19	15	12	9	7	5	4	3	2	1	1
500	19	15	12	9	7	5	4	3	2	1	1
550	19	16	13	10	8	6	5	4	3	2	1
600	20	16	13	11	9	7	6	4	3	3	2
650	20	17	14	12	10	8	7	6	5	4	3
700	20	17	15	13	11	10	8	7	6	6	5
750	20	18	16	14	13	11	10	9	8	8	7
800	21	19	17	15	14	13	12	11	10	10	9
850	21	19	18	16	15	14	13	13	12	11	11
900	22	20	19	18	17	16	15	14	13	13	12
950	22	21	20	19	18	17	17	16	15	15	14
1000	22	21	20	20	19	18	18	17	16	16	15
1050	23	22	21	20	20	19	19	18	17	17	16

Table 17. Proportional size distribution of memorable-size fish (PSD-M) from a yield per recruit model for Striped Bass in the Arkansas River system near the confluence of the Canadian and lower Illinois rivers under different exploitation rates (u) and minimum length requirements. Harvest scenarios where SPR < 0.2 (indicating recruitment overfishing) are shaded gray. Other shaded cells indicate sustainable conditions and shading ranges from red (lowest PSD-M) to green (largest PSD-M).

Exploitation (u)



Minimum length regulation (mm)	0.05	0.1	0.15	0.2	0.25	0.3	0.35	0.4	0.45	0.5	0.55
250	6	5	3	2	1	1	0	0	0	0	0
300	6	5	3	2	1	1	0	0	0	0	0
350	6	5	3	2	1	1	0	0	0	0	0
400	6	5	3	2	1	1	1	0	0	0	0
450	6	5	3	2	2	1	1	0	0	0	0
500	6	5	3	2	2	1	1	0	0	0	0
550	7	5	4	3	2	1	1	0	0	0	0
600	7	5	4	3	2	1	1	1	0	0	0
650	7	5	4	3	2	2	1	1	1	0	0
700	7	5	4	3	3	2	2	1	1	1	0
750	7	6	5	4	3	3	2	2	1	1	1
800	7	6	5	4	4	3	3	2	2	2	2
850	7	6	5	5	4	4	3	3	3	2	2
900	8	7	6	5	5	4	4	4	3	3	3
950	8	7	7	6	6	5	5	5	5	4	4
1000	8	7	7	7	6	6	6	5	5	5	5
1050	8	8	7	7	7	6	6	6	6	5	5

Table 18. Proportional size distribution of stock-size fish (PSD) from a yield per recruit model for Striped Bass in the Arkansas River system near the confluence of the Canadian and lower Illinois rivers under different exploitation rates (u) and maximum length requirements. It was assumed that harvest did not occur on fish < 400 mm (either due to a minimum length requirement or voluntary behavior of anglers). Harvest scenarios where SPR < 0.2 (indicating recruitment overfishing) are shaded gray. Other shaded cells indicate sustainable conditions and shading ranges from red (lowest PSD) to green (largest PSD).

	Exploitation (u)										
Maximum length regulation (mm)	0.05	0.1	0.15	0.2	0.25	0.3	0.35	0.4	0.45	0.5	0.55
500	53	52	51	50	49	48	47	45	44	42	41
550	53	52	51	49	48	46	44	43	41	39	36
600	53	51	50	48	46	44	42	39	37	34	31
650	53	51	49	47	44	42	39	36	33	29	26
700	52	50	48	45	42	39	36	32	29	26	23
750	52	49	46	43	40	37	33	30	27	24	21
800	52	49	45	42	38	35	31	28	25	22	20
850	51	48	44	41	37	34	30	27	24	22	20
900	51	47	44	40	36	33	29	27	24	22	20
950	51	47	43	39	35	32	29	26	24	22	20
1000	50	46	42	38	35	32	29	26	24	22	20
1050	50	46	42	38	35	32	29	26	24	22	20

Table 19. Proportional size distribution of preferred-size fish (PSD-P) from a yield per recruit model for Striped Bass in the Arkansas River system near the confluence of the Canadian and lower Illinois rivers under different exploitation rates (u) and maximum length requirements. It was assumed that harvest did not occur on fish < 400 mm (either due to a minimum length requirement or voluntary behavior of anglers). Harvest scenarios where SPR < 0.2 (indicating recruitment overfishing) are shaded gray. Other shaded cells indicate sustainable conditions and shading ranges from red (lowest PSD-P) to green (largest PSD-P).

	Exploitation (u)										
Maximum length regulation (mm)	0.05	0.1	0.15	0.2	0.25	0.3	0.35	0.4	0.45	0.5	0.55
500	23	22	21	20	19	18	18	17	16	15	14
550	23	22	21	20	18	17	16	15	14	13	12
600	22	21	20	19	17	16	14	13	11	10	8
650	22	21	19	17	16	14	12	10	9	7	5
700	22	20	18	16	14	12	10	8	6	4	3
750	21	19	17	14	12	10	7	5	4	3	1
800	21	18	15	13	10	8	6	4	3	2	1
850	21	18	15	12	9	7	5	3	2	1	1
900	20	17	14	11	8	6	4	3	2	1	1
950	20	16	13	10	7	5	3	2	1	1	1
1000	19	16	12	9	7	5	3	2	1	1	1
1050	19	15	12	9	7	5	3	2	1	1	1

Table 20. Proportional size distribution of memorable-size fish (PSD-M) from a yield per recruit model for Striped Bass in the Arkansas River system near the confluence of the Canadian and lower Illinois rivers under different exploitation rates (u) and

maximum length requirements. It was assumed that harvest did not occur for fish < 400 mm (either due to a minimum length requirement or voluntary behavior of anglers). Harvest scenarios where SPR < 0.2 (indicating recruitment overfishing) are shaded gray. Other shaded cells indicate sustainable conditions and shading ranges from red (lowest PSD-M) to green (larger PSD-M).

	Exploitation (u)										
Maximum length regulation (mm)	0.05	0.1	0.15	0.2	0.25	0.3	0.35	0.4	0.45	0.5	0.55
500	8	8	8	7	7	6	6	6	5	5	5
550	8	8	7	7	6	6	6	5	5	4	4
600	8	8	7	7	6	5	5	4	4	3	3
650	8	7	7	6	5	5	4	3	3	2	2
700	8	7	6	6	5	4	3	2	2	1	1
750	8	7	6	5	4	3	2	2	1	1	0
800	8	6	5	4	3	2	2	1	1	0	0
850	7	6	5	4	3	2	1	1	0	0	0
900	7	6	4	3	2	1	1	0	0	0	0
950	7	5	4	3	2	1	1	0	0	0	0
1000	7	5	4	2	2	1	1	0	0	0	0
1050	7	5	3	2	1	1	1	0	0	0	0

Table 21. Proportional size distribution of quality-size fish (PSD) from a yield per recruit model for Striped Bass in the Arkansas River system near the confluence of the Canadian and lower Illinois rivers under different catch and release mortality rates (u_{rel}) and minimum length requirements (TL_{min}; mm). Harvest scenarios where SPR < 0.2 (indicating recruitment overfishing) are shaded gray. Other shaded cells indicate sustainable conditions and shading ranges from red (lowest PSD) to green (largest PSD).

	u_{rel}																				
TL_{min}	0	0.05	0.1	0.15	0.2	0.25	0.3	0.35	0.4	0.45	0.5	0.55	0.6	0.65	0.7	0.75	0.8	0.85	0.9	0.95	1
250	45	45	45	45	45	45	45	44	44	44	44	44	44	44	44	43	43	43	43	43	43
300	46	45	45	45	45	45	45	45	44	44	44	44	44	44	44	43	43	43	43	43	43
350	46	46	45	45	45	45	45	45	45	44	44	44	44	44	44	43	43	43	43	43	43
400	46	46	46	46	45	45	45	45	45	45	44	44	44	44	44	44	43	43	43	43	43
450	47	46	46	46	46	46	46	45	45	45	45	45	44	44	44	44	44	43	43	43	43
500	47	47	47	47	46	46	46	46	45	45	45	45	45	44	44	44	44	43	43	43	43
550	48	47	47	47	47	46	46	46	46	46	45	45	45	45	44	44	44	44	43	43	43
600	48	48	48	47	47	47	47	46	46	46	46	45	45	45	44	44	44	44	43	43	43
650	49	49	48	48	48	47	47	47	47	46	46	46	45	45	45	44	44	44	43	43	43
700	50	49	49	49	48	48	48	47	47	47	46	46	46	45	45	45	44	44	43	43	43
750	50	50	50	49	49	49	48	48	47	47	47	46	46	46	45	45	44	44	44	43	43
800	51	51	50	50	50	49	49	48	48	47	47	47	46	46	45	45	45	44	44	43	43
850	52	51	51	50	50	50	49	49	48	48	47	47	46	46	46	45	45	44	44	43	43
900	52	52	51	51	50	50	50	49	49	48	48	47	47	46	46	45	45	44	44	43	43
950	53	53	52	52	51	51	50	50	49	49	48	47	47	46	46	45	45	44	44	43	43
1000	53	53	52	52	51	51	50	50	49	49	48	48	47	47	46	45	45	44	44	43	43
1050	54	53	53	52	52	51	51	50	49	49	48	48	47	47	46	46	45	44	44	43	43

Table 22. Proportional size distribution of stock-size fish (PSD) from a yield per recruit model for Striped Bass in the Arkansas River system near the confluence of the Canadian and lower Illinois rivers under different catch and release mortality rates (u_{rel}) and maximum length requirements (TL_{max}; mm). It was assumed that harvest did not occur on fish < 400 mm (either due to a minimum length requirement or voluntary behavior of anglers). Harvest scenarios where SPR < 0.2 (indicating recruitment overfishing) are shaded gray. Other shaded cells indicate sustainable conditions and shading ranges from red (lowest PSD) to green (largest PSD).

	u_{rel}																				
TL_{max}	0	0.05	0.1	0.15	0.2	0.25	0.3	0.35	0.4	0.45	0.5	0.55	0.6	0.65	0.7	0.75	0.8	0.85	0.9	0.95	1
500	54	53	52	52	51	51	50	50	49	48	48	47	47	46	46	45	45	44	44	43	43
550	53	53	52	51	51	50	50	49	49	48	48	47	47	46	46	45	45	44	44	43	43
600	53	52	51	51	50	50	49	49	48	48	47	47	46	46	45	45	45	44	44	43	43
650	52	51	51	50	50	49	49	48	48	47	47	47	46	46	45	45	44	44	44	43	43
700	51	51	50	50	49	49	48	48	47	47	47	46	46	45	45	45	44	44	43	43	43
750	50	50	49	49	48	48	48	47	47	47	46	46	45	45	45	44	44	44	43	43	43
800	49	49	49	48	48	47	47	47	46	46	46	45	45	45	44	44	44	44	43	43	43
850	49	48	48	48	47	47	47	46	46	46	45	45	45	45	44	44	44	44	43	43	43
900	48	48	47	47	47	47	46	46	46	45	45	45	45	44	44	44	44	43	43	43	43
950	47	47	47	46	46	46	46	46	45	45	45	45	44	44	44	44	44	43	43	43	43
1000	47	47	46	46	46	46	46	45	45	45	45	44	44	44	44	44	43	43	43	43	43
1050	46	46	46	46	46	45	45	45	45	45	45	44	44	44	44	44	43	43	43	43	43

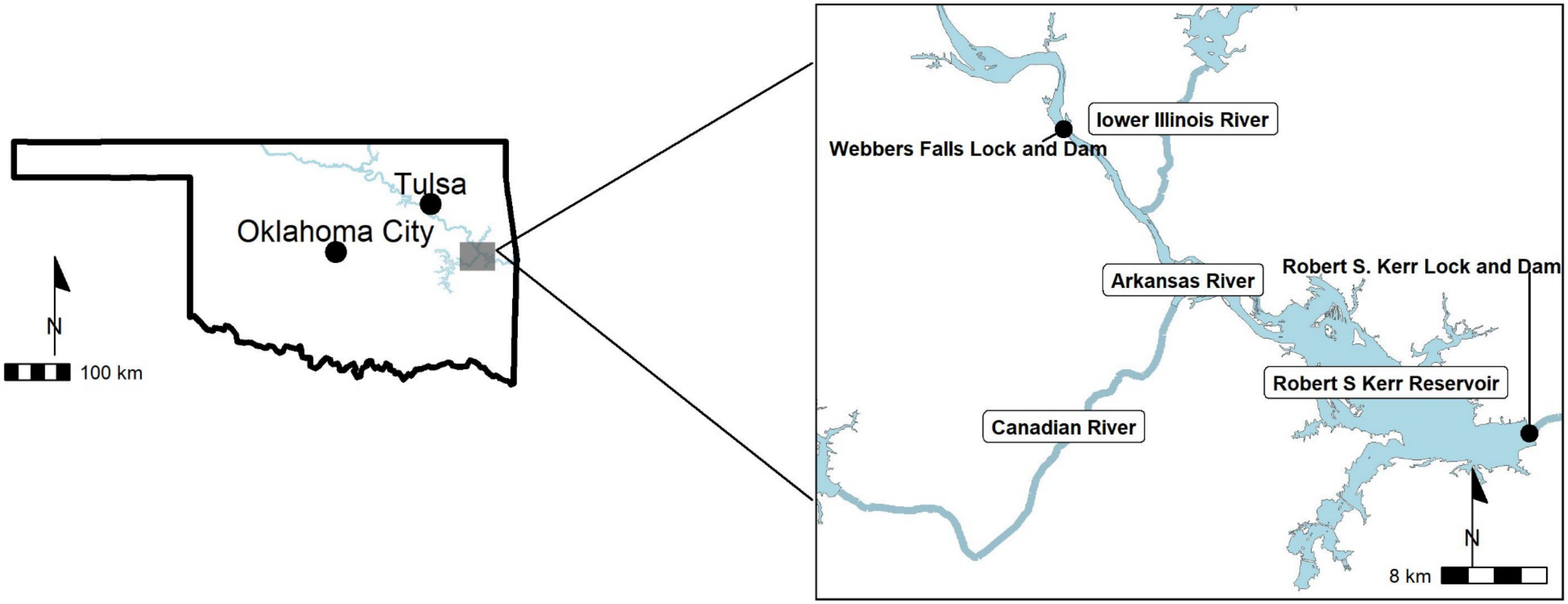


Figure 1. The location of Robert S. Kerr Reservoir river-reservoir complex in eastern Oklahoma. The inset map on the right shows the study site where sampling was conducted.

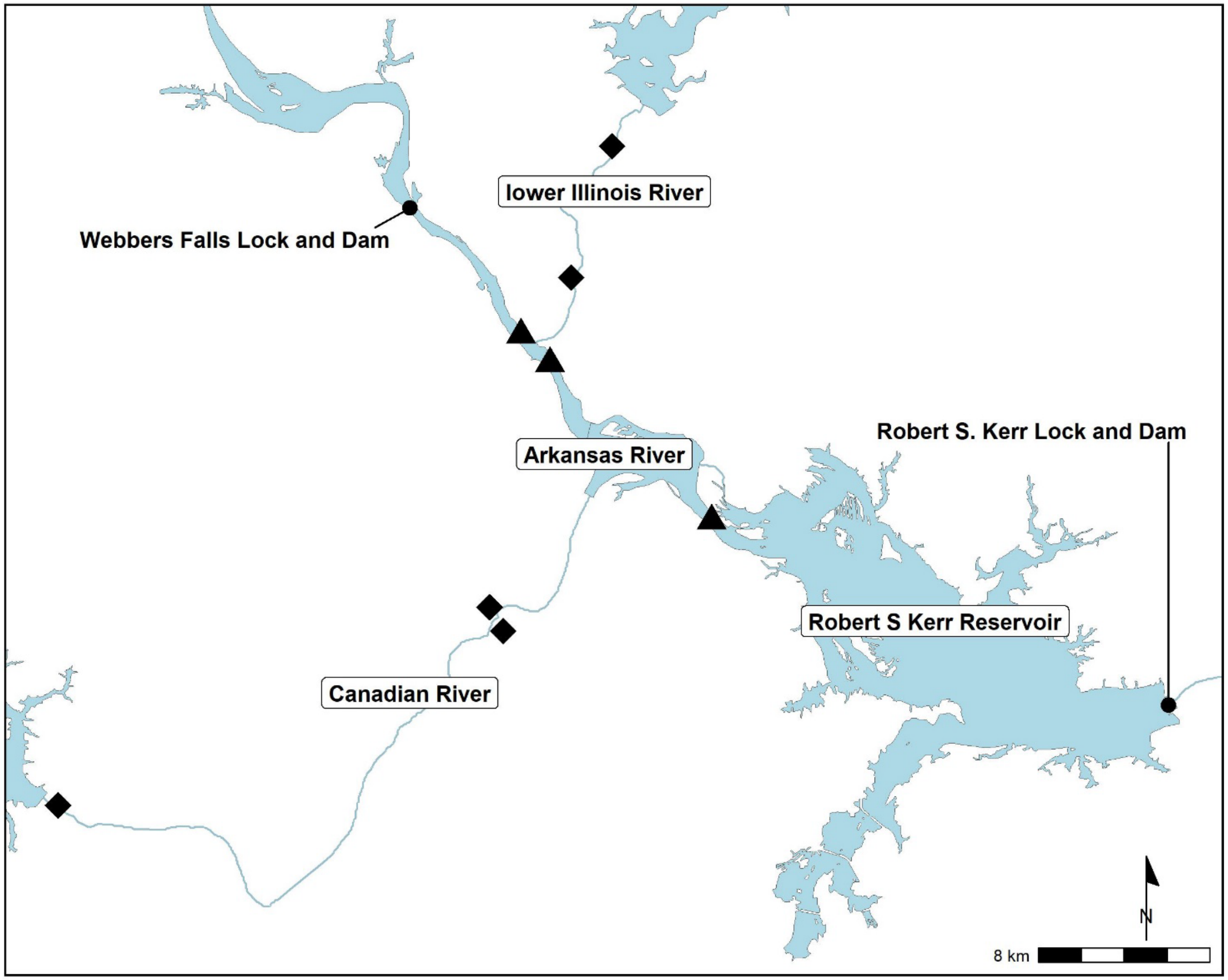


Figure 2. Robert S. Kerr Reservoir river-reservoir complex, including locations where paired passive telemetry receivers were set from 2020–2022. Passive acoustic receiver locations are indicated along the Arkansas River (triangles) and passive radio receivers in the Canadian and lower Illinois rivers (diamonds).

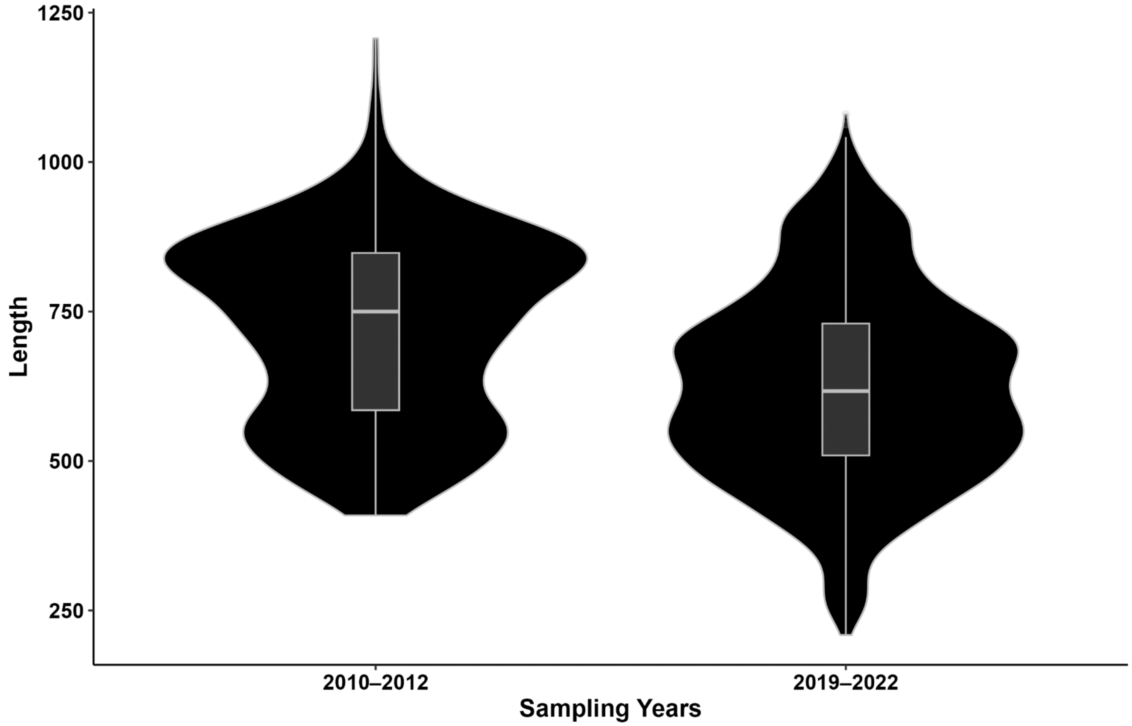


Figure 3. Violin plots with inset boxplots representing the relative abundance of different sizes of Striped Bass sampled from the lower Illinois and Canadian rivers, Oklahoma during 2010–2012 (sampled by the Oklahoma Department of Wildlife Conservation; ODWC) or 2019–2022 (sampled by Oklahoma State University; OSU). The top whisker represents the highest value before the upper fence (3rd quartile + 1.5 * interquartile range), 3rd quartile (75th percentile), median (horizontal line), 1st quartile (25th percentile), and the lowest value before the lower fence (1st quartile - 1.5 * interquartile range) are represented by the box plots.

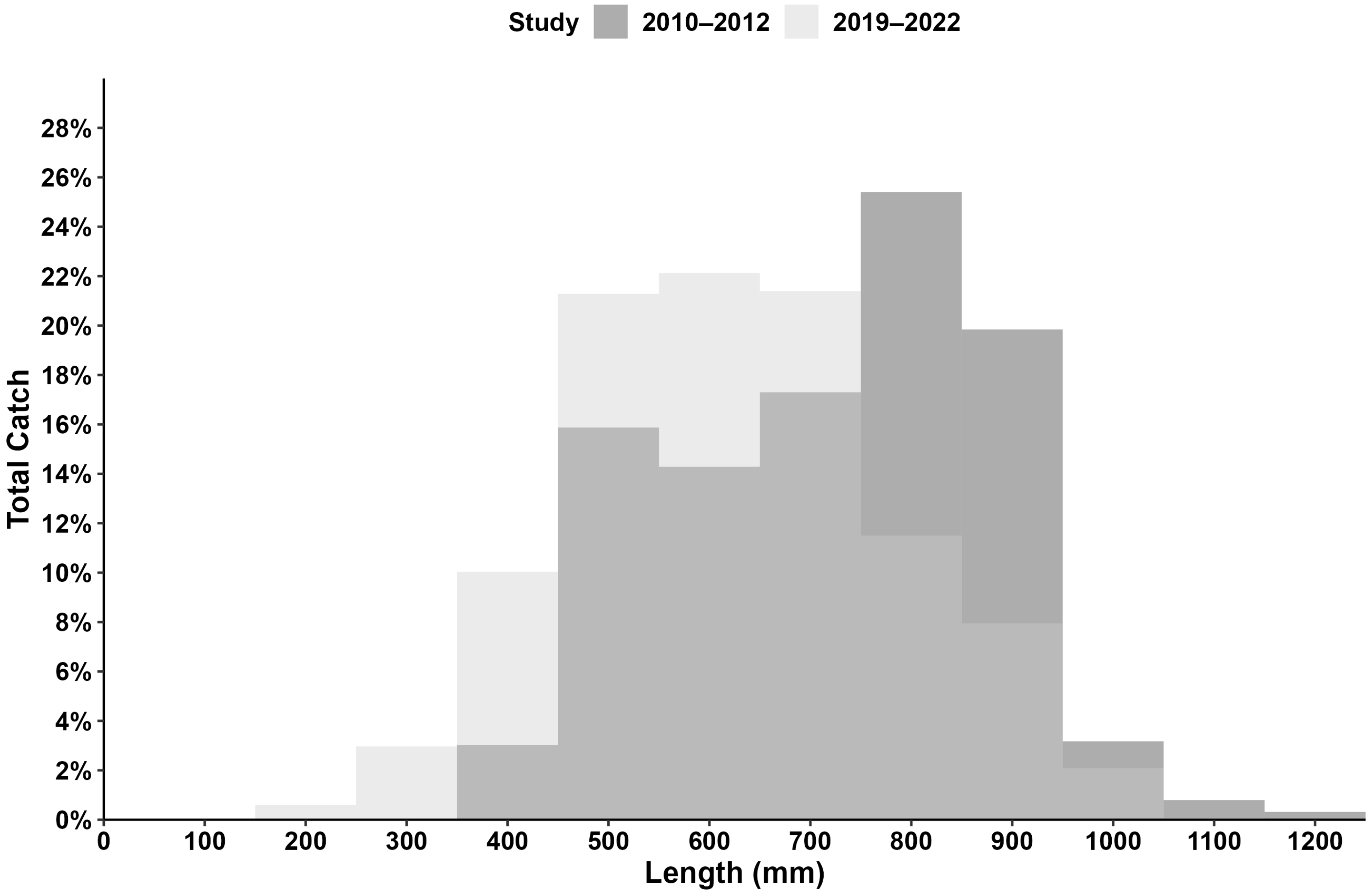


Figure 4. Histogram comparing the length frequencies from the 2010–2012 (dark gray) and 2019–2022 (light grey) Total catch of Striped Bass is shown in 100-mm length bins. The middle shade of gray represents overlapping length frequencies for the two samples.

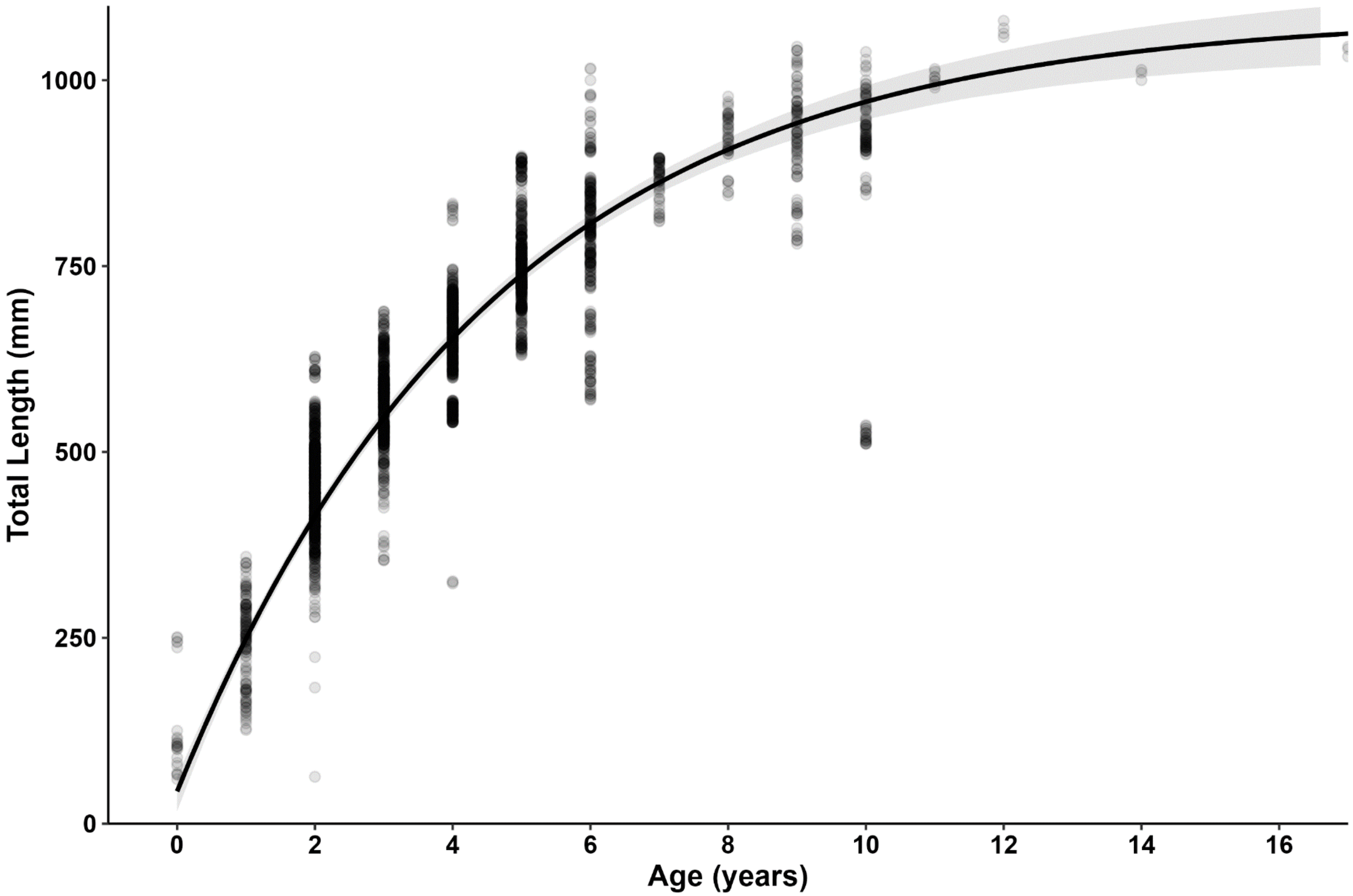


Figure 5. Von Bertalanffy growth curve (black line) with 95% confidence interval (gray band) and Striped Bass age-at-length (points) collected from 2019 to 2022. Ages included are from zero to 17.

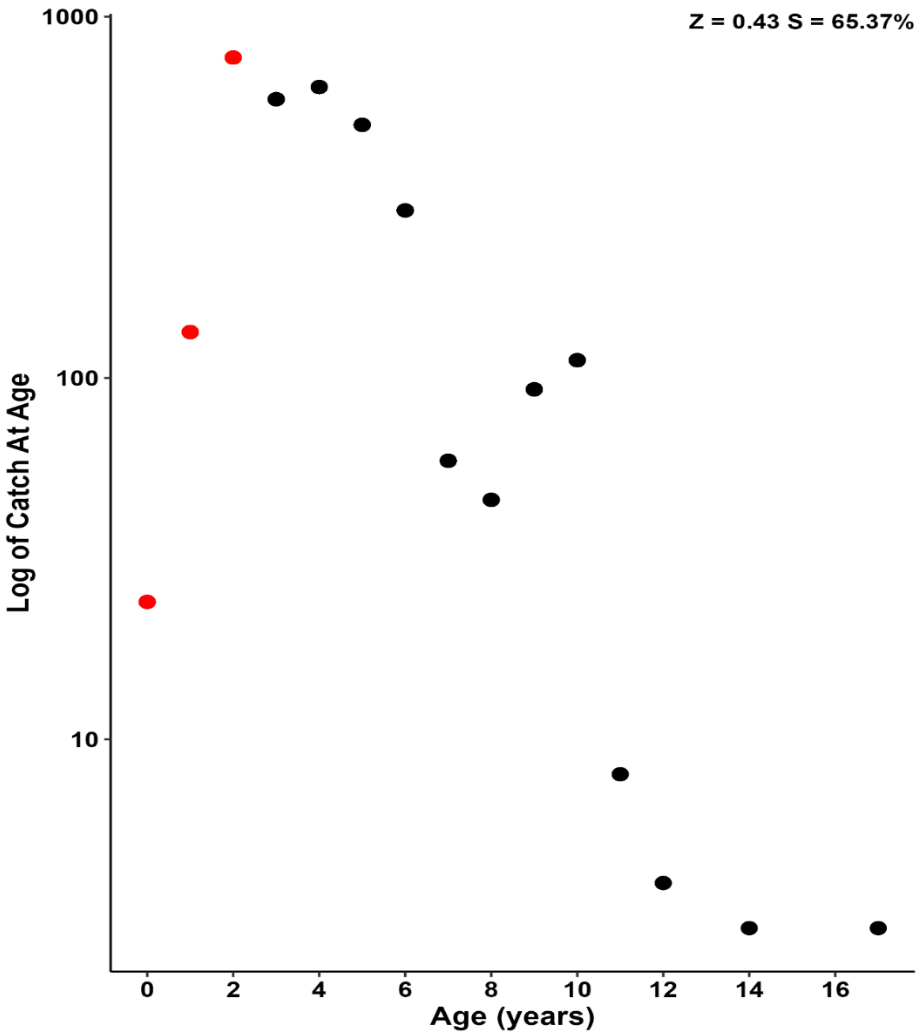


Figure 6. Chapman Robson catch curve for Striped Bass with log transformed number of Striped Bass caught in each age class collected from 2019 to 2022. The instantaneous mortality (Z) and the total survival rate (S) are reported. The black dots indicate age classes used in the catch curve and the red dots indicate age classes not used in the catch curve.

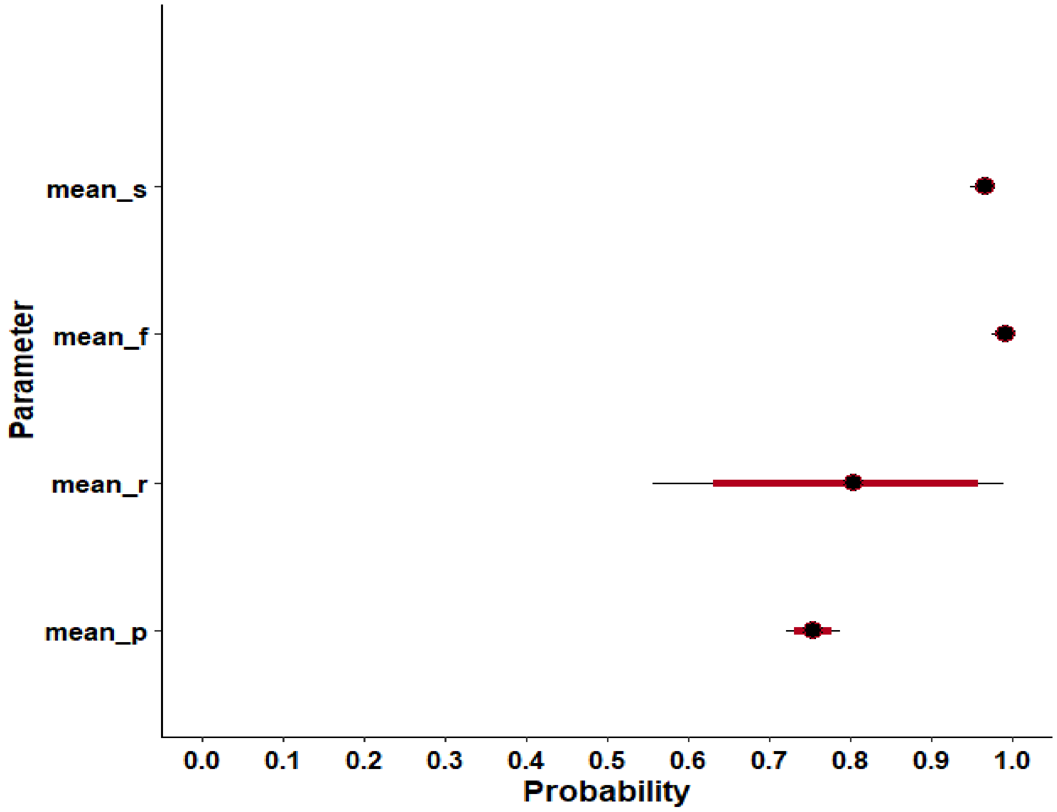


Figure 7. Results from survival-based multistate capture-recapture model of Striped Bass in the Arkansas River system near the confluence of the Canadian and lower Illinois rivers with seven capture occasions (denoted by the number inside of the bracket next to a given parameter) from 2020 - 2022. Parameters were estimated for true survival (mean_s), fidelity probability (mean_f), recovery probability (mean_r), and capture probability (mean_p) for the ten capture-occasions. The dots indicate the median, the thick red line the 80% credible interval, and the thin black line the 95% credible interval.

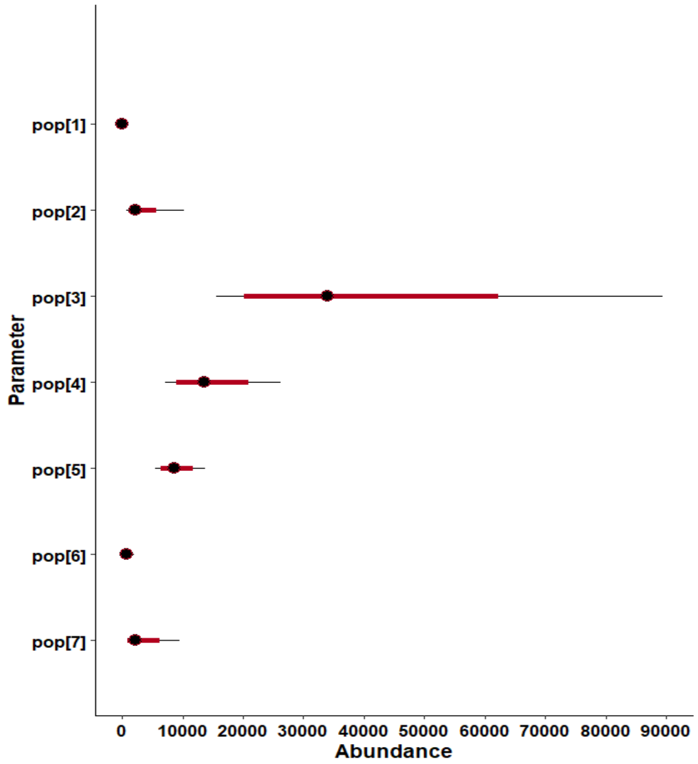


Figure 8. Results from the Bayesian Cormack-Jolly-Seber capture-recapture model with seven capture occasions (denoted by the number inside of the bracket next to a given parameter, data collected seasonally from 2020-2022) for Striped Bass in the Canadian River below Eufaula Dam and the lower Illinois River below Tenkiller Dam, and the Arkansas River from Robert S. Ker Reservoir to the Weber Falls Lock and Dam, Oklahoma. Parameters are listed for estimating population size (pop) as the number of individuals captured at time t divided by the probability of capture at time t. The dots indicate the median, the thick red line reflects the 80% credible interval, and the thin black line indicates the 95% credible interval.

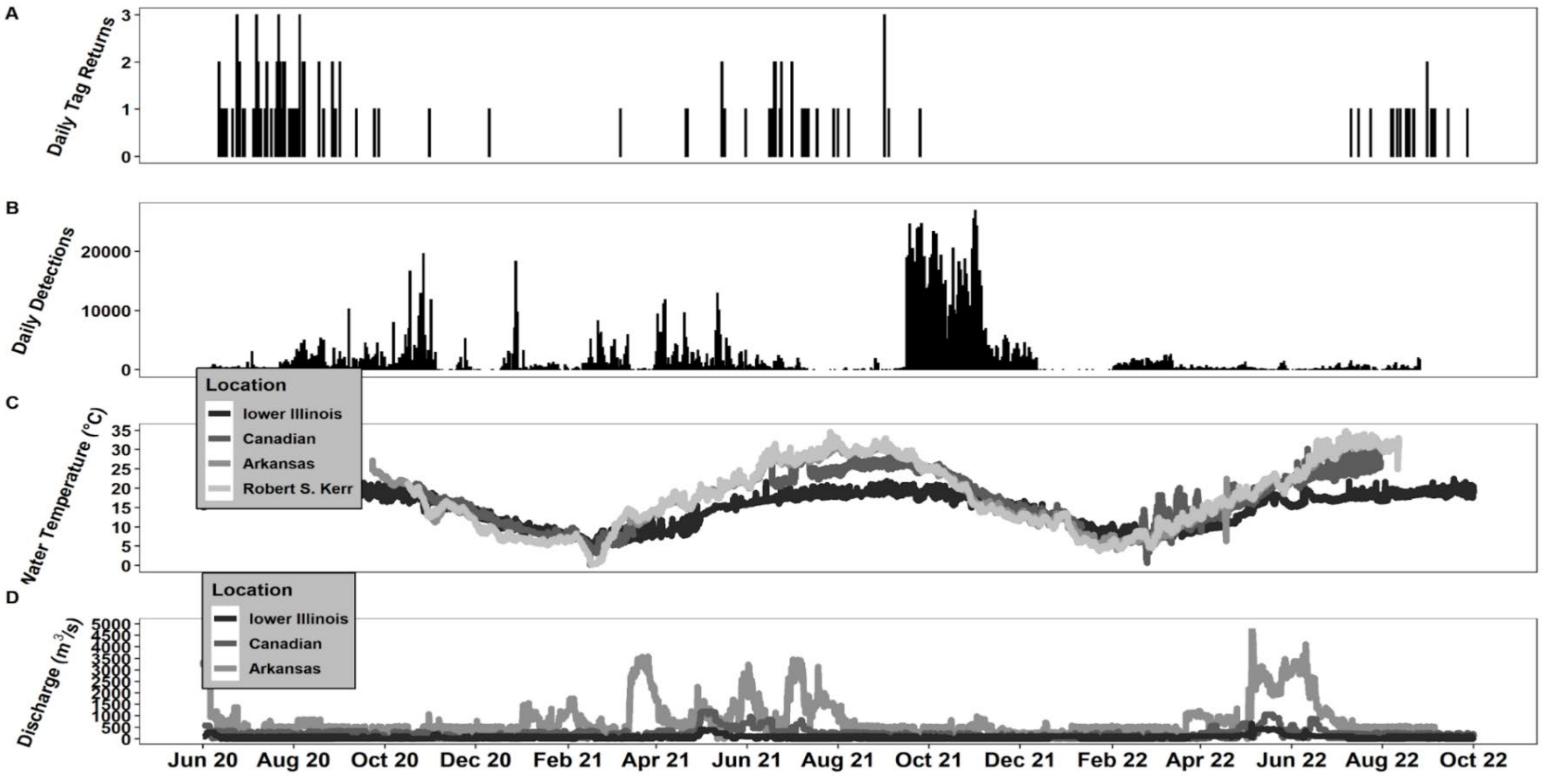


Figure 9. (A) Daily angler reward tag returns from tagged Striped Bass, (B) total daily detections from passive telemetry receivers detecting tagged Striped Bass, (C) water temperature (°C) from the lower Illinois (U.S. Geological Survey stream gage OK-07198000, https://waterdata.usgs.gov/monitoring-location/07198000/#parameterCode=00065&period=P7D&showMedian=true), Canadian (U.S. Geological Survey stream gage OK-07245000, https://waterdata.usgs.gov/monitoring-location/07245000/#parameterCode=00060&period=P7D&showMedian=true), and Arkansas rivers as well as Robert S Kerr Reservoir, and (D) stream discharge (m^3/s;) from the lower Illinois, Canadian, and Arkansas rivers. Daily angler reward tag returns are the total number of reward tags reported by anglers claiming the fish was caught on that day. Total daily detections from passive telemetry receivers includes individual fish that may have been detected multiple times.

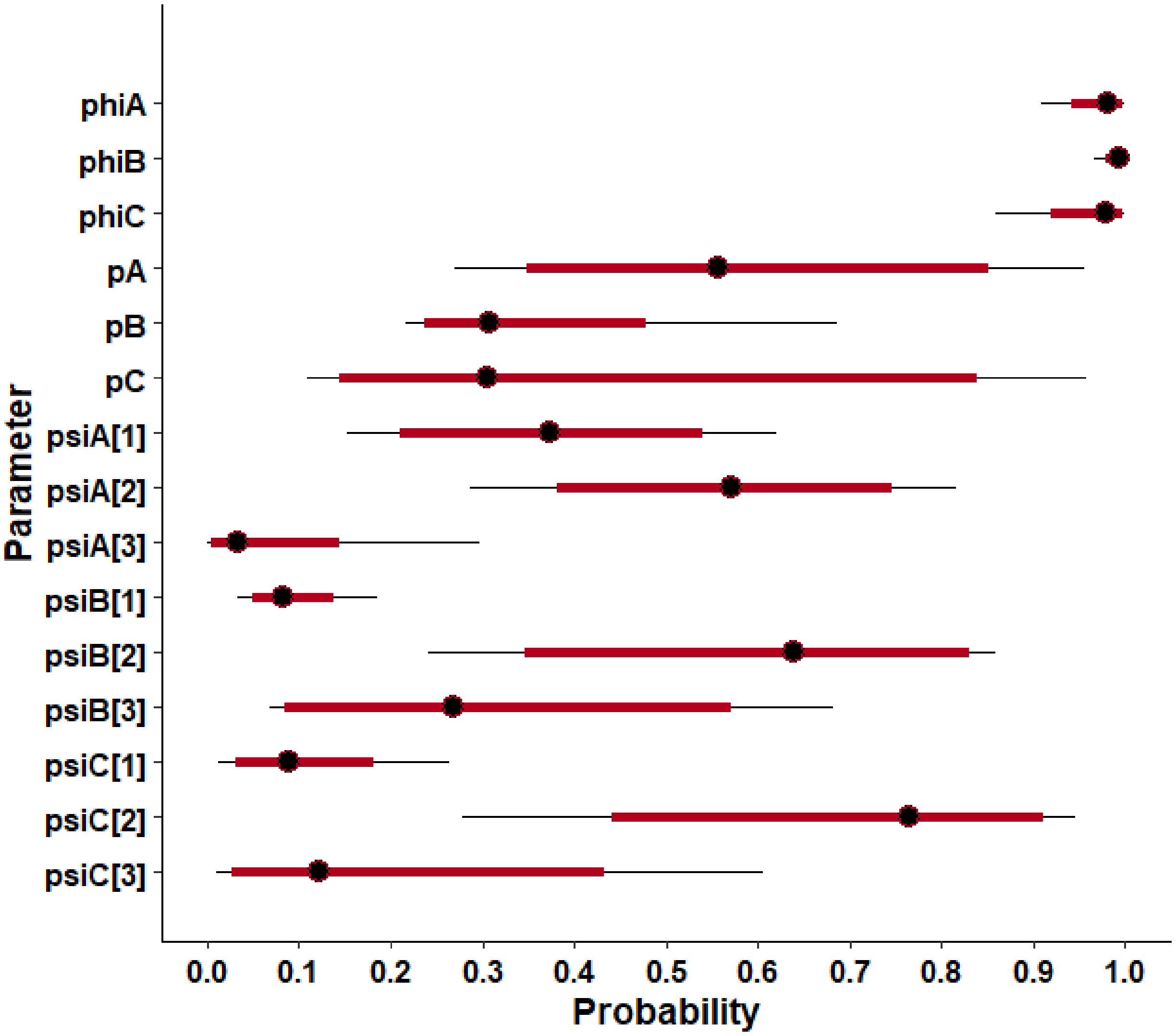


Figure 10. Results from the movement-focused multistate model of Striped Bass with ten capture occasions and parameters for three states (locations) of interest for this study (A denotes the Arkansas River/Robert S. Kerr Reservoir, B the lower Illinois River, and C the Canadian River). The bracketed numbers refer to the segment that is the destination of the transition probability (1 denotes the Arkansas River/Robert S. Kerr Reservoir, 2 the lower Illinois River, and 3 the Canadian River). Parameters estimating apparent survival (phi), capture probability (p), and movement probability from one location to another (psi) for the ten capture-occasions (capture occasion noted by value in brackets). The dots indicate the median, the thick red line the 80% credible interval, and the thin black line the 95% credible interval.