Final Report

Assessment of vital rates (exploitation, size structure, age and growth, and total annual mortality) to evaluate the current harvest regulations for blue catfish (*Ictalurus furcatus*) in the Missouri and Mississippi rivers

Missouri Department of Conservation

September 2019

Prepared by:

Kyle Winders and Joe McMullen

9 September 2019

Table of Contents

Tables

Figures

Appendices

Abstract

Blue catfish (*Ictalurus furcatus*) are native to the Missouri and Mississippi rivers, and support extremely important fisheries on these big rivers. The Missouri River supports a recreational fishery, and the Mississippi River supports both recreational and commercial fisheries. Missouri's big river, blue catfish populations have not been intensively researched or managed in the past, and information needed to inform management and regulatory decisions is lacking. Blue catfish were sampled in the Mississippi and Missouri rivers using low-frequency electrofishing, and these data, along with tag return information, were used to estimate exploitation and other population demographics (e.g., size structure, age and growth, and total annual mortality). Management and regulatory recommendations focus on increasing yield available to fishers and ensuring sustainability of big river, blue catfish populations.

During 2015 and 2016, a total of 6,639 blue catfish ranging in size from 3-53 inches (76-1,348 mm) total length (TL) were collected from eight study sites. Pectoral spines were aged from 1,874 blue catfish; ages ranged from 1-19 years on the Mississippi River and 2-18 on the Missouri River. In the Mississippi River, fish reached 15 inches by age 4, 18 inches by age 5, 24 inches (5 pounds) by age 8, 30 inches (10 pounds) by age 11, and 38 inches (20 pounds) by age 17. Missouri River blue catfish were estimated to take an additional year to reach the same lengths. To estimate exploitation, we tagged 759 blue catfish in the Mississippi River and 915 in the Missouri River, with approximately 70 percent of tags having a standard reward value ($25) and the remainder having a high reward value ($150). As of 1 January 2019, 311 blue catfish tags were reported by fishers. Reporting rates differed between sites and rivers; reporting rates on the Mississippi River ranged from 63-100 percent and from 40-88 percent on the Missouri River. Total annual exploitation was 10 percent (6 percent for recreational harvest and 4 percent for commercial harvest) on the Mississippi River and 12.7 percent (all recreational harvest) on the Missouri River. On the Mississippi River local exploitation ranged from approximately 7 percent at site 2 to 16 percent at sites 1 and 4. Local exploitation on the Missouri River was lowest at sites 5 and 7 (9 percent), slightly higher at site 8 (11 percent), and highest at site 6 (18 percent).

Growth or recruitment overfishing was not evident when we incorporated size-specific exploitation rates in our simulations. If fishing effort remains steady, our models predict that a minimum length limit (MLL) would offer the greatest improvement in yield and would have the added benefit of improving trophy fishing potential. Furthermore, recreational anglers are thought to be more supportive of a MLL to improve chances of catching a trophy-sized blue catfish as opposed to other regulations including gear restrictions or reduced daily bag limits. Commercial fishers may also support a MLL given the predicted increase in yield. Therefore, fisheries managers aiming to increase yield on the Mississippi and Missouri rivers should consider a MLL (e.g., 18 or 21 inches TL). In our simulations a protected slot limit of 26-34 inches, like that at Lake of the Ozarks and Harry S. Truman Lake, improved the trophy fishing potential more than predicted with a MLL, but decreased yield by 20-34 percent. If public opinion favors trophy fishing potential and fishers are willing to accept a minimal decline in yield, then restricting the number of fish over 30 or 34 inches per day should be considered, as well. This option would be most appropriate on the Missouri River where maintaining or improving yield is not currently a management objective.

Recommendations:

- Complete data analysis and final report for flathead catfish during FY2020.
- In coordination with Outreach & Education Division staff develop a communication plan during FY2020. Inform stakeholders about the outcomes of this research and determine constituent attitudes and opinions concerning catfish harvest regulations and management objectives.
    - Survey recreational and commercial catfish fishers during FY2020, to determine attitudes and preferences associated with catfish management, angling, and harvest.
    - During FY2020 inform and coordinate with neighboring state agencies (IL, KS, KY, NE, and TN) responsible for managing border water fisheries.
    - Conduct public meetings during FY2021.
- Based on the results of this study (blue catfish and flathead catfish final reports), public input (catfish harvest survey and public meetings), and discussions with neighboring state agencies:
    - If public sentiment is similar to existing human dimensions data (i.e., fishers are in large part harvest oriented):
        - Coordinate communication, planning, and development of regulation change proposals for blue and flathead catfish concurrently during FY2021.
        - Propose a minimum length limit on recreationally harvested blue catfish from the Missouri and Mississippi rivers during FY2021
        - Propose a minimum length limit on commercially harvested blue catfish from the Mississippi River and possibly the St. Francis River during FY2021
        - Recreational and commercial minimum length limits should be set at the same level on the Mississippi River and possibly the St Francis River.
    - If public sentiment is different than existing human dimensions data (e.g., anglers are willing to sacrifice yield to improve trophy fishing potential):
        - Develop appropriate regulation change proposals (if necessary at all) for blue catfish and flathead catfish concurrently during FY2021.
        - If necessary, propose regulation changes on recreationally harvested blue catfish from the Missouri and Mississippi rivers during FY2021.
        - If necessary, propose regulation changes on commercially harvested blue catfish from the Mississippi River and possibly the St. Francis River.
        - Recreational and commercial length limits should be set at the same level on the Mississippi River and possibly the St. Francis River.
- Update Missouri's catfish management plan and objectives by FY2023. Consideration should be given to drafting more quantitative management objectives (e.g., catch per unit effort, size structure, or growth rates), and objectives that outline recommendations for reevaluation of these fisheries.

Introduction

Blue catfish support important recreational and commercial fisheries in Missouri. Catfish ranked third in popularity among recreational freshwater anglers in the U.S., drawing 8.1 million anglers in 2016 (USDI 2018). On big rivers such as the Missouri, as much as 70 percent of total angler effort may be directed toward catfish (Weithman and Fleener 1988). Statewide recreational fishing regulations apply on the Missouri River where anglers may harvest five blue catfish daily, with no length limits or closed season (MDC 2019). On the Mississippi River, recreational anglers may harvest 20 blue catfish and channel catfish (*Ictalurus punctatus*) combined, daily, with no length limits or closed season. Commercial catfish harvest in Missouri is restricted to the Mississippi River and the portion of the St. Francis River that forms the Missouri-Arkansas border. In 2017, blue catfish accounted for 9 percent (75,890 lb) of fish harvested by commercial fishers, but represented 21 percent ($44,016.20) of the total wholesale value (MDC 2018). An unlimited number of catfish over 15 inches TL may be commercially harvested year-round. Due to increasing harvest levels and declines in the proportion of legal catfish in the population, the Missouri River was closed to commercial catfish harvest in 1992 to allocate catfish harvest to recreational fishers (Stanovick 1999).

Although most recreational catfish anglers do not fish in tournaments or consider themselves trophy anglers, trophy catfish angling and catfish tournaments are increasing in popularity (Arterburn et al. 2002). Public surveys and meetings are needed to determine how or if the attitudes and preferences of anglers have changed. An increase in demand for large, live catfish for use in pay lakes has been identified as a potential concern. The Missouri Department of Conservation (MDC) has been contacted by constituents who believe that overharvest has caused declines in the number of large catfish in the Mississippi and Missouri rivers. Because catfish are long-lived, relatively slow growing, lay fewer eggs than other sport fish, and because larger, older catfish are more effective breeders, selective harvest of large individuals could reduce local catfish numbers (Colehour 2009). Furthermore, both commercial and recreational catfish fishers are more harvest oriented than anglers fishing for other species (Wilde and Ditton 1999), making catfish populations susceptible to growth overfishing (i.e., fish are harvested before reaching their growth potential) and recruitment overfishing (i.e., high proportion of large fish harvested over a long-time period thereby reducing the fishery's fecundity). In response to these concerns, other states (e.g., Alabama and Tennessee) have restricted take of large catfish (e.g., only one catfish over 34 inches may be harvested per day) (SDAFS 2011). However, regulations that restrict the harvest of large catfish seem to be based on public sentiment rather than scientific evidence of their effectiveness.

Even though catfish support important fisheries that seem to be growing in popularity among recreational and commercial fishers, big river catfish populations have not been intensively researched or managed. In the *Big River Management and Coordination White Paper* (MDC 2010), the Division Review Team listed blue catfish population assessments as a high priority. *Managing Missouri's Catfish; A Statewide Catfish Management Plan* (MDC 2003) listed three objectives pertaining to blue catfish populations in the Missouri and Mississippi rivers:

- Increase yield of catfish on the Mississippi River to recreational and commercial fishers.

- Continue to refine existing standardized sampling techniques that provide a more representative sample of flathead catfish and blue catfish populations in big rivers.
- Develop creel survey methods that will accurately measure angler effort and harvest of catfish populations in large rivers.

Recognizing a lack of data needed to characterize Missouri's big river, blue catfish fisheries, a pilot project was conducted to assess the feasibility of a statewide big river catfish study to resolve identified knowledge gaps (MDC 2015). During spring and fall 2013 and spring 2014, blue catfish were sampled using low-frequency electrofishing (EF) on the Mississippi and Missouri rivers. Specifically, the pilot study was designed to determine if low-frequency electrofishing is effective and efficient at sampling blue catfish in big rivers and to determine the amount of electrofishing effort necessary to collect sufficient numbers of fish for population and exploitation analysis. Additionally, the pilot study identified the most appropriate and standardized electrofishing methods to employ. Pilot study results were used to design the subsequent statewide investigation to collect data needed to assess big river, catfish fisheries and evaluate current and potential harvest regulations. Management and regulatory recommendations resulting from this study focus on increasing yield available to fishers and ensuring sustainability of big river, blue catfish populations. Fisheries data was collected to assess population demographics (e.g., longevity, age and growth, size structure, and total annual mortality) among Mississippi and Missouri river blue catfish populations and estimate exploitation by recreational and commercial fishers.

Methods

Site Selection

There were 459 locations (i.e., river miles) on the Missouri River and 229 locations on the Mississippi River considered for sampling sites. Unsuitable river reaches (e.g., highly industrialized, limited accessibility, or variable water conductivity) were not considered (Table 1). Using the R (R Core Team 2014) package spsurvey, four locations were selected using Generalized Random Tessellation Stratified (Stevens and Olsen 2004) on each river (Table 2, Figure 1). Each location selected served as the downstream boundary of each study site. Study sites were 20 river miles (32 km) in length; slightly larger than the median annual movement range of blue catfish in the lower Missouri River and upper Mississippi River (Garrett and Rabeni 2011; Tripp et al. 2011).

Sampling Protocols

Sampling protocols were finalized and distributed to field crews prior to the commencement of the study. Sampling protocols are presented in Appendix 1.

Size Structure

Descriptive statistics of length-structure distributions included mean total length, length-frequency histograms, and proportional size distributions (PSD) by river. PSD indices were calculated using blue catfish length categories described by Anderson and Neumann (1996) as follows: stock (300 mm or 12 in), quality (510 mm or 20 in), preferred (760 mm or 30 in), memorable (890 mm or 35 in), and trophy (1140 mm or 45 in). Mean lengths and proportional size distributions by river and year were compared using one-way Analysis of Variance (α=0.05). The length frequency distributions of fish collected in 2015 and 2016 were compared with Kolmogorov-Smirnov (KS) two-sample tests.

Fish Tagging and Estimating Exploitation

All blue catfish collected were measured to total length (TL) and a subset were weighed, fitted with Carlin dangler tags below the dorsal fin, and released at the capture location (Guy et al. 1996; Sullivan and Vining 2011; Bodine et al. 2018). Tags were distributed among twelve size groups (2-inch intervals except 35-39.9 and ≥40 in TL) starting at 15 inches, the minimum length limit (MLL) for commercial harvest and the size catfish become vulnerable to angler size-selective exploitation (Travnichek 2011). We attempted to tag 132 fish in each site with equal numbers of tagged fish in each size group (Pollock et al. 2001). Fish were tagged during standard sampling and during additional targeted sampling. To encourage tag reporting by fishers, tags were marked with a reward value of either US$25 or $150. We attempted to tag, in random order and in each size group, 75 percent of fish with standard tags ($25) and 25 percent with high-reward tags, except the two larger size groups were split 50/50 to more precisely estimate exploitation of memorable and trophy class fish. Each tag contained the reward value, a contact phone number, and a unique tag number. Two tag colors were used to distinguish the reward value and minimize misidentification by fishers. However, specific reward values and site locations were not mentioned to prevent artificially increased fishing effort (i.e., fishing for tags). Fishers catching tagged fish provided information regarding fish length, date and location caught, capture method (e.g., fishing gear), permit type, and whether the fish was harvested or released. Rewards and information regarding date and location the fish was tagged were mailed to the fishers after the tag was returned to MDC.

Annual exploitation rate (μ) was estimated following Bodine et al. (2018) at the local-site scale and at the river scale for three categories (total, fishing gear, and size specific) as

$$\mu_i = \frac{\sum_r \left(\frac{H_{r,i}}{RR_{r,.}}\right)}{\left(\sum_r M_{r,i} \times \left(1 - TL_{.,.}\right) - \left[\sum_r \left\{\frac{CR_{r,i}}{RR_{r,.}}\right\}\right]\right)}$$

where r = reward value of a tag, either $25 or $150; i = category (i.e., fishing gear or size-group); $M_{r,i}$= number of marked fish with a tag value r released in category i; $H_{r,i}$= number of harvested fish with a tag value r in category i, limited to the first year post-tagging; $CR_{r,i}$= number of caught and released fish with a tag value r released in category i, limited to the first year post-tagging; $RR_{r,.}$= reporting rate for tag value r, assuming the same for all categories i; and $TL_{.,.}$= tag loss rate of 1.1 percent (Sullivan and Vining 2011), assuming the same for all values r and categories i.

Reporting rate of standard tags ($RR_{25,.}$) was estimated as

$$RR_{25,.} = \frac{\left(\frac{R_{25,.}}{M_{25,.}}\right)}{\left(\left[\frac{R_{150,.}}{M_{150,.}}\right] \Big/ RR_{150,.}\right)}$$

where $R_{25,.}$= number of standard tags reported; $M_{25,.}$= number of marked fish with standard tags; $R_{150,.}$= number of high-reward tags reported; $M_{150,.}$= number of marked fish with high-reward tags; and $RR_{150,.}$= reporting rate of high-reward tags, assumed to be 100 percent. All tags reported before 1 January 2019 were included in our reporting rate estimate.

In our alternative scenario on the Mississippi River (scenario 2; see Results and Discussion section in this paper for more details) we adjusted the reporting rate of high-reward tags to 75 percent for fish 29 inches and longer.

Age, Growth, and Mortality

For a subset of blue catfish collected, weight was regressed against length after all data were log-transformed. Weight-length regressions were used in model calculations of mean weight of fish harvested and total yield.

Pectoral spines, including the articulating process, were removed from fish with the target of collecting 10 spines from fish in each 2-inch size group starting at 7 inches from each site. Otoliths were not collected from sampled fish because of the lethality, even though spines have been shown to underestimate ages of catfish compared to otolith age estimates (Nash and Irwin 1999; Columbo et al. 2010; Olive et al. 2011; Homer et al. 2015). However, otoliths were collected from a sample of commercially harvested fish within the study sites on the Mississippi River and were compared to spine age estimates. Pectoral spines and lapilli otoliths were processed using methods described by Buckmeier et al. (2002). Ages were estimated for each fish by three independent readers with agreement defined as either unanimous or two readers agreed with the third reader within one year. Disagreements were reconciled during a subsequent concert read. A scatter plot of pairwise comparisons of age estimates from otoliths and spine sections was generated to assess bias in age assignment (Campana et al. 1995). Difference in age estimates between structures was computed and plotted against total length to demonstrate direction of error in age estimates (Nash and Irwin 2000).

Growth was estimated by calculating mean TL at age and fitting the von Bertalanffy curve (von Bertalanffy 1938). Changes in TL, standardized to 365 days, of fish tagged and recaptured during sampling in subsequent years were compared to annual change of mean TL at estimated age.

For mortality estimation, all aged fish were used to construct an age-length key for each river. The key was used to assign ages to all unaged, newly fin clipped fish collected during standard sampling. All fish that were recaptured during standard sampling (identified by fin clip) or collected during targeted sampling were excluded from mortality estimation. The weighted catch curve method was used to estimate instantaneous total mortality rate (Z; Robson and Chapman 1961; Ricker 1975). Ages that were on the ascending limb of the catch curve were assumed to not be fully recruited to our standard EF sampling and were omitted from the analysis. Instantaneous total mortality was converted to total annual mortality (A= 1-e^{-Z}) and total annual survival (S= 1-A).

Total annual survival was also estimated using a tag recovery model (Brownie et al. 1985) corrected for bias of catch and release fishing where the fish is released, but the tag is removed (Smith et al. 2000). Our tag recovery models used additional data from fishers who, in theory, were spread out across the population range and had the chance to encounter and report tags. Therefore, the assumption of population closure did not apply, and true survival could be estimated. For comparison with the survival estimates derived from catch curve regression, tag recovery models were restricted to the same ages that were fully recruited to standard EF sampling. The total annual survival estimates were converted to total annual mortality (A= 1-S).

Annualized natural mortality (v) was estimated by subtracting our estimates of exploitation (μ) from our two estimates of A. Also, we used Fishery Analysis and Modeling Simulator (FAMS) version 1.64.4 (Slipke and Maceina 2014) to examine potential ranges of instantaneous natural mortality (M) and conditional natural mortality (cm) based on our von Bertalanffy parameters, maximum age, and average water temperature.

Simulation Modeling to Predict the Effects of Length Limits

Population modeling was performed using FAMS version 1.64.4 (Slipke and Maceina 2014). Conditional mortality rates were needed for modeling and were calculated as

$$cf = 1 - e^{(\mu \times Z)/(1-S)}$$

$$cm = 1 - e^{(v \times Z)/(1-S)}$$

where cf= conditional fishing mortality and cm= conditional natural mortality.

We used a yield-per-recruit model to examine how total yield (pounds of fish harvested), spawning potential ratio (SPR), and number of size-specific fish in the population were affected by various exploitation rates and length limits. We also used a dynamic pool model, which was an age-structured model where *cf* was adjusted based on our size-specific exploitation estimates to examine how total yield, SPR, and number of fish in the population were affected by various exploitation rates for various sizes of fish. We identified exploitation rates that would likely induce growth and recruitment overfishing. Growth overfishing was identified by the descending limb of the yield curve and recruitment overfishing was identified as the point at which the SPR was less than 20 percent (Goodyear and Christensen 1984). For SPR, Colehour (2009) found that no blue catfish collected from the Mississippi River less than 20 inches (508 mm) were mature. Therefore, we considered fish reproductively mature at age 6 based on the age assigned to a 20-inch fish using our length-age key. We used a log-transformed length-fecundity relationship adapted from Colehour (2009).

$$\log(Fecundity) = 2.591(\log[TL]) - 2.8092$$

Trophy fish was defined based on the size of blue catfish the highest percentage (16.2 percent) of Missouri anglers surveyed considered to be a trophy (20 lb [9,071 g]; Reitz 2003). The second most popular opinion with 14.8 percent of responses was 10 pounds (4,535 g). Other specific sizes of fish we were interested in examining included 5 pounds (2,267 g) and 2 pounds (907 g) based on work by Reitz and Travnichek (2006). Those reports were based on weight, so we converted weights to lengths for population modeling using our weight-length regressions.

We also examined what length limits (i.e., MLL and slot limits) and "big fish" daily bag limits would protect against growth and recruitment overfishing and what effect these harvest regulations may have on total yield and number of size-specific fish in the population. Kuklinski and Boxrucker (2008) found that 6 percent of Oklahoma anglers harvested blue catfish over 30 inches. Over half of those anglers (84 of 151 anglers; 55 percent) harvested more than one blue catfish over 30 inches during a single angling trip. Assuming those anglers harvested two blue catfish over 30 inches, then reducing the daily bag limit to no more than one blue catfish over 30 inches per day would decrease harvest from 235 to 151. Therefore, in our simulations where one blue catfish over 30 or 34 inches could be kept daily we decreased our number of large fish harvested by 36 percent and calculated new exploitation rates. These models were age-structured and used our size-specific exploitation estimates. All model predictions were compared to a 15-inch MLL which represented current conditions where blue catfish were not vulnerable to harvest until 15 inches.

Results

Missouri River

Sampling Effort and Fish Collection

Standardized, stratified-random electrofishing (EF) runs were made in the Missouri River during spring 2015 (N=237) and 2016 (N=269) for a total effort of 49.2 EF hours. An additional 38.7 hours of EF and 4 gill net, 10 hoop net, and 57 trotline nights were expended during targeted sampling. A total of 2,987 blue catfish was collected during EF runs in spring 2015 and 2016, ranging from 3-53 inches (78-1,348 mm) TL.

Size Structure

Mean length of blue catfish collected was not significantly different between years [2015=21.8 in (SE=0.17); 2016 = 22.2 in (SE=0.23); p=0.24]. However, length-frequency distributions were significantly different between 2015 and 2016 (p<0.0001). The difference between 2015 and 2016 length-frequency distributions was due largely to a strong cohort of sub-stock length blue catfish collected during 2016 (Figure 2). There was no significant year effect on blue catfish PSD-Q (p=0.18), which averaged 71 percent across all Missouri River sites (range 57-88%). PSD-P, PSD-M, and PSD-T were also not significantly different between years and averaged 16, 4.5, and 0.44 percent, respectively (Figure 3).

Age and Growth

Length was a significant predictor of weight resulting with a significant weight-length regression for the Missouri River ($p<0.0001$, $R^2=0.97$). Lengths of blue catfish that averaged 2, 5, 10, and 20 pounds were 18, 24, 30, and 38 inches (457, 610, 762, and 965 mm), respectively (Table 3).

We collected, processed, and estimated ages for 1,011 blue catfish pectoral spines collected during standard and targeted sampling. Based on spine age estimates, mean TL increased on average by 1.6 inches (39.9 mm) per year in the Missouri River (Table 4; Figure 4). Comparatively, when we examined growth of recaptured, tagged fish (n=27) during subsequent years of sampling in the Missouri River, fish TL increased by an average of 1.6 inches (39.4 mm) per year (Figure 5).

Aged fish from the Missouri River ranged from 2 to 18 years, and the von Bertalanffy growth curve was a good fit to the length-at-age data ($p<0.0001$, $R^2=0.97$; Table 5). Growth curves predicted fish to reach 15 inches by age 5, 18 inches by age 6, 24 inches by age 9, 30 inches by age 12, and 38 inches by age 18 (Table 3).

Fish Tagging and Exploitation

In spring 2015 and 2016, we tagged 470 and 445 blue catfish in the Missouri River, respectively. Approximately 70 percent of tags during each year were the standard reward value. As of 1 January 2019, 181 blue catfish tags from the Missouri River were reported by fishers (Appendix 2). Our empirical estimates of reporting rates were 58 percent on the Missouri River (all recreational permit holders) with reporting rates by site ranging from 40-88 percent (Table 6).

For all sizes classes combined, annual exploitation was 12.7 percent on the Missouri River (Table 7). Site-specific total annual exploitation estimates were based on local reporting rates and was lowest at sites 5 and 7 (9 percent), slightly higher at site 8 (11 percent), and highest at site 6 (18 percent).

Size-specific exploitation was estimated at the river scale, but could not be estimated at the local-site scale due to too few high-reward tags returned from some sites in some size groups. Exploitation varied by fish size and was generally higher for larger fish where annual exploitation of blue catfish greater than or equal to 25 inches was 17.7 percent. The size group with the highest exploitation (35.0 percent) on the Missouri River was 31-32.9 inches (Table 8 and Figure 6).

Blue catfish were harvested from five different gears on the Missouri River. Gear-specific exploitation was highest with trotlines. Rod and reel fishing was the second highest method of harvest, even though catch and release was more popular with this gear (Table 9).

Mortality

Full recruitment to our sampling appeared to occur at age 8 (approximately 25 inches, or 635 mm; Figure 7). The weighted catch curve regression indicated that total annual mortality of blue catfish age 8 and older was 35.0 percent on the Missouri River ($Z=-0.431$, $R^2=0.863$; Figure 8). In comparison, our estimates of total annual mortality of fish greater than or equal to 25 inches from the tag recovery model was 34.5 percent.

Annualized natural mortality was estimated as the remainder of total mortality unexplained by fishing mortality where exploitation estimates of fish greater than or equal to 25 inches was 17.7 percent (Table 8). Therefore, our estimates of annual natural mortality (*v*) on the Missouri River ranged from 16.8 to 17.3 percent (*M*=-0.206 to -0.213; cm=0.186 to 0.192). These estimates were near the upper range of the empirical estimators of natural mortality calculated using FAMS where estimates of *M* ranged from 0.11-0.20 and cm ranged from 0.10-0.19.

Yield-per-Recruit Models with Equal Exploitation Across All Fish Sizes

Our models indicated that with no size selective harvest (exploitation equal among all fish sizes) and a 15-inch MLL, growth overfishing would occur when exploitation rates exceeded 21.6 percent and recruitment overfishing would occur at rates exceeding 22.5 percent. With an 18-inch MLL growth and recruitment overfishing would occur at exploitation rates above 28.9 percent and 31.6 percent, respectively. Under a 21 or 24-inch length limit growth or recruitment overfishing were not predicted to occur at any level of exploitation less than 50 percent (Figure 10).

At current levels of exploitation (12.7 percent for all fish sizes combined), our models indicated maximum yield gain of 4 percent was achieved when the MLL was increased to 18 or 21 inches. A MLL greater than 21 inches was predicted to decrease yield (Figure 9). Slot limits, where fish within the slot were protected, or vice versa, and reduced daily bag limits all predicted reduced yield.

With an 18-inch MLL, the number of trophy fish (≥ 38 inches) was predicted to increase by 13 percent compared to a 15-inch MLL (Figure 10). Also, the number of 18, 24, and 30-inch fish were all expected to increase by 13 percent. The average weight of harvested fish would increase by 31 percent (increase of 1.5 lb [679 g]), and the number of fish harvested would decrease by 21 percent (Figure 10). Under a 21-inch MLL our models predicted the number of 18-inch fish would increase by 13 percent compared to a 15-inch MLL; however, these fish would not be legal to harvest under this scenario. The number of 24, 30, and 38-inch fish were all expected to increase by 24 percent, the average weight of harvested fish would increase by 57 percent (2.7 lb [1,234 g]), and number of fish harvested would decrease by 34 percent (Figure 10).

Dynamic Pool Models with Size-Specific Exploitation

When we incorporated size-specific exploitation estimates in our dynamic pool model with a 15-inch MLL, exploitation would have to increase by a multiplier of three before yield decreased and by a multiplier of five before SPR fell below 0.2. This was primarily because our current exploitation estimate of fish less than age 7 was only 3 percent. Our models indicated that older aged fish (i.e., ≥ age 8) could be harvested at high rates without jeopardizing yield or SPR.

On the Missouri River, in our age-structured model (Table 10) maximum yield would be achieved under a 24-inch MLL; however, this yield was only 4.5 percent higher than the predicted yield under a 15-inch MLL (Figure 11).

In all models, the number of fish harvested decreased with increased MLL, but the mean weight of fish harvested increased. This tradeoff was not equal where the percent gain in mean weight of fish harvested was always greater than the percent loss in number of fish harvested (Figures 10 and 11).

On the Missouri River an 18-inch MLL was predicted to increase numbers of all sizes of fish by 6 percent compared to a 15-inch MLL. The number of 24, 30, and 38-inch fish were predicted to increase by an additional 4 and 15 percent with a 21 and 24-inch MLL, respectively (10 and 21 percent increase compared to the 15-inch MLL; Figure 12).

A slot limit of 26-34 inches (660-864 mm), where fish within the slot were released, was predicted to decrease yield on the Missouri River by 34 percent compared to a 15-inch MLL. The numbers of fish within the slot and above the slot were predicted to increase by 43 percent and 587 percent, respectively (Figure 12). However, the number of fish harvested and mean weight of fish harvested were both predicted to decrease (27 and 9 percent, respectively; Figure 11).

Models where the conditional fishing mortality of fish greater than 30 or 34 inches was reduced (simulating a “big fish” daily bag limit of one fish) all predicted reductions in yield (1-5 percent), number of fish harvested, and average weights of fish harvested (Figure 11). The number of 38-inch fish was predicted to increase by 98 or 16 percent with a simulated daily limit of one over 30 inches or 34 inches, respectively (Figure 12).

Mississippi River

Sampling Effort and Fish Collection

Standardized stratified-random EF runs were made during spring 2015 (N=277) and 2016 (N=299) for a total effort of 69.2 EF hours. An additional 40.6 hours of EF and 48 gill net and 75 trotline nights were expended during targeted sampling. A total of 3,652 blue catfish was collected during electrofishing runs in spring 2015 and 2016 ranging in size from 3-50 inches (76-1,270 mm) TL.

Size Structure

Mean length of blue catfish collected was significantly different between years ($p<0.0001$) and was higher during 2015 (21.2 inches, SE=0.19) than during 2016 (19.6 inches, SE=0.19). Length-frequency distributions were significantly different between 2015 and 2016 ($p<0.0001$) largely due to a strong cohort of sub-stock length blue catfish collected during 2016 (Figure 2). There was no significant year effect on blue catfish PSD-Q ($p=0.95$), which averaged 67 percent across all Mississippi River sites (range 36-81%). PSD-P, PSD-M, and PSD-T were also not significantly different between years and averaged 12, 4.6, and 0.66 percent, respectively (Figure 3).

Age and Growth

Length was a significant predictor of weight resulting with a significant weight-length regression for the Mississippi River ($p<0.0001$, $R^2=0.96$). Size of fish that were legal to commercially harvest (≥15 inches) averaged 1 pound (500 g). Lengths of blue catfish that averaged weights of 2, 5, 10, and 20 pounds were 18, 24, 30, and 38 inches, respectively (Table 3).

We collected, processed, and estimated ages for 863 blue catfish pectoral spines collected during standard and targeted sampling. In addition, lapilli otoliths and pectoral spines were collected from 240 and 176 commercially harvested fish with both aging structures collected from 162 fish. Only 42 percent of ages from spine sections were in exact agreement with ages from otoliths; but, 88 percent were within one year of agreement (Figure 13). The difference in ages between spines and otoliths did not show any correlations to fish length (Figure 14). Based on spine age estimates, mean TL increased on average by 1.6 inches (40.2 mm) per year in the Mississippi River (Table 4; Figure 4). Comparatively, when we examined growth of recaptured, tagged fish (n=26) during subsequent years of sampling in the Mississippi River, fish TL increased by an average of 1.6 inches (39.8 mm) per year (Figure 5).

Aged fish from the Mississippi River ranged from 1 to 19 years, and the von Bertalanffy growth curve was a good fit to the length-at-age data ($p<0.0001$, $R^2=0.97$; Table 5). Growth curves predicted fish to reach 15 inches by age 4, 18 by age 5, 24 by age 8, 30 by age 11, and 38 by age 17 (Table 3).

Fish Tagging and Exploitation

In spring 2015 and 2016, we tagged 380 and 379 blue catfish in the Mississippi River, respectively. Approximately 70 percent of tags during each year were the standard reward value. As of 1 January 2019, 130 blue catfish tags from the Mississippi River were reported by fishers (Appendix 2). Our empirical estimates of reporting rates were 82 percent on the Mississippi River where commercial and recreational fishing permit holders reported standard tags at near equal rates (83 and 82 percent, respectively). Reporting rates differed among sites and ranged from 63-100 percent (Table 6).

At the river scale, for all size classes combined annual exploitation was 10 percent on the Mississippi River. Most exploitation on the Mississippi River was from recreational fishers (6 percent) and not commercial fishers (4 percent). Site-specific total annual exploitation estimates were based on local reporting rates. Local exploitation ranged from approximately 7 percent at sites 2 and 3 to 16 percent at sites 1 and 4 (Table 7).

Size-specific exploitation was estimated at the river scale, but could not be estimated at the local-site scale due to too few high-reward tags returned from some sites in some size groups. Exploitation varied by fish size where annual exploitation of blue catfish greater than or equal to 25 inches was 14.1 percent. Exploitation dropped to minimal values (2.0 percent) on the Mississippi River for the 31-32.9-inch size group (Table 8 and Figure 6).

Blue catfish were harvested from seven different fishing gears on the Mississippi River. Gear-specific exploitation was highest with trotlines for both recreational and commercial fishers. Rod and reel fishing was the second highest method of harvest, even though catch and release was more popular with this gear (Table 9).

Mortality

Full recruitment to our sampling appeared to occur at age 8 (approximately 25 inches, or 635 mm) (Figure 7). The weighted catch curve regression indicated that total annual mortality of blue catfish age 8 and older was 38.2 percent on the Mississippi River (Z=-0.481, R^2=0.975; Figure 8). In comparison, our estimates of total annual mortality of fish greater than or equal to 25 inches from the tag recovery model was 35.3 percent.

Annualized natural mortality was estimated as the remainder of total mortality unexplained by fishing mortality where exploitation estimates of fish greater than or equal to 25 inches was 14.1 percent (Table 8). Therefore, our estimates of annual natural mortality (*v*) on the Mississippi River in this scenario (scenario 1) ranged from 21.2 to 24.1 percent (M=-0.261 to -0.303; cm=0.230 to 0.262). These estimates were above the range of the empirical estimators of natural mortality using FAMS where estimates of *M* ranged from 0.12-0.21 and cm ranged from 0.10-0.19.

Alternative Fishing and Natural Mortality (Scenario 2)

The fishing and natural mortality estimates for the Mississippi River presented above were used for simulation modeling as scenario 1, but we investigated an alternative scenario (scenario 2) to address concerns regarding these estimates (i.e., low exploitation estimates for the 31-32.9-inch size group). The reasoning for these concerns are discussed in more detail in the Discussion section of this paper.

Lowering the assumed reporting rate of the high-reward tags to 75 percent on the Mississippi River for blue catfish greater than 29 inches dropped the reporting rate of standard tags for these sizes of fish to 51 percent. These adjustments increased the overall exploitation rate to 13.7 percent and the exploitation rate for fish greater than or equal to 25 inches to 18.8 percent (Table 8).

Therefore, our estimates of annual natural mortality (*v*) on the Mississippi River in scenario 2 ranged from 16.5 to 19.4 percent (M=-0.204 to -0.244; cm=0.184 to 0.217). These estimates were near the upper range of the empirical estimators of natural mortality using FAMS where estimates of *M* ranged from 0.12-0.21 and cm ranged from 0.10-0.19.

Yield-per-Recruit Models with Equal Exploitation Across All Fish Sizes

Our models indicated that with no size selective harvest (exploitation equal among all fish sizes) and with a 15-inch MLL, growth overfishing would occur when exploitation rates exceeded 26.3 or 18.9 percent (scenario 1 and 2, respectively). With an 18-inch MLL growth overfishing would occur at exploitation rates above 37.0 and 24.3 percent, respectively. Under a 21 or 24-inch MLL growth overfishing was not predicted to occur at any level of exploitation less than 50 percent (Figure 15).

Recruitment overfishing was predicted to occur under a 15-inch MLL when exploitation rates exceeded 21.9 percent (scenario 1) or 19.8 percent (scenario 2). Our models indicated that with an 18-inch MLL recruitment overfishing would occur at rates exceeding 28.1 and 25.2 percent, respectively. Under a 21 or 24-inch MLL recruitment overfishing was not predicted to occur at any level of exploitation less than 40 percent in either scenario (Figure 16).

At current levels of exploitation (10-13.7 percent for all fish combined), yield would be maximized on the Mississippi River with a MLL of 18 or 21 inches depending on the natural mortality rate (scenario 1 and 2, respectively; Figure 15). The lower exploitation rate and higher rate of natural mortality in scenario 1 led to small gains in yield (1 percent) with an increased MLL of 18 inches. Also, in this scenario, yield was only decreased by 2 percent with a MLL of 21 inches. The largest increase in yield would be expected when natural mortality rates were lower (scenario 2); but our models predicted that when cm=0.20 an increase of the MLL from 15 to 21 inches would not increase yield by more than 8.5 percent (Figure 15). Slot limits where fish within the slot were protected, or vice versa, and reduced daily bag limits all predicted reduced yield.

In scenario 1, with an 18-inch MLL the number of trophy fish was predicted to increase by 15 percent compared to a 15-inch MLL. Also, the number of 18, 24, and 30-inch fish were all expected to increase by 15 percent. The average weight of harvested fish would increase by 36 percent (increase of 1.4 lb [637 g]), and the number of fish harvested would decrease by 26 percent. Under a 21-inch MLL our models predicted the number of 18-inch fish would increase by 16 percent compared to a 15-inch MLL; however, these fish would not be legal to harvest under this scenario. The number of 24, 30, and 38-inch (trophy) fish were all predicted to increase by 27 percent, the average weight of harvested fish increased by 66 percent (2.6 lbs [1,162 g]), and number of fish harvested decreased by 41 percent (Figure 17).

In scenario 2, with an 18-inch MLL the number of trophy fish was predicted to increase by 19 percent compared to a 15-inch MLL. Also, the number of 18, 24, and 30-inch fish were all expected to increase by 20 percent. The average weight of harvested fish would increase by 34 percent (increase of 1.4 lb [649 g]), and the number of fish harvested would decrease by 21 percent. Under a 21-inch MLL our models predicted the number of 18-inch fish would increase by 20 percent compared to a 15-inch MLL; however, these fish would not be legal to harvest under this scenario. The number of 24, 30, and 38-inch fish were all predicted to increase by 36 percent, the average weight of harvested fish increased by 63 percent (2.6 lb [1,180 g]), and number of fish harvested decreased by 34 percent (Figure 18).

Dynamic Pool Models with Size-Specific Exploitation

When we incorporated our size-specific exploitation estimates in our age-structured model (Table 10) with a 15-inch MLL exploitation would have to increase by a multiplier of three before yield decreased and by a multiplier of five before SPR fell below 0.2. This was primarily because our current exploitation estimates of fish less than age 7 was only 3 percent. Our models indicated that older aged fish (i.e., ≥ age 8) could be harvested at high rates without jeopardizing yield or SPR.

In scenario 1, the expected increase in yield from increased MLL were negated by the higher natural mortality rate because large numbers of fish died before being harvested (Figure 19). In scenario 2, increases in MLL up to 24 inches were all predicted to increase yield with the greatest increase of 8.6 percent under a 24-inch MLL (Figure 20).

In both scenarios, the number of fish harvested decreased with increased MLL, but the mean weight of fish harvested increased. This tradeoff was not equal where the percent gain in mean weight of fish harvested was always greater than the percent loss in number of fish harvested (Figures 19 and 20).

In both scenarios on the Mississippi River, an 11 percent gain in number of all sizes was predicted under an 18-inch MLL. There was no additional increase in the number of 18-inch fish under a 21-inch MLL, but the numbers of 24, 30, and 38-inch fish increased by another 8.5 percent (19.5 percent increase compared to the 15-inch MLL). Under a 24-inch MLL the numbers of 24, 30, and 38-inch fish increased by another 21 percent (40.5 percent increase compared to the 15-inch MLL; Figures 21 and 22).

A slot limit of 26-34 inches (660-864 mm) where fish within the slot were released was predicted to decrease yield on the Mississippi River by 20 and 26 percent (scenario 1 and 2, respectively) compared to a 15-inch MLL (Figures 21 and 22). In scenario 1, there was no change in the number of fish less than 26 inches (below the slot), whereas the number of 30-inch fish (within slot) was predicted to increase by 30 percent and the number of 38-inch fish (above the slot) was predicted to more than double (111 percent) (Figure 21). In scenario 2, the number of 30-inch fish (within slot) was predicted to increase by 39 percent and the number of trophy fish (above the slot) was predicted to be 589 percent higher (Figure 22).

In both scenarios, models where the conditional fishing mortality of fish greater than 30 or 34 inches was reduced (simulating a “big fish” daily bag limit of one fish) all predicted reductions in yield (1-4 percent), number of fish harvested, and average weights of fish harvested (Figures 19 and 20). With a simulated daily limit of one over 30 inches, the number of 38-inch fish was predicted to increase by 37 and 64 percent in scenario 1 and 2, respectively. Whereas, with a daily limit of one over 34 inches the number of 38-inch fish was predicted to increase by 5 percent in both scenarios (Figures 21 and 22).

Discussion

Blue catfish support extremely important recreational and commercial fisheries on Missouri’s big rivers. Catfish harvest is important, however trophy and tournament angling for catfish is increasing in popularity. An increase in demand for large, live catfish for use in pay lakes has been identified as a potential concern and some constituents believe that overharvest has caused declines in the number of large catfish in the Mississippi and Missouri rivers. This study was conducted to assess big river catfish fisheries and evaluate harvest regulations to identify those that will ensure sustainability and increase yield of blue catfish available to fishers. MDC’s current catfish management objectives are qualitative, but serve as a basis for this report’s recommendations. The results of this study could be used to establish a new management plan with more quantitative objectives (e.g., catch per unit effort, size structure, or growth rates).

Low-frequency pulsed DC EF (15 Hz, 30 percent duty cycle) was effective at collecting various sizes of blue catfish, but appeared to be less efficient at collecting younger age classes as fish were not fully recruited to our sampling methods until age 8. However, Bodine and Shoup (2010) and Morris et al.

(2018) found no length effect on catch rates or capture prone responses of blue catfish when using the same waveform. The dissimilarities between our sampling efficiencies and the responses seen in the trials performed by Morris et al. (2018) and the study by Bodine and Shoup (2010) may be due to environmental conditions (i.e., water velocity, depth, water temperature) during our sampling or that habitats with high densities of younger age classes of blue catfish were not completely sampled even though we attempted to proportionally sample all habitat types present within each study site.

Estimates of longevity and growth of blue catfish were similar between the Missouri and Mississippi rivers and were higher than those in the Harry S. Truman Dam tailrace, Missouri (Graham and Deisanti 1999). Our growth rates of blue catfish were like those in Mark Twain Lake, Missouri; however, theoretical maximum age was much greater in Mark Twain Lake (28.5 years; Michaletz et al. 2019). Our range of estimated exploitation rates among sites for blue catfish (6.7-18.0 percent) was similar to estimates reported in Mark Twain Lake (8-12%; Michaletz et al. 2019), the Harry S. Truman Dam tailrace (8-15%; Graham and Deisanti 1999), Kentucky Lake, Kentucky (17%; Timmons 1999), and Lake Wilson, Alabama (8-22%; Holley et al. 2009) but was much less than estimates reported in Harry S. Truman Lake, Missouri (25-33%; Sullivan and Vining 2011).

Our estimates of total annual mortality by catch curve and tag-recovery analysis indicated that total mortality was higher on the Mississippi River where exploitation estimates were lower, resulting in different natural mortality rate estimates between the Missouri and Mississippi rivers. Studies have shown that fish populations with similar longevity, growth parameters, and mean environmental temperature tend to have similar natural mortality rates (Pauly 1980; Hoenig 1983; Peterson and Wroblewski 1984; Chen and Watanabe 1989; Jensen 1996; Quinn and Deriso 1999). Our estimates of natural mortality may have differed between the two rivers due to errors with our total annual mortality or exploitation estimations. Given that we estimated total annual mortality using two independent analyses which yielded very similar results there was greater possibility that the underlying assumptions with our exploitation estimates were violated. A key assumption in our exploitation estimates was that high-reward tags were fully reported. Underreporting of high-reward tags would have led to underestimating exploitation and overestimating natural mortality. Overestimation of natural mortality can lead to erroneous yield calculations and extremely high estimates of sustainable exploitation rates where a lower, more conservative estimate of natural mortality can avoid that danger (Clark 1999).

Examination of size-specific exploitation rates raised concerns with some size-classes (particularly 29-30.9, 31-32.9, and 33-34.9 inches) on the Mississippi River where high-reward tags may have been underreported. These size-classes were within the protected slot limit of blue catfish on Harry S. Truman Lake and Lake of the Ozarks, Missouri. Additional information from commercial fishing reports and commercial fishing creel data indicate larger fish (i.e., 29 inches and above) are harvested in relatively high frequencies on the Mississippi River (Appendix 3). Also, some commercial fishers that report the majority of harvest of blue catfish on the Mississippi River and fish close to study sites did not report any tags. Therefore, for sensitivity purposes, we adjusted the reporting rate of the high-reward tags to 75 percent for fish over 29 inches, derived new estimates of exploitation and natural mortality, and modeled an alternative scenario (Mississippi River scenario 2). We assumed 75 percent may have represented to lowest reporting rate for the high-reward tags, so when examined together, the two scenarios on the Mississippi River provide a conservative range of predictions for the effects of various length limits on yield and size structure.

Commercial fishers accounted for 27 percent of blue catfish tag returns and 39 percent of blue catfish harvest on the Mississippi River during our study. This percentage was disproportionally high given there were only 15 commercial fishers that reported tags, whereas 91 recreational anglers reported a total of 95 tagged blue catfish on the Mississippi River. Similarly, when commercial fishing was legal on the Missouri River, Stanovick (1999) reported that commercial fishers accounted for 38 percent of catfish harvest but represented only 11 percent of recreational and commercial harvesters combined. Annually, from 2015 to 2018, the number of Missouri commercial fishers reporting harvest of blue catfish from the Mississippi River ranged from 42 to 53 (Table 11) (MDC unpublished data). The number of Missouri commercial fishers reporting harvest of blue catfish from within a Mississippi River study site (Sites 1-4) ranged from 8-13 during the same time frame.

Growth or recruitment overfishing was not evident when we incorporated size-specific exploitation rates. However, annual exploitation rates were variable among sites and our study sites represented less than 15 percent of the total length of the Missouri and Mississippi rivers in Missouri. There could be reaches on the Missouri or Mississippi rivers with higher exploitation than we observed in this study, so it is possible that local growth overfishing is occurring. However, the effects would likely be short-lived as blue catfish were very mobile and moved an average of 47 river miles between captures (median distance = 9.0 river miles; Appendix 2).

In a 2002 survey of Missouri catfish anglers the preferred method of fishing for blue catfish was rod and reel (Reitz and Travnichek 2006), but during this study the number of tagged blue catfish caught by rod and reel was second to trotlines. Reducing exploitation of all fish sizes would improve trophy fishing opportunity, but Missouri catfish anglers were evenly split in opposition or support of gear restrictions and more than half were opposed to reduced daily bag limits (Reitz and Travnicheck 2006). We did not conduct creel surveys during this study, but Kuklinski and Boxrucker (2008) found that less than 2 percent of Oklahoma catfish anglers caught a daily limit of 15 blue catfish and channel catfish, in the aggregate, with no length limits. Therefore, we hypothesize that Missouri’s recreational, daily bag limits on catfish from the Mississippi and Missouri rivers only slightly limit blue catfish harvest and an extreme reduction in the current daily bag limit would be needed to reduce exploitation and improve trophy fishing opportunities. However, on the Mississippi River where there is no daily bag limit for commercial fishers, a reduced limit could reduce exploitation, but may have economic impacts.

Regulations limiting the harvest of larger blue catfish to one fish per day may improve the trophy fishing potential if unregulated harvest of larger blue catfish is high. Kuklinski and Boxrucker (2008) found that only 3 percent of anglers harvested multiple blue catfish greater than 30 inches (762 mm) during a single angling trip. However, these rare instances accounted for at least 35 percent of the harvest of blue catfish of that size. Our models that reduced harvest of larger fish were based on the findings of Kuklinski and Boxrucker (2008), but we hypothesize that commercial fishers would be more likely to harvest multiple blue catfish greater than 30 inches per day compared to the Oklahoma anglers. Therefore, limiting harvest of larger blue catfish where commercial fishing is allowed may have greater impact on the trophy fishing potential, but would also be likely to decrease yield more than the 1-4 percent as predicted in our simulations. States such as Kentucky, where pay lakes are becoming very popular and sources of trophy catfish for stocking pay lakes include public waters such as the Ohio River, have implemented regulations that limit harvest of trophy catfish (KDFWR 2019). Stricter regulations on the Ohio River could reallocate commercial harvest of trophy catfish to the Mississippi River. Therefore, we strongly advise that commercial harvest of trophy catfish in the Mississippi River be monitored in the future.

In 2014, to meet management objectives for blue catfish on Harry S. Truman Lake and Lake of the Ozarks, Missouri, new regulations were imposed by MDC that increased the daily bag limit from 5 to 10, created a protected slot limit of 26-34 inches, and limited harvest of fish above the slot to two fish daily (MDC 2018b). In our simulations on the Missouri and Mississippi rivers, a protected slot limit of 26-34 inches improved the trophy fishing potential more than predicted with an increased MLL, but decreased yield by 20-34 percent. The differences between Harry S. Truman Lake and Lake of the Ozarks and the Missouri and Mississippi rivers regarding the simulated slot limit and population predictions can be attributed to differences in population dynamics including faster growth, greater longevity, and lower mortality.

The greatest improvement in both yield and trophy fishing potential in our simulations where fishing effort remained steady was predicted with an increased MLL. Reitz and Travnicheck (2006) found that Missouri anglers were like Texas anglers (Wilde and Riechers 1994), where blue catfish anglers were more supportive of a MLL to improve chances of catching a trophy-sized catfish as opposed to other regulations such as gear restrictions or reduced daily bag limits. Commercial fishers should also be supportive of a MLL given they were predicted to increase yield. Therefore, based on our simulations, fisheries managers aiming to increase yield on the Mississippi and Missouri rivers should focus on using a MLL (i.e., 18, 21 inches TL) to meet specific management objectives. If public opinion favors trophy fishing potential and fishers are willing to accept a minimal decline in yield, then restricting the number of fish over 30 or 34 inches per day should be considered, as well. This option would be most appropriate on the Missouri River where maintaining or improving yield is not currently a management objective.

Acknowledgements

We would like to thank the many Missouri Department of Conservation staff members involved in this project including Jake Allman, Mark Boone, Danny Brown, Joshua Bruegge, Shane Creasy, Ross Dames, Eric Dennis, Matt Engel, Zach Ford, Heather Garrison, Craig Gemming, Jennifer Girondo, Randy Haydon, Dave Herzog, Dave Knuth, Kevin Krause, Joseph Lawler, Philip Marley, Tory Mason, Adam McDaniel, Brian McKeage, Kevin Meneau, Darby Niswonger, David Ostendorf, Denise Otto, Sarah Peper, Quinton Phelps, Phil Pitts, Dyan Pursell, Tyler Ruoff, Lynn Schrader, Marley Schwendemann, Kevin Sullivan, Vince Travnicheck, Sara Tripp, Ivan Vining, Kasey Whiteman, and Chris Williamson.

References

Anderson, R. O. and R. M. Neumann. 1996. Length, weight, and associated structural indices. In Murphy, B.R. and Willis, D.W. (eds.), Fisheries techniques, 2nd ed., p. 447–482. American Fisheries Society, Bethesda, Maryland.

Arterburn, J. E., D. J. Kirby and C. R. Berry, Jr. 2002. A survey of angler attitudes and biologist opinions regarding trophy catfish and their management. Fisheries 27(5):10-21.

Bodine, K. A., and D. E. Shoup. 2010. Capture efficiency of Blue Catfish electrofishing and the effects of temperature, habitat, and reservoir location on electrofishing-derived length structure indices and relative abundance. North American Journal of Fisheries Management 30:613-621.

Bodine, K. A., J. W. Schlechte, and D. E. Shoup. 2018. An indirect method for estimating size-specific exploitation. North American Journal of Fisheries Management 38(5):1085-1090.

Brownie, C., D. R. Anderson, K. P. Burnham, and D. S. Robson. 1985. Statistical inference from band recovery data – a handbook, 2nd ed. U.S. Fish and Wildlife Service, Resource Publication 156. Washington, DC.

Buckmeier, D. L., E. R. Irwin, R. K. Betsill, and J. A. Prentice. 2011. Validity of otoliths and pectoral spines for estimating ages of channel catfish. North American Journal of Fisheries Management 22(3):934-942.

Campana, S. E., M. C. Annand, and J. I. McMillan. 1995. Graphical and statistical methods for determining the consistency of age determinations. Transactions of the American Fisheries Society 124:131-138.

Chen, S., and S. Watanabe. 1989. Age dependence and natural mortality coefficient in fish population dynamics. Nippon Suisan Gakkaishi 55:205-208.

Clark, W. G. 1999. The effects of an erroneous natural mortality rate on a simple age-structured stock assessment. Canadian Journal of Fisheries and Aquatic Sciences 56:1721-1731.

Colehour, J.D. 2009. Fecundity of Flathead Catfish and Blue Catfish from the Mississippi River between Hannibal and Cape Girardeau, Missouri. Master’s Thesis. University of Missouri, Columbia, Missouri.

Columbo, R. E., Q. E. Phelps, C. M. Miller, J. E. Garvey, R. C. Heidinger, and N. S. Richards. 2010. Comparison of channel catfish estimates and resulting population demographics using two common structures. North American Journal of Fisheries Management 30:305-308.

Garrett, D. L., and C. F. Rabeni. 2011. Intra-annual movement and migration of Flathead Catfish and Blue Catfish in the lower Missouri River and tributaries. Pages 495-509 *in* P. H. Michaletz and V. H. Travnichek, editors. Conservation, Ecology, and Management of Catfish: The Second International Symposium. American Fisheries Society, Symposium 77, Bethesda, Maryland.

Goodyear, C. P., and S. W. Christensen. 1984. On the ability to detect the influence of spawning stock on recruitment. North American Journal of Fisheries Management 4:186-193.

Graham, K. A., and K. Deisanti. 1999. The population and fishery of Blue Catfish and Channel Catfish in the Harry S. Truman dam tailwater, Missouri. Pages 361-376 *in* E. R. Irwin, W. A. Hubert, C. F. Rabeni, H. L. Schramm, Jr., and T. Coon, editors. Catfish 2000: proceedings of the international ictalurid symposium. American Fisheries Society, Symposium 24, Bethesda, Maryland.

Guy, C. S., H. L. Blankenship, and L. A. Nielsen. 1996. Tagging and marking. Pages 353–383 *in* B. R. Murphy and D. W. Willis, editors. Fisheries techniques, 2nd edition. American Fisheries Society, Bethesda, Maryland.

Hoenig, J. M. 1983. Empirical use of longevity data to estimate mortality rates. Fishery Bulletin 82:898-903.

Holley, M. P., M. D. Marshall, and M. J. Maceina. 2009. Fishery and population characteristics of Blue Catfish and Channel Catfish and potential impacts of minimum length limits on the fishery in Lake Wilson, Alabama. North American Journal of Fisheries Management 29:1183-1194.

Homer, M. D., J. T. Peterson, and C. A. Jennings. 2015. Evaluation of three aging techniques and back-calculated growth for introduced Blue Catfish from Lake Oconee, Georgia. Southeastern Naturalist 14(4): 740-756.

Jensen, A. L. 1996. Beverton and Holt life history invariants result from optimal trade-off of reproduction and survival. Canadian Journal of Fishers and Aquatic Sciences 53:820-822.

KDFWR (Kentucky Department of Fish and Wildlife Resources). 2019. Kentucky Administrative Regulations, Title 301, Chapter 1:155 Commercial Fishing Requirements. Frankfort, Kentucky.

Kuklinski, K. E., and J. Boxrucker. 2008. Catfish angling and harvest statistics with an emphasis on trophy blue catfish management in Oklahoma. Proceedings of the Annual Conference of the Southeastern Association of Fish and Wildlife Agencies 62:149-153.

MDC (Missouri Department of Conservation). 2003. Managing Missouri's catfish: a statewide catfish management plan. MDC, Jefferson City, Missouri.

MDC (Missouri Department of Conservation). 2010. Big river management and coordination white paper. MDC, Jefferson City, Missouri.

MDC (Missouri Department of Conservation). 2015. Evaluation of low-frequency electrofishing as an effective method for sampling Blue Catfish and Flathead Catfish populations in the Missouri and Mississippi rivers. MDC, Jefferson City, MO.

MDC (Missouri Department of Conservation). 2018. Missouri commercial fish harvest 2017. MDC. Jefferson City, Missouri.

MDC (Missouri Department of Conservation). 2019. *Wildlife Code of Missouri* rules of the Conservation Commission. MDC. Jefferson City, Missouri.

Michaletz, P. H., H. R. Dames, and S. L. Abel. 2019. Population assessment and angler exploitation of blue catfish in Mark Twain Lake. Missouri Department of Conservation, Federal Aid to Sport Fish Restoration, Project F-55-R, Final report, Jefferson City.

Morris, W. Z. 2018. Determining electrofishing response thresholds of Smallmouth Bass (*Micropterus dolomieu*), Flathead Catfish (*Pylodictus olivaris*), and Blue Catfish (*Ictalurus furcatus*). Master's thesis. University of Missouri, Columbia, Missouri.

Nash, M. K., and E. R. Irwin. 1999. Use of otoliths versus pectoral spines for aging adult Flathead Catfish. Pages 309–316 *in* E. R. Irwin, W. A. Hubert, C. F. Rabeni, H. L. Schramm, Jr., and T. Coon, editors. Catfish 2000: Proceedings of the International Ictalurid Symposium. American Fisheries Society, Symposium 24, Bethesda, Maryland.

Olive, J., H. L. Schramm Jr., P. D. Gerard, and E. Irwin. 2011. An evaluation of agreement between pectoral spines and otoliths for estimating ages of catfishes. Pages 679–688 *in* P. H. Michaletz and V. H. Travnichek, editors. Conservation, Ecology, and Management of Catfish: The Second International Symposium. American Fisheries Society, Symposium 77, Bethesda, Maryland.

Pauly, D. 1980. On the interrelationship between natural mortality, growth parameters, and mean environmental temperature in 175 fish stocks. Journal du Conseil International pour l'Exploration de la Mer 39:175-192.

Perterson, I., and J. S. Wroblewski. 1984. Mortality rate of fishes in the pelagic ecosystem. Canadian Journal of Fisheries and Aquatic Sciences 41:1117-1120.

Pollock, K. H., J. M. Hoenig, W. S. Hearn, and B. Calingaert. 2001. Tag reporting rate estimation: 1. an evaluation of the high-reward tagging method. North American Journal of Fisheries Management, 21(3):521-532.

Quinn, T. J., II, and R. B. Deriso. 1999. Quantitative fish dynamics. Oxford University Press, New York.

R Core Team. 2014. R: A language and environment for statistical computing, url: https://www.R-project.org.

Reitz, R. A. 2003. Catfish angling in Missouri: results from the 2002 mail survey. MDC. Jefferson City, Missouri.

Reitz, R. A. and V. H. Travnichek. 2006. Examining the relationship between species preference and catfish angler demographics, angling behavior, and management opinions. Proceedings of the Annual Conference Southeastern Association of Fish and Wildlife Agencies 60:145-151.

Ricker, W. E., 1975. Computation and interpretation of biological statistics of fish populations. Bulletin – Fisheries Research Board of Canada, 191, 382 p.

Robson, D. S., and D. G. Chapman. 1961. Catch curves and mortality rates. Transactions of the American Fisheries Society 90:181-189.

SDAFS (Southern Division of the American Fisheries Society). 2011. State Catfish Regulations. American Fisheries Society, Bethesda, Maryland. Available: https://docs.google.com/spreadsheet/pub?hl=en_US&hl=en_US&key=0Al-h4JFfmW6VdDNfUHRTU0U5cVI2cWNDTXgxekNWZGc&output=html. (March 2019).

Slipke, J. W., and M. J. Maceina. 2014. Fishery analysis and modeling simulator. Version 1.64. American Fisheries Society, Bethesda, Maryland.

Smith, D. R., K. P. Burnham, D. M. Kahn, X. He, C. J. Goshorn, K. A. Hattala, and A. W. Kahnle. 2000. Bias in survival estimates from tag-recovery models where catch-and-release is common, with an example from Atlantic striped bass (Morone saxatilis). Canadian Journal of Fish and Aquatic Sciences 57(5):886-897.

Stanovick, J. S. 1999. Recreational harvest rates, release rates and average length of catfish on the Missouri River, Missouri before and after the commercial catfishing ban. Pages 443-446 *in* E. R. Irwin, W. A. Huber, C. F. Rabeni, H. L. Schramm, Jr. and T. Coon, editor. Catfish 2000: Proceedings of the International Ictalurid Symposium. American Fisheries Society, Symposium 24, Bethesda, Maryland.

Stevens Jr, D.L. and A.R. Olsen. 2004. Spatially balanced sampling of natural resources. Journal of American Statistical Association 99 (465):262-278.

Sullivan, K. P., and I. W. Vining. 2011. Assessing angler exploitation of Blue Catfish and Flathead Catfish in a Missouri reservoir using reward tags. Pages 199–207 *in* P. H. Michaletz and V. H. Travnichek, editors. Conservation, Ecology, and Management of Catfish: The Second International Symposium. American Fisheries Society, Symposium 77, Bethesda, Maryland.

Timmons, T. J. 1999. Movement and exploitation of Blue and Channel Catfish in Kentucky Lake. Pages 187-192 *in* E. R. Irwin, W. A. Hubert, C. F. Rabeni, H. L. Schramm, Jr., and T. Coon, editors. Catfish 2000: Proceedings of the International Ictalurid Symposium. American Fisheries Society, Symposium 24, Bethesda, Maryland.

Travnichek, V. H. 2011. Monthly variation and influence of habitat and river stage on electrofishing catch rates and population indices of Flathead Catfish from the lower Missouri River. Pages 621-635 *in* P. H. Michaletz and V. H. Travnichek, editors. Conservation, Ecology, and Management of Catfish: The Second International Symposium. American Fisheries Society, Symposium 77, Bethesda, Maryland.

Tripp, S. J., M. J. Hill, H. A. Calkins, R. C. Brooks, D. P. Herzog, D. E. Ostendorf, R. A. Hrabik, and J. E. Garvey. 2011. Blue Catfish movement in the upper Mississippi River. Pages 511-519 *in* P. H. Michaletz and V. H. Travnichek, editors. Conservation, Ecology, and Management of Catfish: The Second International Symposium. American Fisheries Society, Symposium 77, Bethesda, Maryland.

USDI (U.S. Department of Interior), U.S. Fish and Wildlife Service, and U.S. Department of Commerce, U.S. Census Bureau. 2018. 2016 national survey of fishing, hunting, and wildlife-associated recreation. Washington D.C.

von Bertalanffy, L. 1938. A quantitative theory of organic growth (inquiries on growth laws II). Human Biology 10:181-213.

Weithman, A. S. and G. G. Fleener. 1988. Recreational use along the Missouri River in Missouri. Pages 67-78 *in* N. G. Benson, editor. The Missouri River – The Resources, Their Uses and Values. North Central Division of the American Fisheries Society Special Publication 8. American Fisheries Society, Bethesda, Maryland.

Wilde, G. R. and R. B. Ditton. 1999. Differences in attitudes and fishing motives among Texas catfish anglers. Pages 395-405 *in* E. R. Irwin, W. A. Hubert, C. F. Rabeni, H. L. Schramm, Jr., and T. Coon, editors. Catfish 2000: Proceedings of the International Ictalurid Symposium. American Fisheries Society, Symposium 24, Bethesda, Maryland.

Wilde, G. R., and R. K. Riechers. 1994. Demographic and social characteristics and management preferences of Texas freshwater catfish anglers. Proceedings of the Annual Conference Southeastern Association of Fish and Wildlife Agencies 46:393-401.

Tables

Table 1. River reaches not considered during site selection.

River	Unsuitable Areas to be Avoided	River Miles Excluded from the Random Site Selection Process
Mississippi River	Ohio River Confluence – LMR RM 932-952 & UMR RM 0-35	LMR RM 913-952 & UMR RM 0-35
Mississippi River	St. Louis Riverfront – UMR RM 169-180	UMR RM 150-180
Mississippi River	Mel Price Lock & Dam – UMR RM 201	UMR RM 182-201
Mississippi River	Lock & Dam 25 – UMR RM 242	UMR RM 223-246
Mississippi River	Lock & Dam 24 – UMR RM 274 (Upstream Boundary)	UMR RM 255-274
Missouri River	Osage River Confluence – MOR RM 115-130	MOR RM 96-130
Missouri River	Kansas City Riverfront – MOR RM 360-380	MOR RM 341-380
Missouri River	MO-IA Border – MOR RM 553 (Upstream Boundary)	MOR RM 534-553

Table 2. Study sites and corresponding river miles.

River	Sites	From (Downstream Boundary)	To (Upstream Boundary)
Mississippi River	Site 1 – Donaldson Point to Hickman Bend	LMR RM 902	LMR RM 922
Mississippi River	Site 2 – Picayune Chute to Grand Tower	UMR RM 61	UMR RM 81
Mississippi River	Site 3 – Chester to Ste. Genevieve	UMR RM 105	UMR RM 125
Mississippi River	Site 4 – Norton Wood Access to Lock & Dam 24	UMR RM 253.4	UMR RM 273.4
Missouri River	Site 5 – St. Charles to Weldon Springs	MO RM 25	MO RM 45
Missouri River	Site 6 – Lamine River to Lisbon Bottoms	MO RM 200	MO RM 220
Missouri River	Site 7 – Cranberry Bend to Lexington	MO RM 290	MO RM 310
Missouri River	Site 8 – Bob Brown to Thurnau	MO RM 487	MO RM 507

Table 3. Average age (years) for blue catfish to reach various lengths and weights in the Mississippi River and Missouri River.

Total length (in)	Total length (mm)	Weight (lbs)	Age to reach size on the Mississippi River	Age to reach size Missouri River
15	381	1	4	5
18	457	2	5	6
24	610	5	8	9
30	762	10	11	12
38	965	20	17	18

Table 4. Sample sizes and mean total lengths by age estimates from spines of blue catfish in the Mississippi River and Missouri River. Two standard errors are shown in parenthesis.

Age (years)	Sample Size - Mississippi River	Sample Size - Missouri River	Mean Total Length (in) - Mississippi River	Mean Total Length (in) - Missouri River	Mean Total Length (mm) - Mississippi River	Mean Total Length (mm) - Missouri River
1*	14	0	9.5 (0.7)		241 (17.9)	
2	92	50	9.9 (0.4)	8.3 (0.3)	252 (9.9)	210 (6.7)
3	90	51	12.8 (0.6)	10.9 (0.5)	325 (15.8)	278 (13.1)
4	89	70	14.8 (0.7)	12.6 (0.4)	377 (17.7)	319 (10.7)
5	83	138	18.1 (0.7)	16.5 (0.4)	459 (17.6)	420 (10.9)
6	65	105	20.7 (1.0)	19.1 (0.6)	525 (24.3)	485 (14.8)
7	70	62	22.7 (0.7)	21.5 (0.8)	577 (17.7)	547 (19.4)
8	77	80	24.8 (0.8)	23.2 (0.6)	631 (21.0)	589 (16.5)
9	84	90	27.3 (0.8)	25.2 (0.7)	693 (21.0)	641 (17.2)
10	66	102	30.2 (1.1)	27.5 (0.7)	766 (27.7)	699 (16.7)
11	34	76	31.7 (2.1)	29.1 (0.9)	804 (53.3)	739 (23.0)
12	31	52	34.4 (2.3)	30.4 (1.0)	875 (59.5)	772 (25.0)
13	23	46	35.0 (1.9)	32.4 (1.1)	890 (48.5)	823 (28.4)
14	23	50	38.4 (2.6)	33.7 (1.4)	976 (66.7)	855 (36.3)
15	9	19	37.7 (4.2)	36.3 (2.5)	958 (106.0)	923 (62.3)
16	6	14	38.7 (5.3)	39.8 (3.8)	984 (134.2)	1011 (95.8)
17	4	5	34.6 (8.8)	39.1 (5.3)	880 (224.0)	993 (133.9)
18	2	1	38.3 (14.7)	33.4	973 (374.2)	848
19	1	0	38.0		965	

* Mean length of age-1 is likely an overestimate because age structures were not collected from blue catfish <7 inches.

Table 5. Population parameters estimated for the blue catfish population in the Mississippi River and the Missouri River. Weight-length regression is with $\log_{10}$-transformed length (mm) and weight (g) data.

Parameter	Value - Mississippi River	Value - Missouri River
Weight-length regression slope (b)	3.4537	3.1408
Weight-length regression intercept (a)	-6.2563	-5.402
von Bertalanffy growth curve - L_∞	1242.8	1294.3
von Bertalanffy growth curve - K	0.0856	0.0773
von Bertalanffy growth curve - t_0	-0.7712	-0.0612
Weighted catch curve - Z	-0.4811	-0.4307
Weighted catch curve - Max age	21.7	23.4

Table 6. Number of standard-reward ($25) and high-reward ($150) tags marked and reported prior to January 2019 and estimated standard tag reporting rate by river, permit type, and site.

River / Site	Marked $25	Marked $150	Reported $25	Reported $150	Reporting Rate
Mississippi River	529	230	85	45	0.82
Recreational			62	33	0.82
Commercial			23	12	0.83
1	175	78	28	19	0.63
2	171	75	23	12	0.84
3	158	66	27	10	1.00
4	30	16	7	4	0.93
Missouri River	640	275	104	77	0.58
5	157	63	24	11	0.88
6	181	80	27	30	0.40
7	139	59	23	18	0.54
8	163	73	30	18	0.75

Table 7. Number of standard-reward ($25) and high-reward ($150) tags harvested and caught and released within 365 days post-tagging and estimates of total annual exploitation by river, permit type, and site.

River / Site	Harvested $25	Harvested $150	Caught and Released $25	Caught and Released $150	Exploitation Rate
Mississippi	44	22	4	4	0.10
Recreational	28	12	3	4	0.062
Commercial	16	10	1	0	0.039
1	17	11	2	0	0.15
2	12	2	1	4	0.068
3	11	6	1	0	0.077
4	4	3	0	0	0.16
Missouri	49	27	10	11	0.127
5	12	6	3	1	0.092
6	13	13	1	6	0.18
7	8	4	0	1	0.096
8	16	4	6	3	0.11

Table 8. Size-specific exploitation rates of blue catfish on the Mississippi River and Missouri River. Exploitation rates of blue catfish 25 inches and larger is also presented and were the estimates used to separate total mortality estimates into fishing and natural mortality components.

Size (inches)	**Exploitation Rate -** Missouri	**Exploitation Rate -** Mississippi Scenario 1	**Exploitation Rate -** Mississippi Scenario 2
Overall	0.127	0.100	0.137
15-16.9	0.037	0.053	0.053
17-18.9	0.041	0.064	0.064
19-20.9	0	0.049	0.049
21-22.9	0.044	0.11	0.11
23-24.9	0.10	0.076	0.076
25-26.9	0.17	0.21	0.21
27-28.9	0.14	0.15	0.15
29-30.9	0.20	0.050	0.077
31-32.9	0.35	0.020	0.027
33-34.9	0.29	0.13	0.19
35-39.9	0.14	0.22	0.33
40+	0.13	0.09	0.13
≥25	0.177	0.141	0.188

Table 9. Gear-specific exploitation rates of blue catfish on the Mississippi River and Missouri River.

Method	Mississippi River Harvested	Mississippi River Released	Mississippi River Exploitation Rate	Missouri River Harvested	Missouri River Released	Missouri River Exploitation Rate
Bank Pole	2	0	0.0032	14	3	0.020
Gill Net	1	0	0.0016			
Hoop Net	5	0	0.0077			
Jug Line				9	1	0.013
Limb Line	4	1	0.0058	3	0	0.006
Rod/Reel	17	6	0.026	22	11	0.037
Trammel Net	4	0	0.0058			
Trot Line	33	1	0.050	28	6	0.046

Table 10a. Conditional natural mortality rates (cm) and conditional fishing mortality rates (cf) by age-classes used for Missouri River dynamic pool models.

Age from	Age to	Cm	Cf
0	0	0	0
1	8	0.2	0.05
9	11	0.2	0.22
12	14	0.2	0.38
15	23	0.2	0.15

Table 11b. Conditional natural mortality rates (cm) and conditional fishing mortality rates (cf) by age-classes used for Mississippi River scenario 1 dynamic pool models.

Age from	Age to	Cm	Cf
0	0	0	0
1	7	0.25	0.09
8	9	0.25	0.22
10	11	0.25	0.05
12	22	0.25	0.18

Table 12c. Conditional natural mortality rates (cm) and conditional fishing mortality rates (cf) by age-classes used for Mississippi River scenario 2 dynamic pool models.

Age from	Age to	Cm	Cf
0	0	0	0

Age from	Age to	Cm	Cf
1	7	0.2	0.09
8	9	0.2	0.30
10	11	0.2	0.06
12	22	0.2	0.26

Table 13. Pounds of blue catfish commercially harvested and number of commercial blue catfish harvesters from the Mississippi River and from each study site annually from 2015-2018 (unpublished data). *2018 includes preliminary data.

Location	2015 Harvest (lbs.)	2015 Harvesters (No.)	2016 Harvest (lbs.)	2016 Harvesters (No.)	2017 Harvest (lbs.)	2017 Harvesters (No.)	2018* Harvest (lbs.)	2018* Harvesters (No.)
Mississippi River	51,999	53	48,436	42	75,764	47	74,826	52
- **Site 1**	2,159	4	0	0	0	0	0	0
- **Site 2**	407	2	1,184	1	1,842	2	978	1
- **Site 3**	1,560	3	531	3	473	2	1,209	2
- **Site 4**	591	4	99	4	1,167	8	2,748	10

Figures

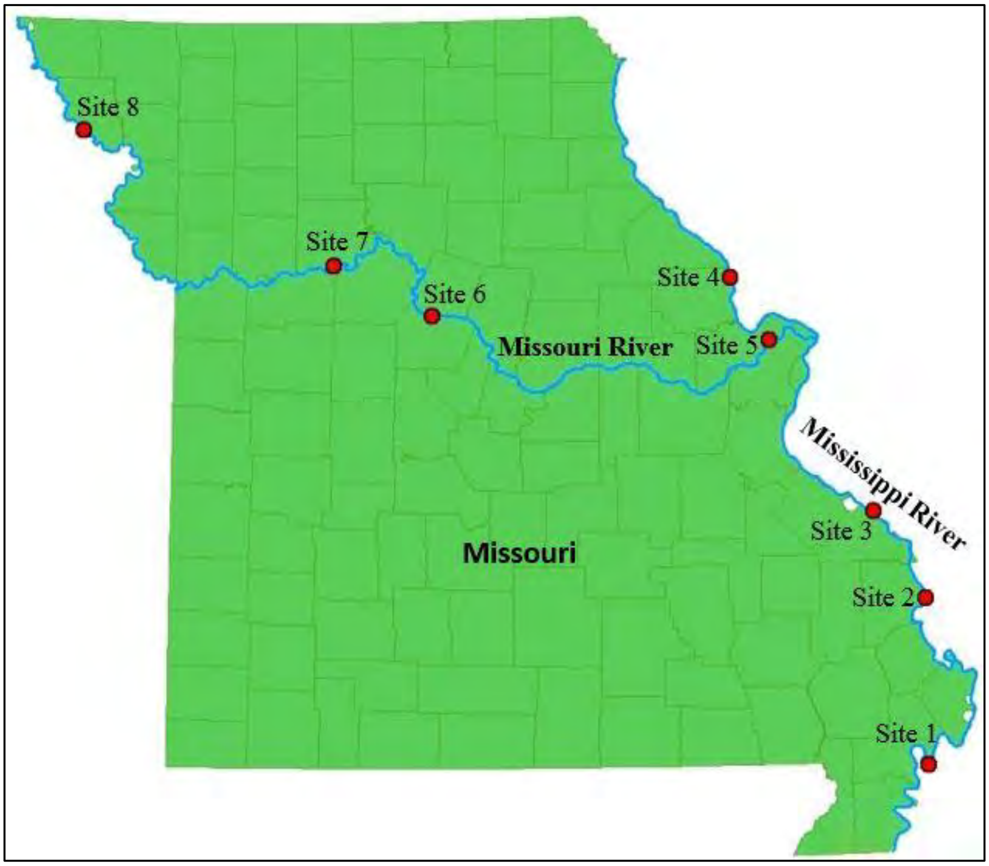

Figure 1. Map of study sites.

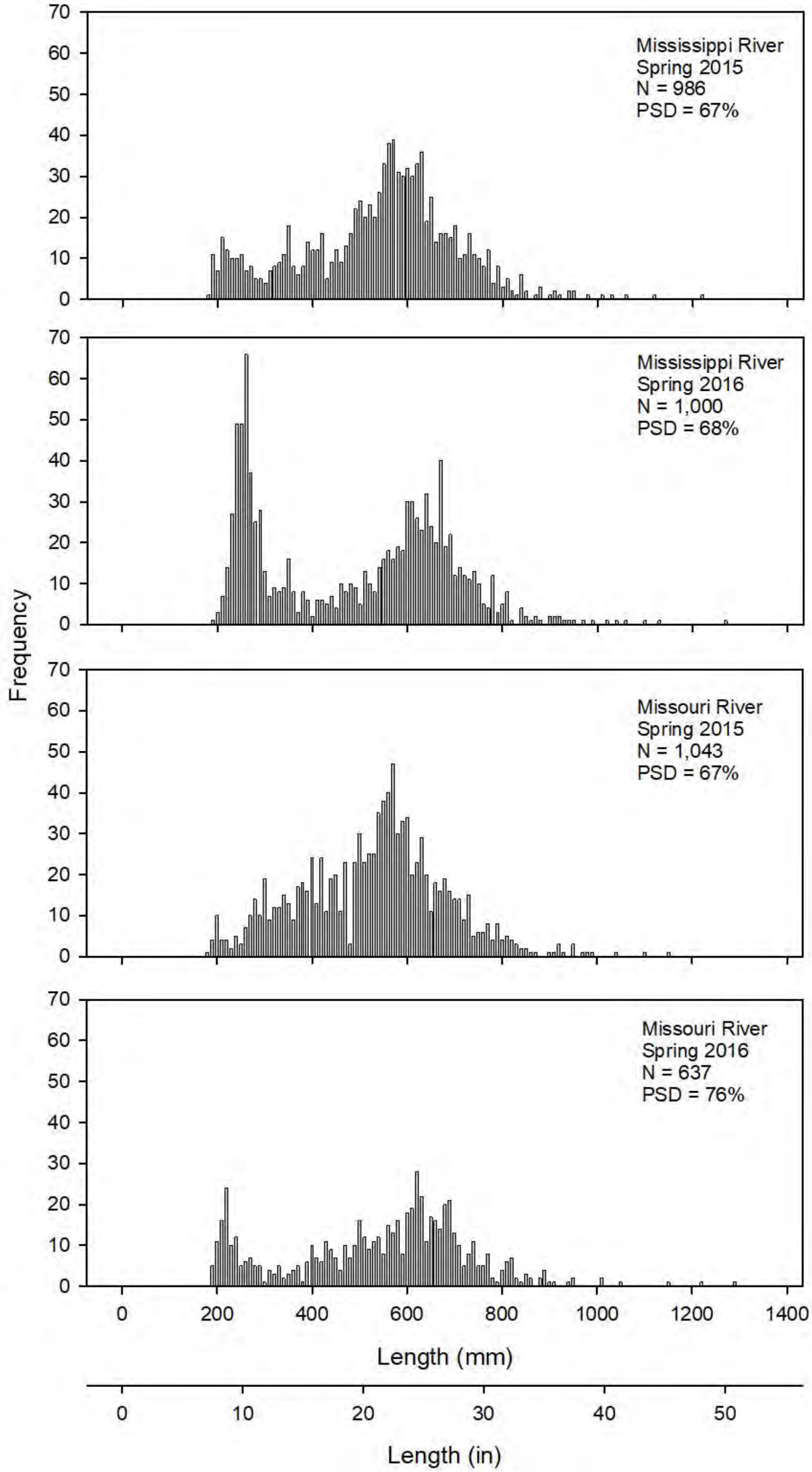

Figure 2. Length-frequency distributions of blue catfish collected during standard, random electrofishing sampling.

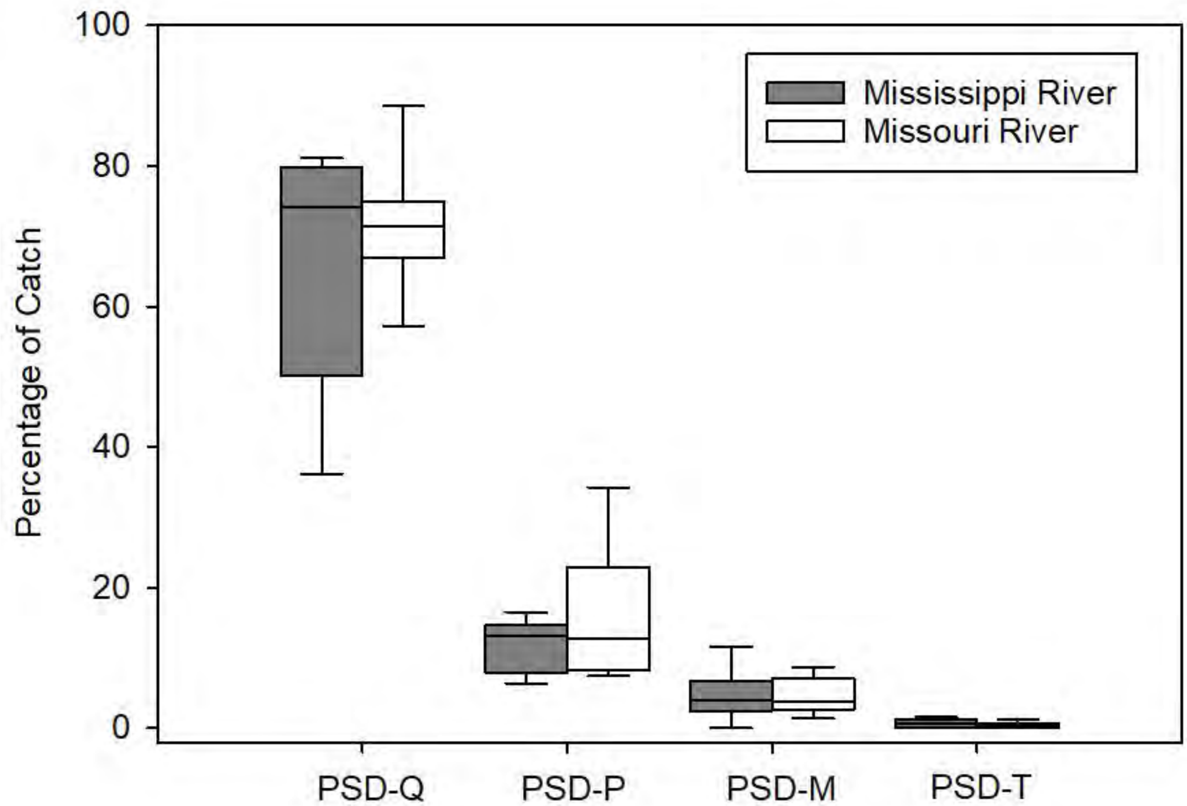

Figure 3. Proportional-size distributions of blue catfish collected in the Mississippi River and the Missouri River. PSD indices were calculated using blue catfish length categories described by Anderson and Neumann (1996) as follows: stock (12 in or 300 mm), quality (20 in or 510 mm), preferred (30 in or 760 mm), memorable (35 in or 890 mm), and trophy (45 in or 1140 mm).

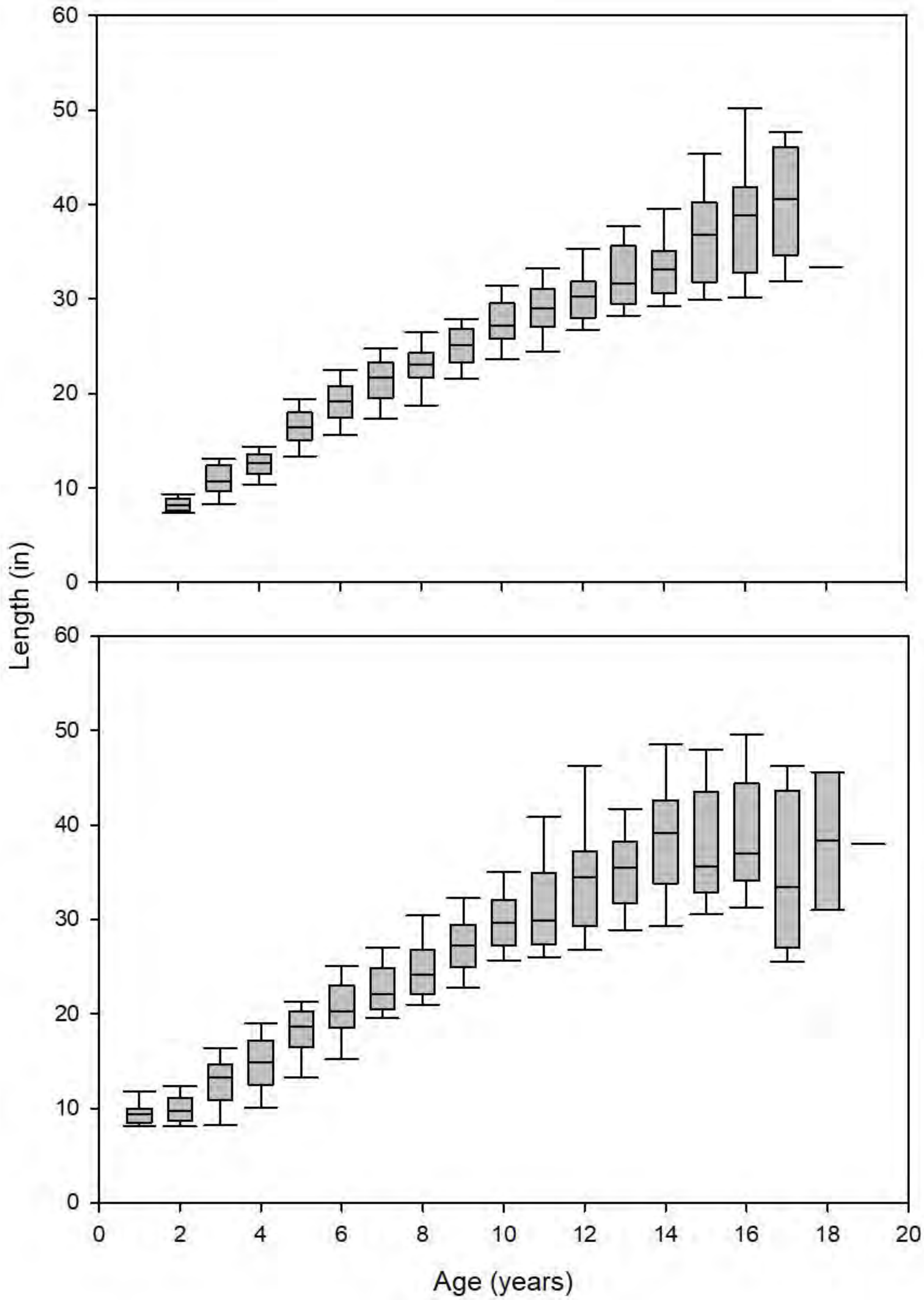

Figure 4. Boxplot of total length by estimated at age of blue catfish collected in the Missouri River (top panel) and the Mississippi River (bottom panel). Boxes represent upper and lower quartiles with the median depicted by the line within the box. Vertical error bars represent two standard errors.

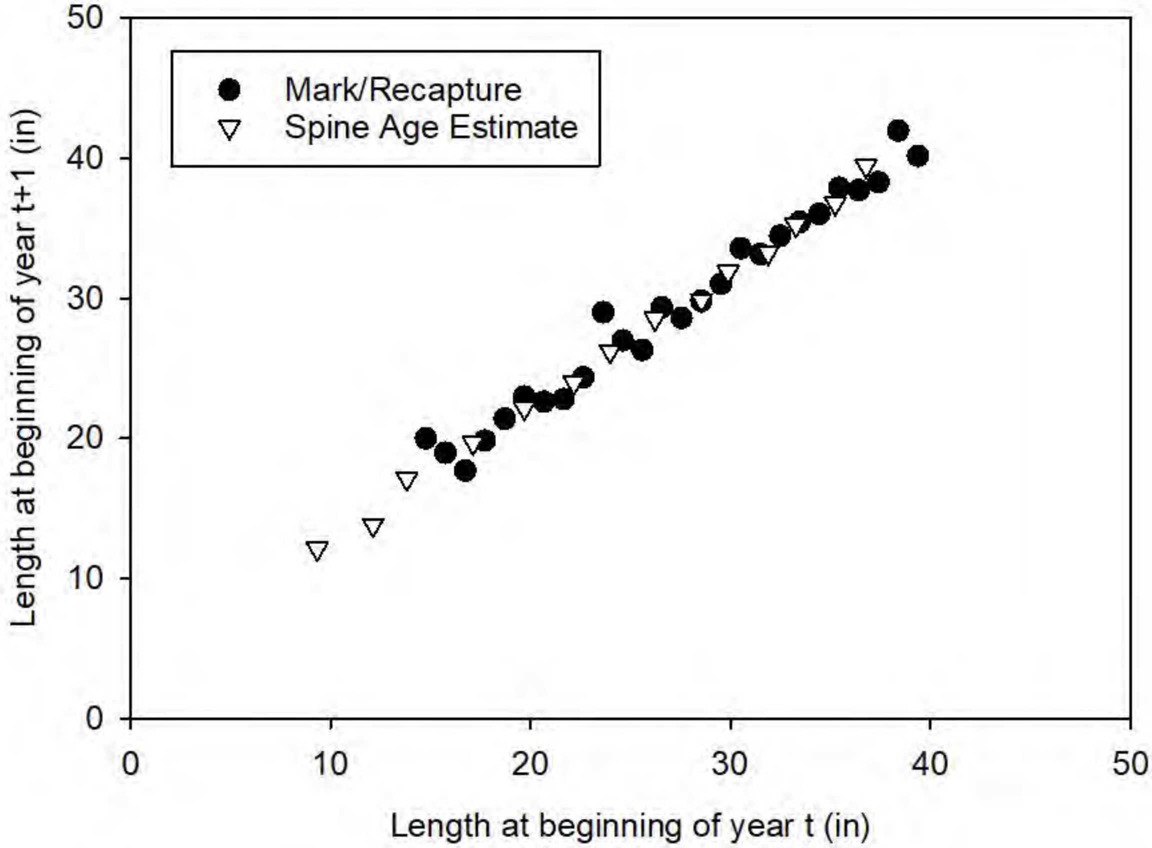

Figure 5. Annual growth increments of blue catfish calculated from tagged fish that were recaptured during subsequent years and from pectoral spine age estimates.

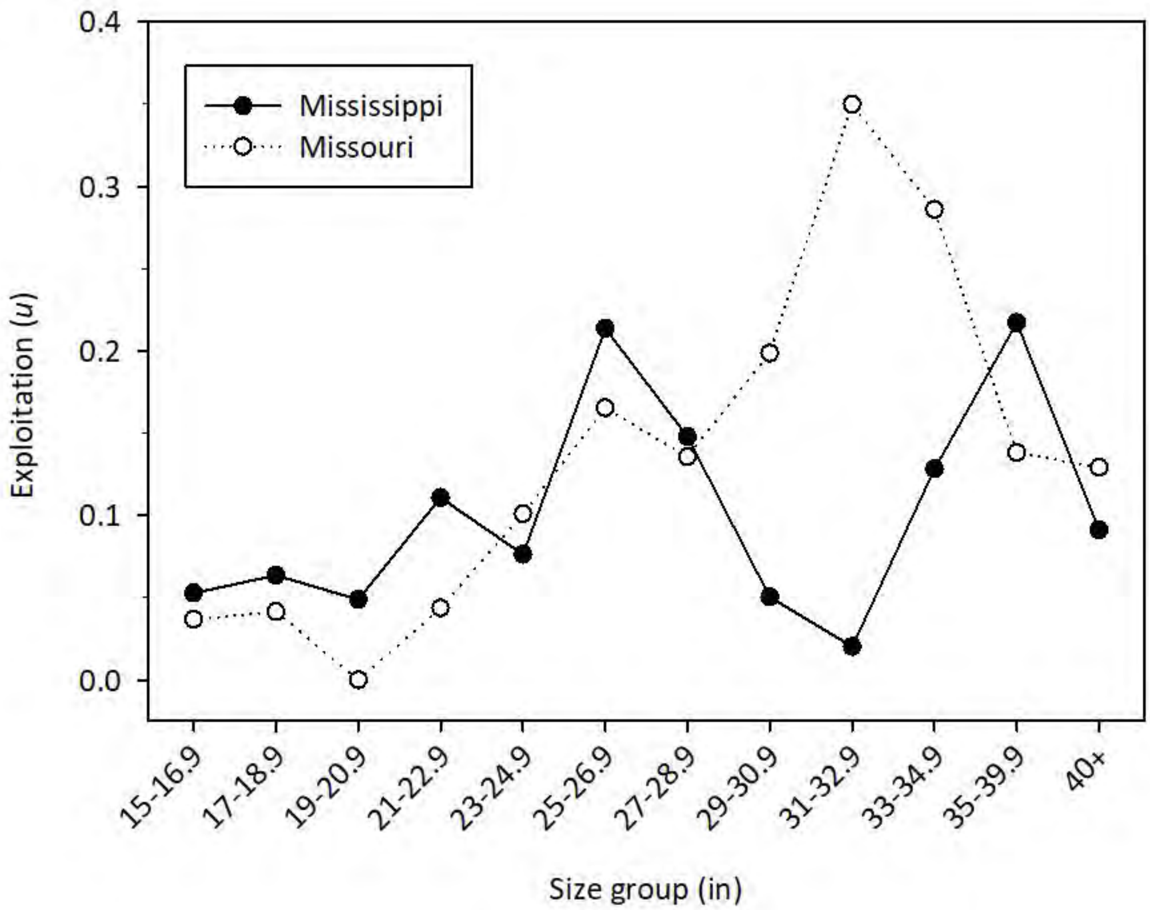

Figure 6. Exploitation of blue catfish by size group on the Mississippi River and Missouri River.

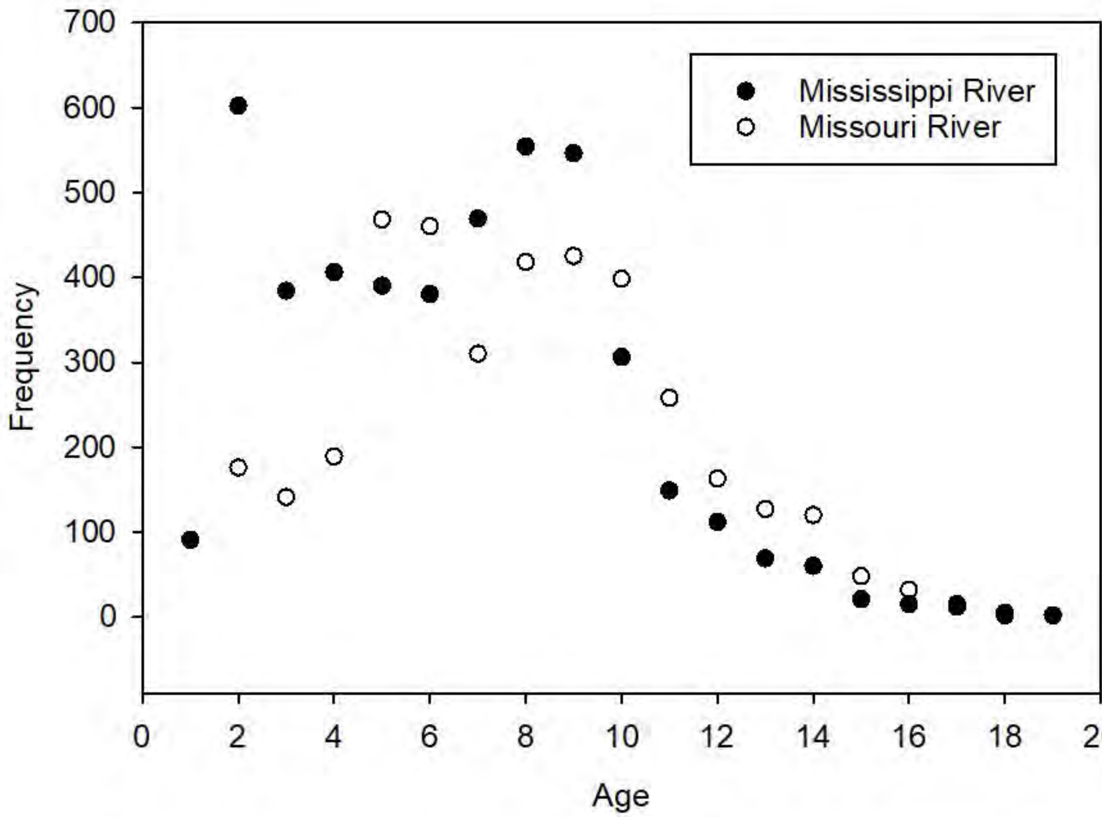

Figure 7. Age frequency plot of blue catfish collected during sampling in the Mississippi River and the Missouri River.

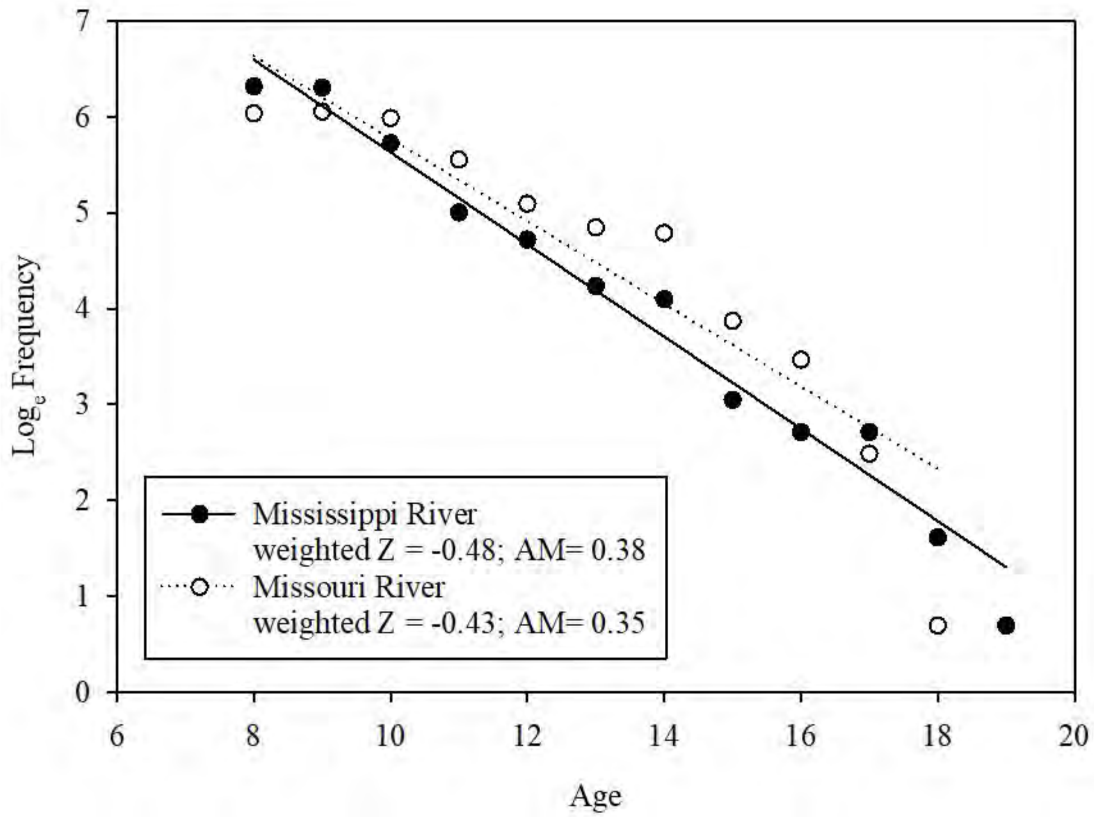

Figure 8. Weighted catch-curve for total annual mortality estimation of blue catfish in the Mississippi River and the Missouri River.

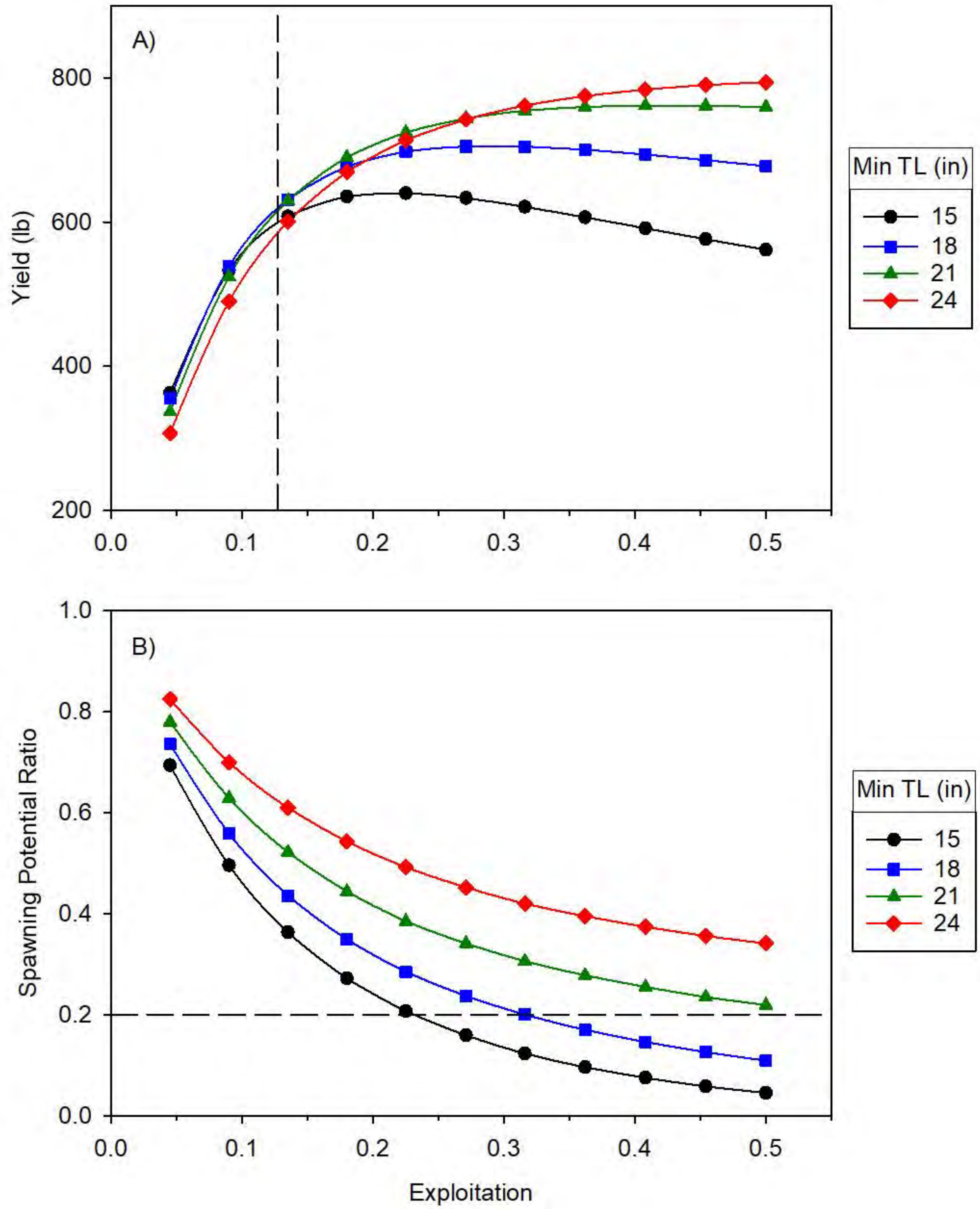

Figure 9. Missouri River. Yield-per-recruit model under varying minimum length limits with cm=0.20 and exploitation equal among all sizes. At current levels of exploitation (vertical dashed line) predicted yield was greatest with an 18 to 21-inch minimum length limit (panel A). Exploitation rates that would induce growth overfishing were identified by the descending limb of the yield curve. Recruitment overfishing was identified as the point where the spawning potential ratio dropped below 0.20 (horizontal dashed line; panel B).

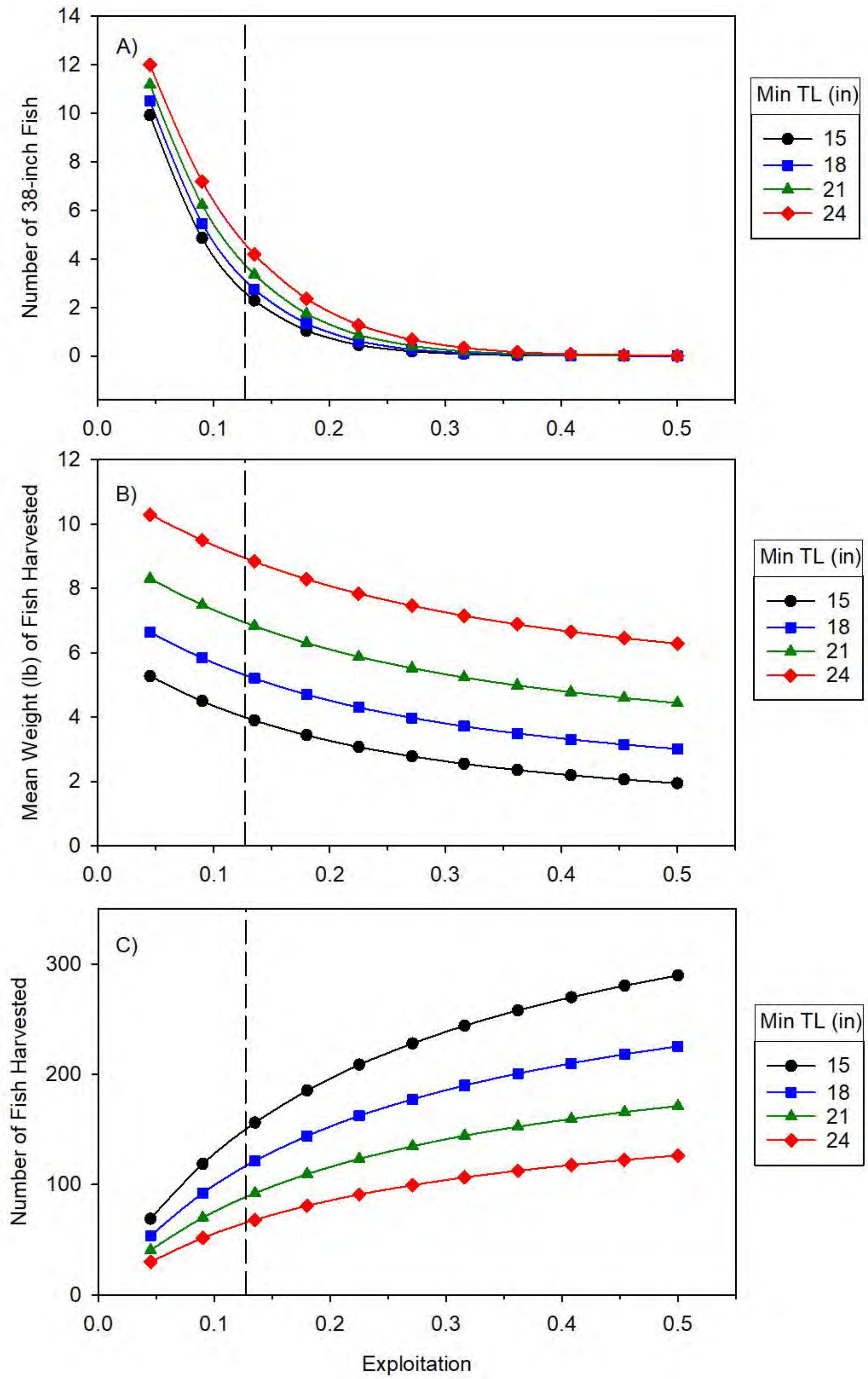

Figure 10. Missouri River. Yield-per-recruit model with cm=0.20 and exploitation equal among all sizes. Predicted number of trophy-size (38 inches) blue catfish (panel A), mean weight of fish harvested (panel B), and number of fish harvested (panel C) under varying minimum length limits. Estimates of overall of exploitation (12.7 percent) is depicted by the vertical dashed line in all panels.

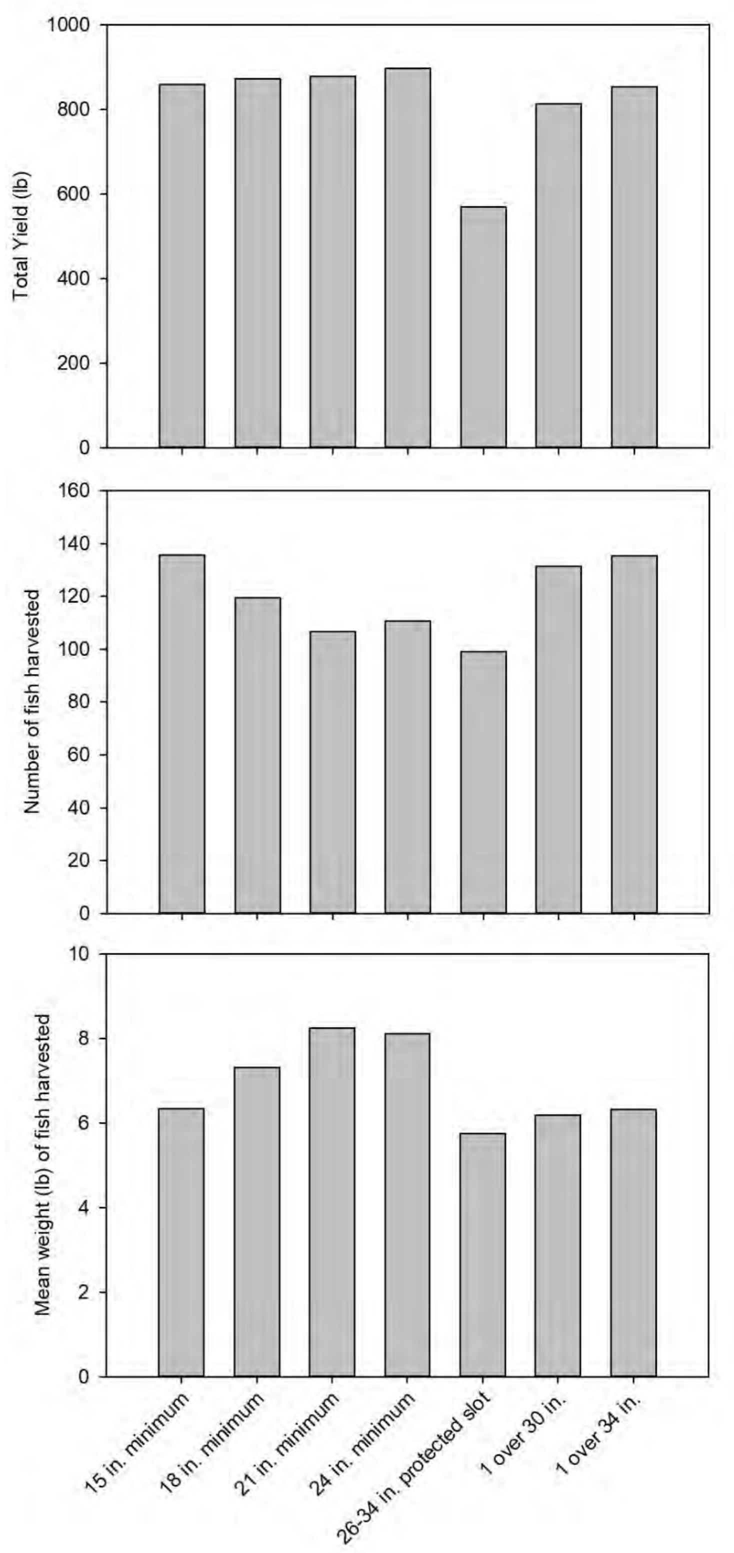

Figure 11. Missouri River. Comparison of the predicted yield (top panel), number of fish harvested (middle panel), and mean weight of fish harvested (bottom panel) from the dynamic-pool-model under various harvest regulations.

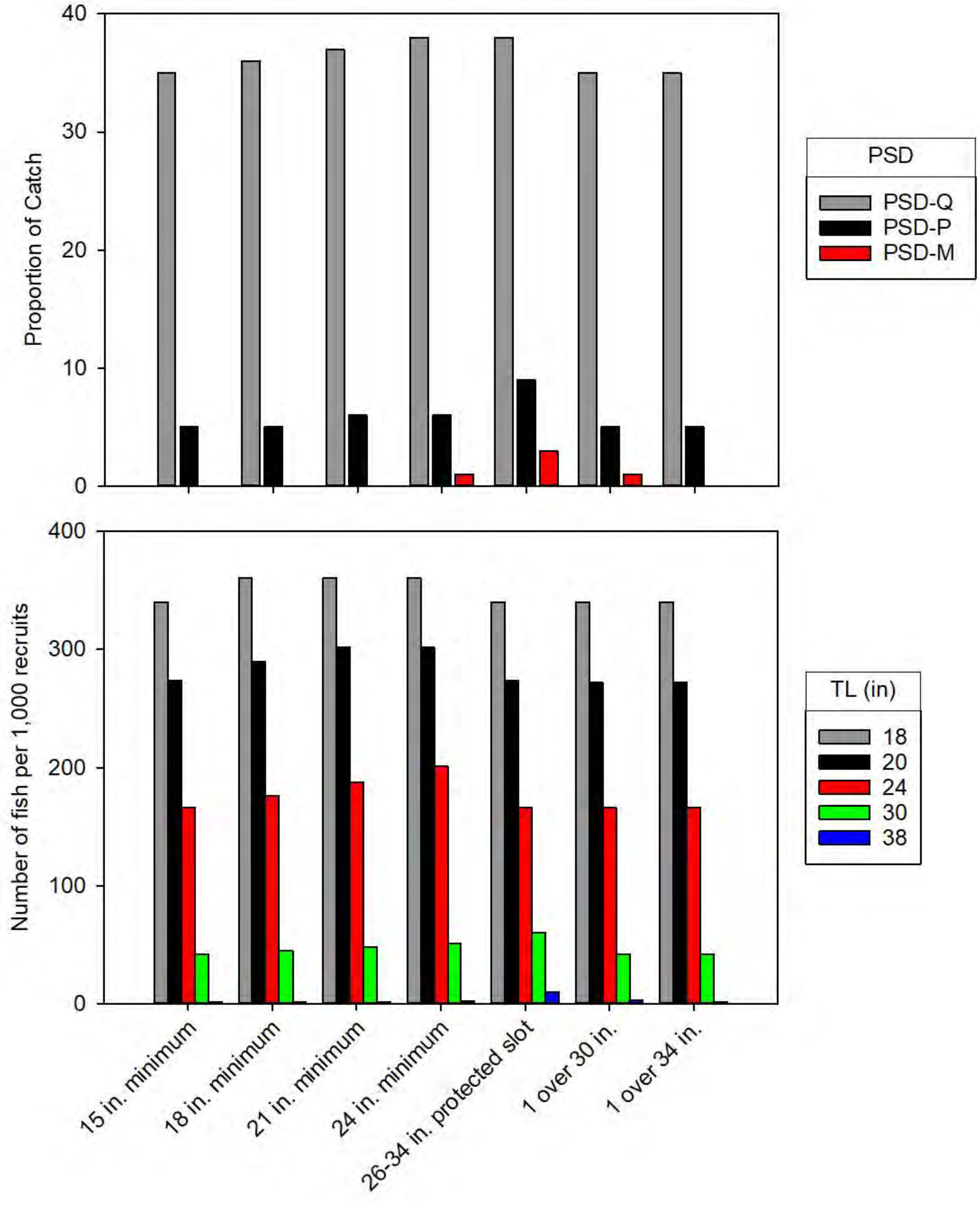

Figure 12. Missouri River. Comparison of the proportional size distributions (top panel) and number of fish at specific sizes (bottom panel) from the dynamic-pool-model under various harvest regulations.

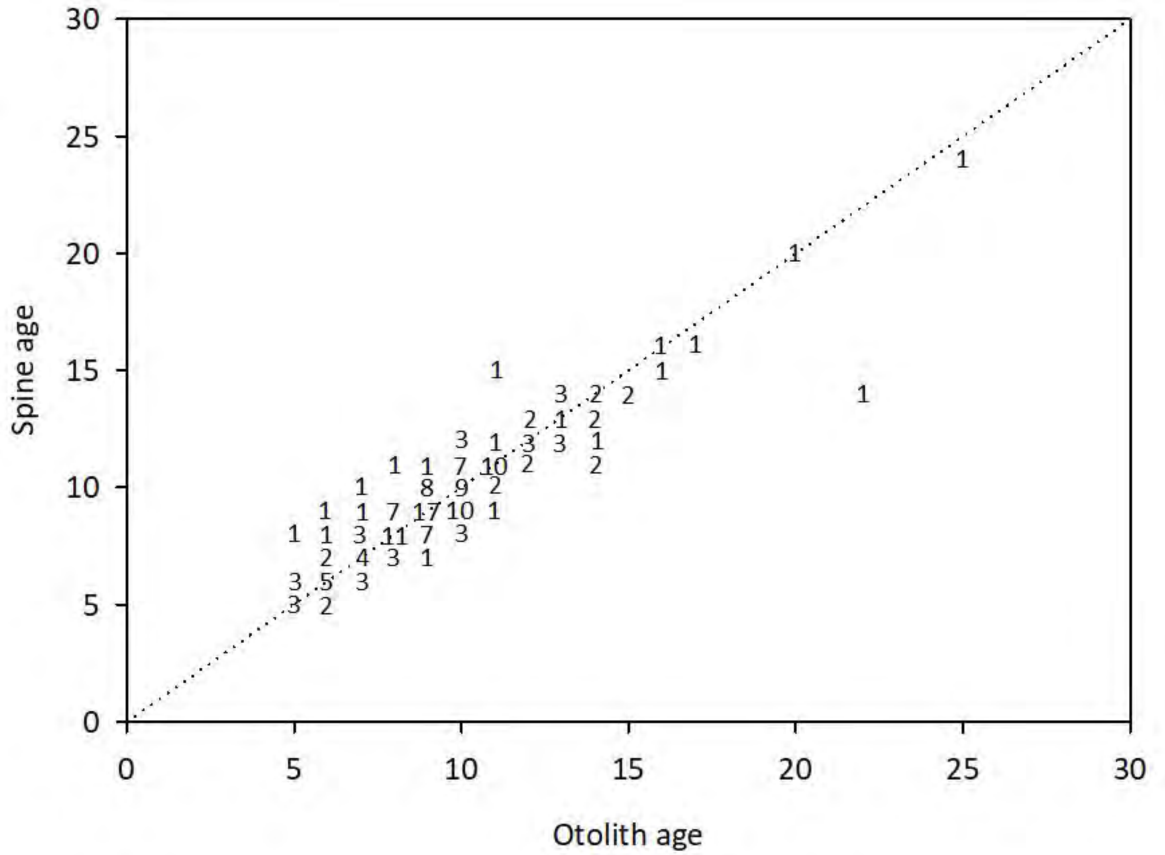

Figure 13. Age bias plot for age estimates of blue catfish (concert read) from otoliths and spine sections. Numbers indicate sample sizes. The dashed line represents agreement between age estimates.

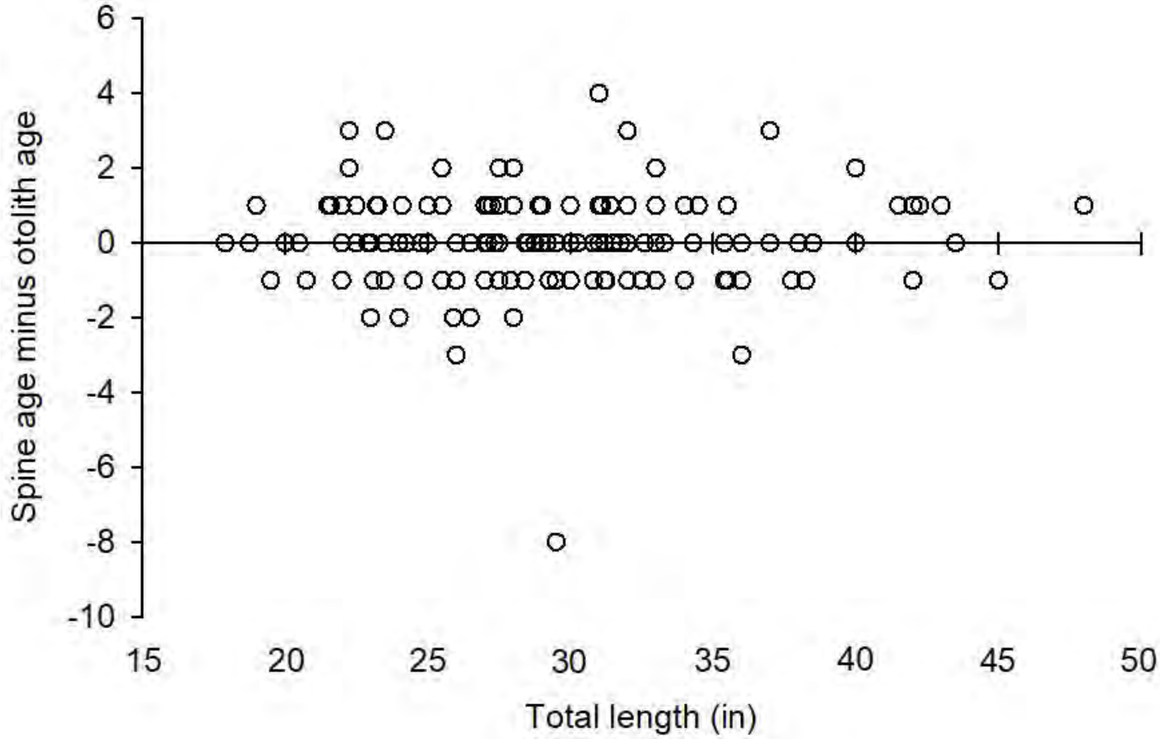

Figure 14. Differences between ages estimated from spine and otolith sections in relation to total length of blue catfish.

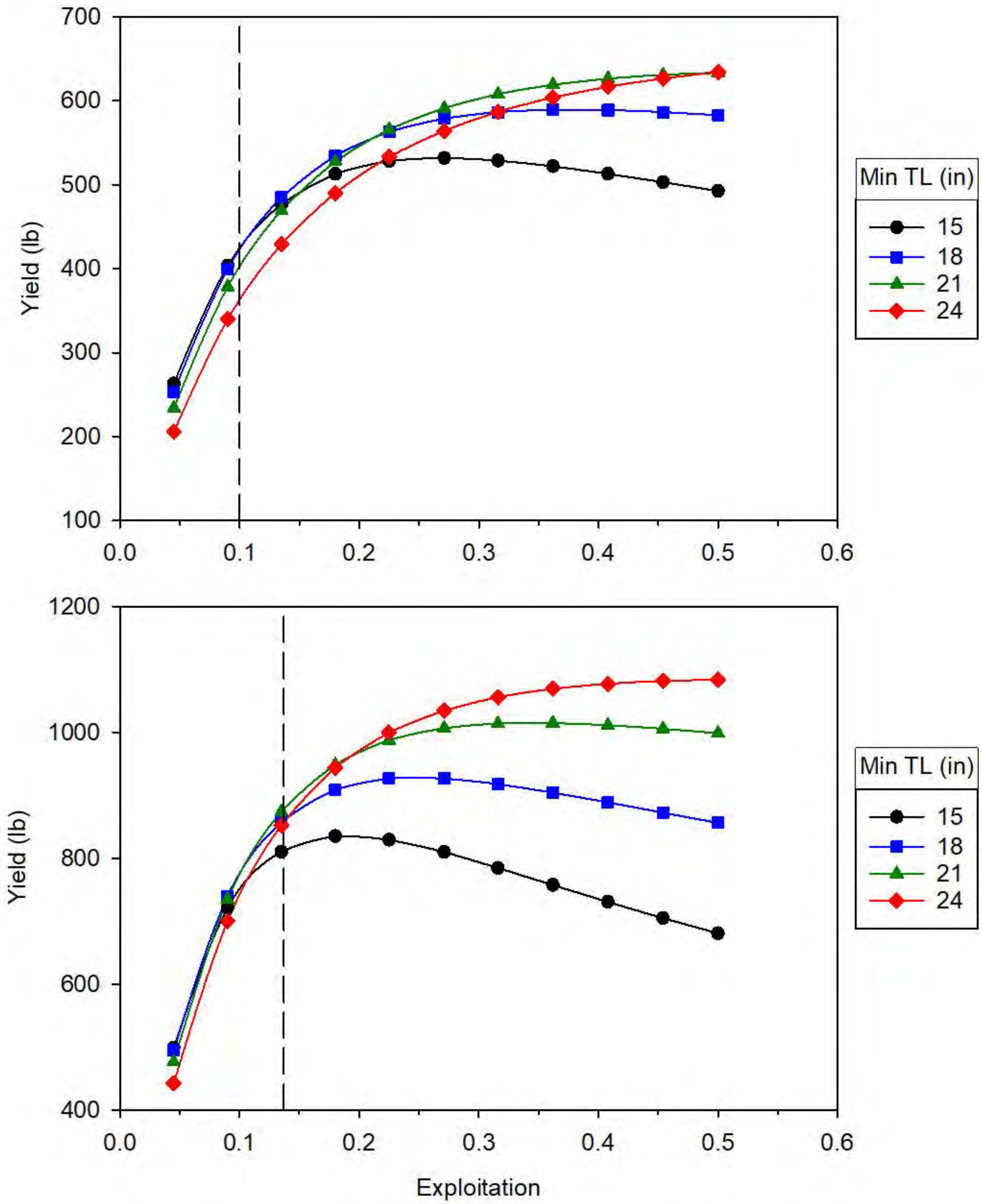

Figure 15. Mississippi River. Yield-per-recruit model for scenario 1 (top panel) and scenario 2 (bottom panel) under varying minimum length limits and exploitation equal among all sizes. At current levels of exploitation (vertical dashed line) predicted yield was greatest with an 18 or 21-inch minimum length limit. Exploitation rates that would induce growth overfishing were identified by the descending limb of the yield curve.

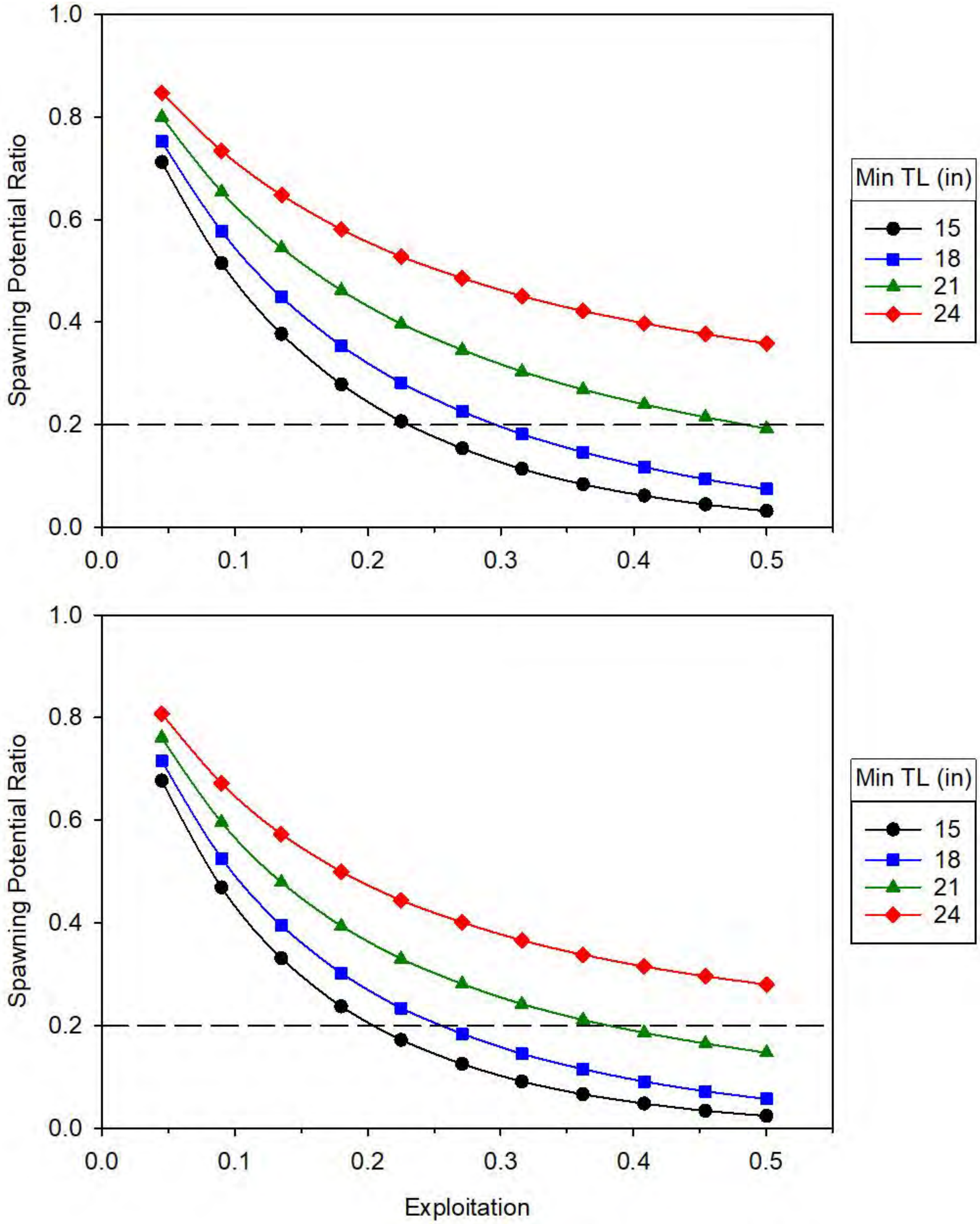

Figure 16. Mississippi River. Spawning potential ratio for scenario 1 (top panel) and scenario 2 (bottom panel) under varying minimum length limits and exploitation equal among all sizes. Recruitment overfishing was identified as the point where the spawning potential ratio dropped below 0.20 (horizontal dashed line).

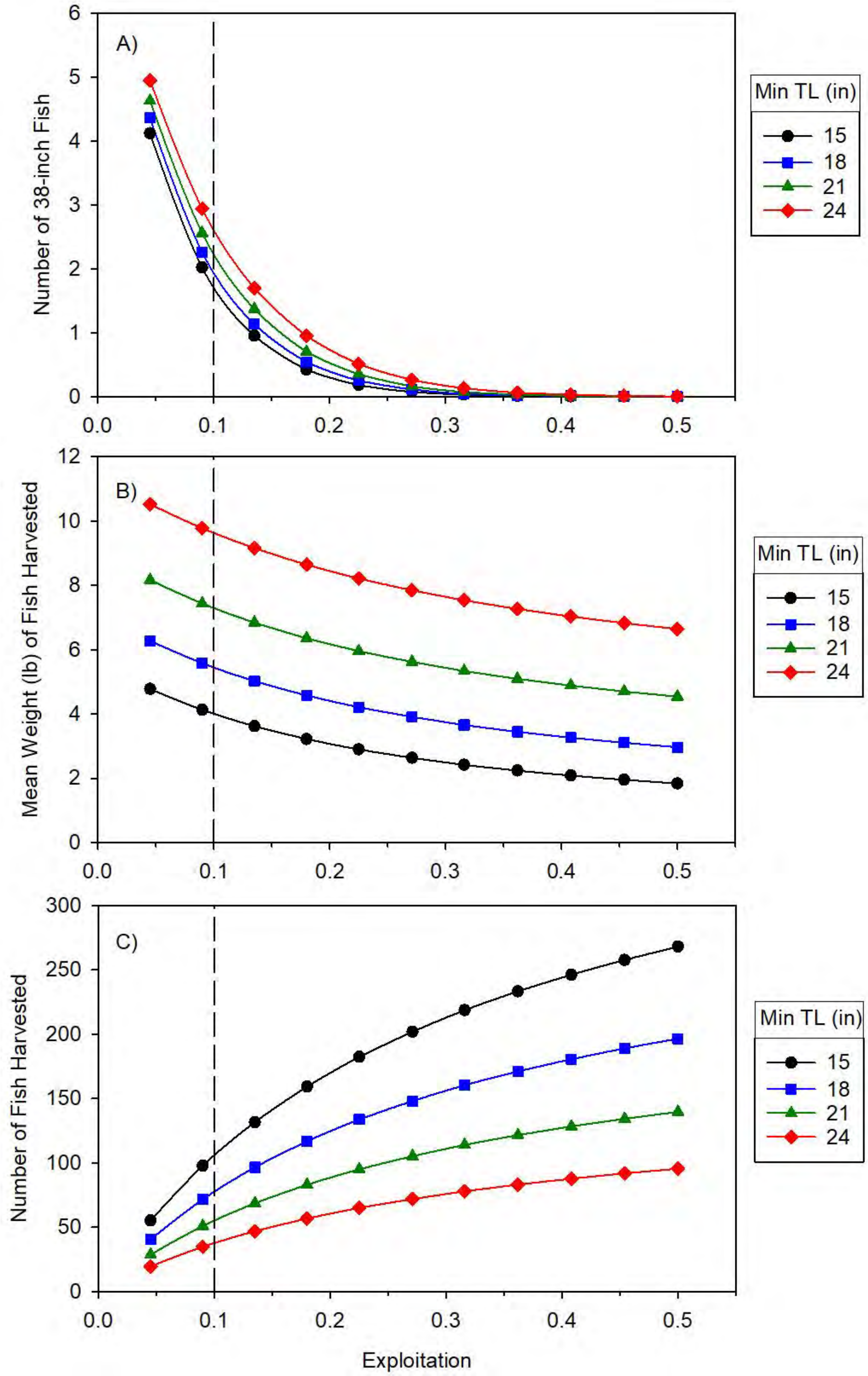

Figure 17. Mississippi River – scenario 1. Yield-per-recruit model with cm=0.25 and exploitation equal among all sizes. Predicted number of trophy-size (38 inches) blue catfish (A), mean weight of fish harvested (B), and number of fish harvested (C) under varying minimum length limits. Estimates of overall of exploitation (10.0 percent) is depicted by the vertical dashed line in all panels.

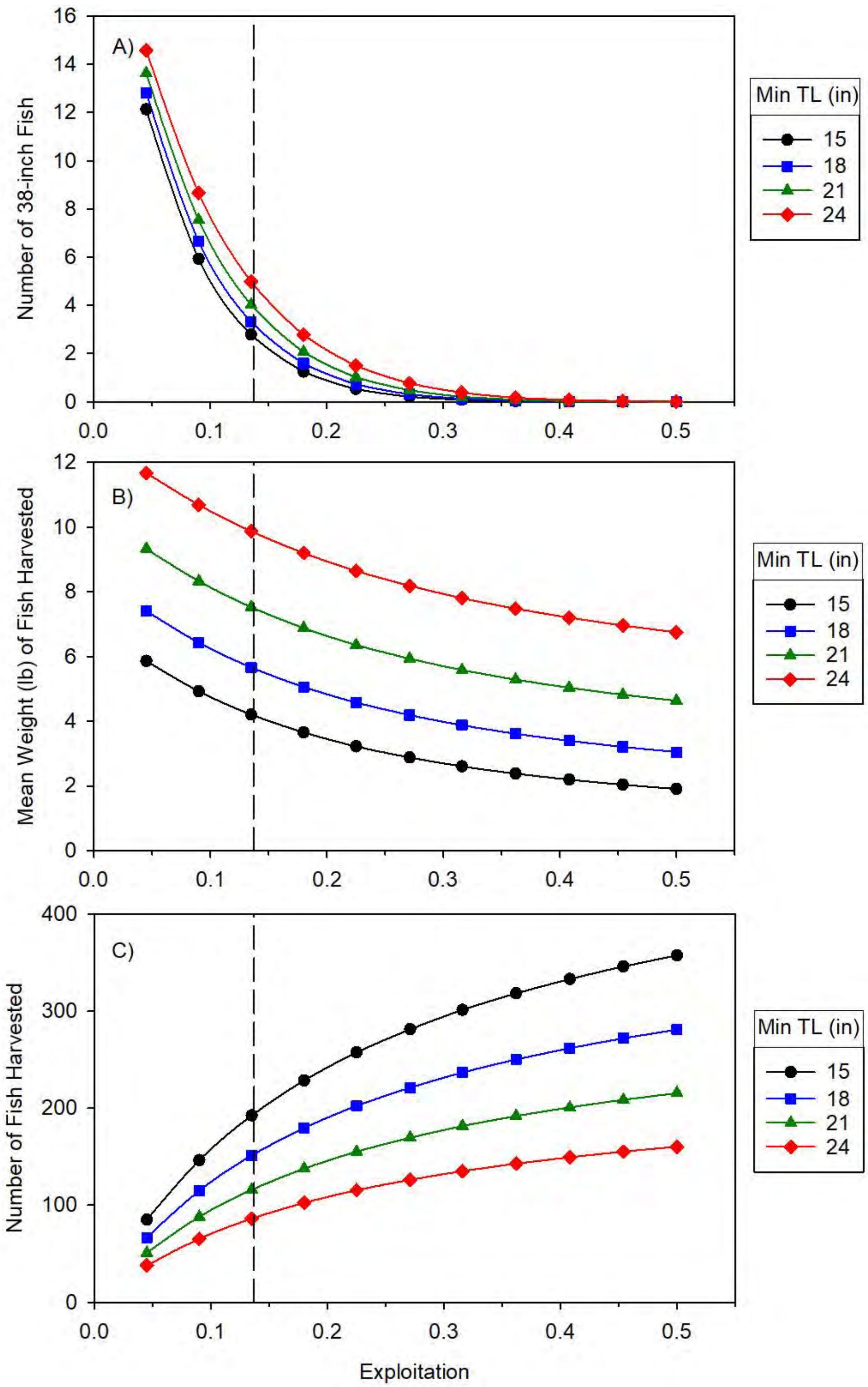

Figure 18. Mississippi River – scenario 2. Yield-per-recruit model with cm=0.20 and exploitation equal among all sizes. Predicted number of trophy-size (38 inches) blue catfish (A), mean weight of fish harvested (B), and number of fish harvested (C) under varying minimum length limits. Estimates of overall of exploitation (13.7 percent) is depicted by the vertical dashed line in all panels.

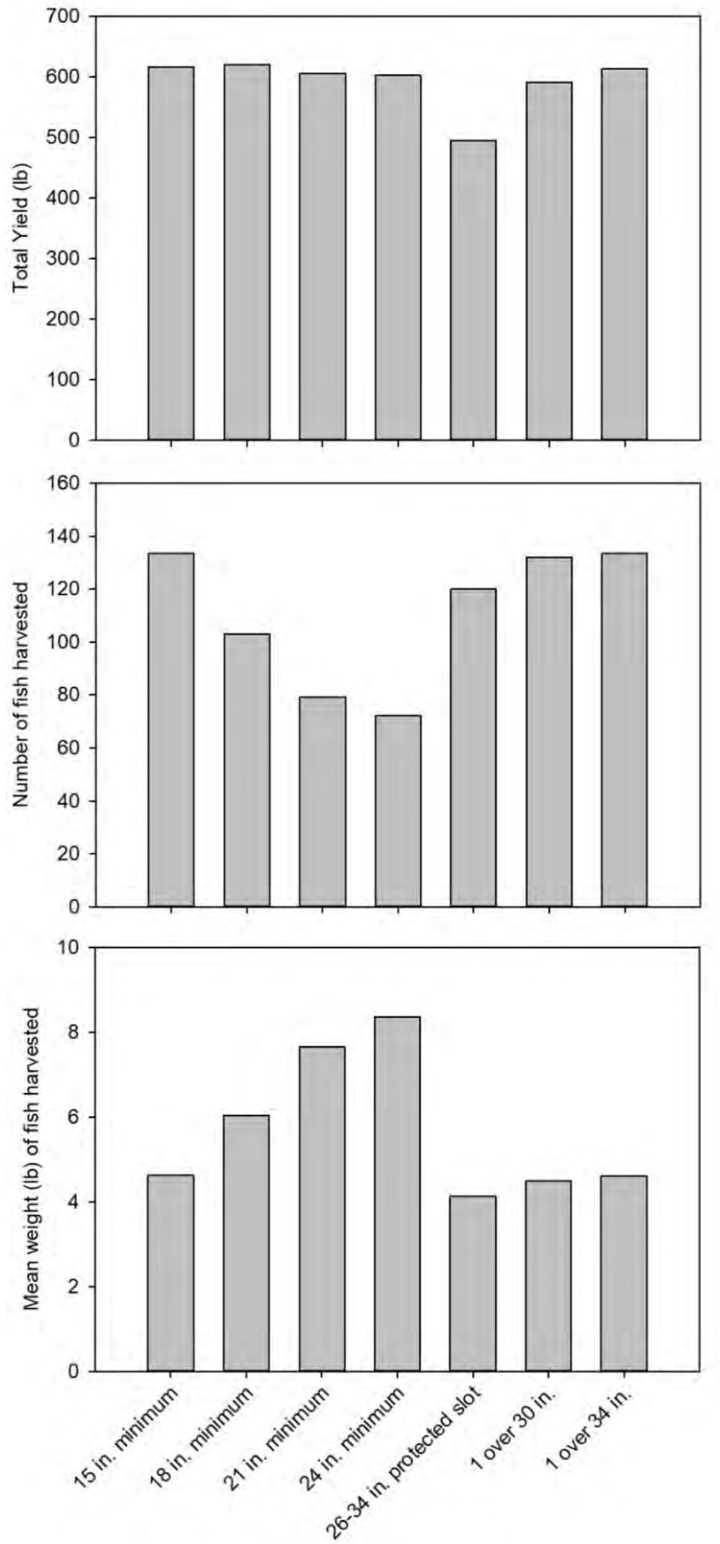

Figure 19. Mississippi River – scenario 1. Comparison of the predicted yield (top panel), number of fish harvested (middle panel), and mean weight of fish harvested (bottom panel) from the dynamic-pool-model under various harvest regulations.

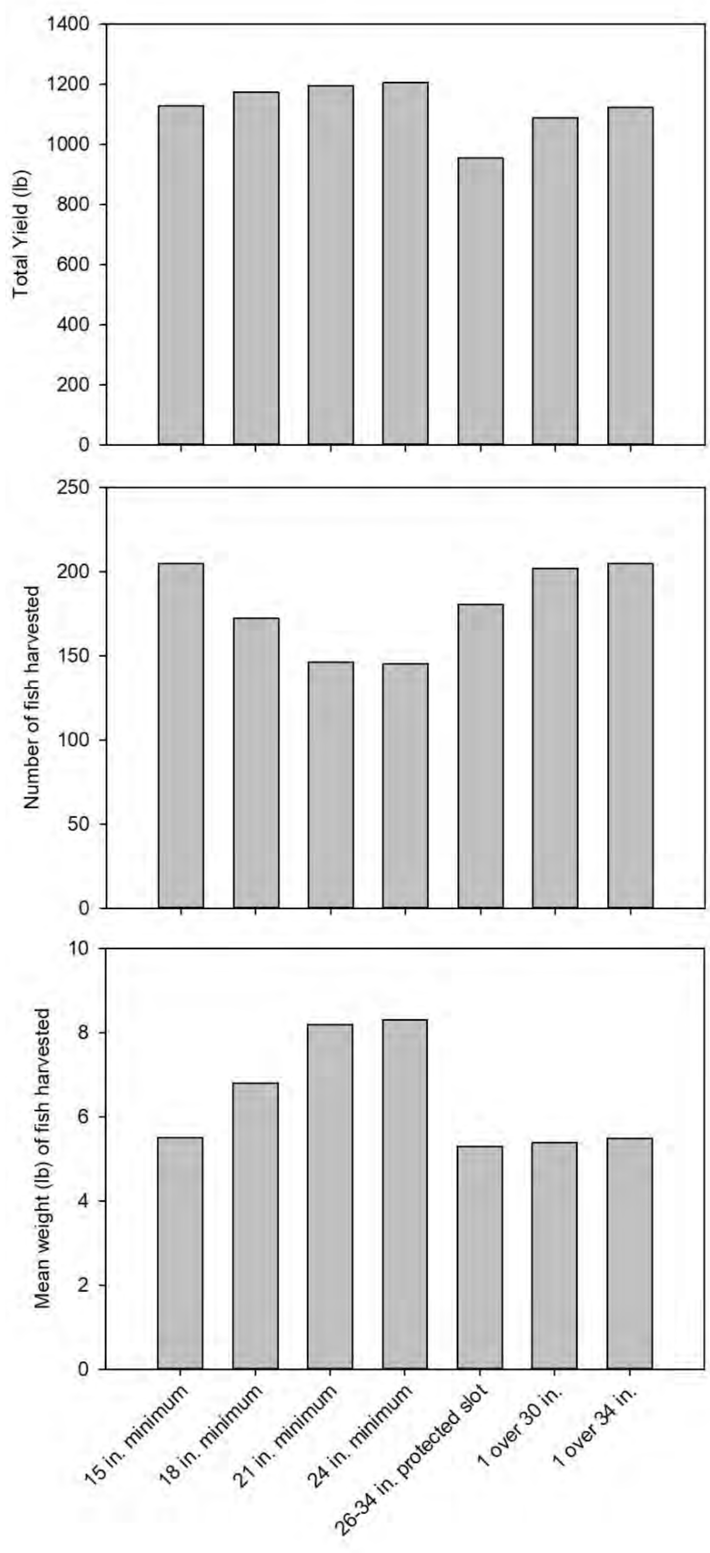

Figure 20. Mississippi River – scenario 2. Comparison of the predicted yield (top panel), number of fish harvested (middle panel), and mean weight of fish harvested (bottom panel) from the dynamic-pool-model under various harvest regulations.

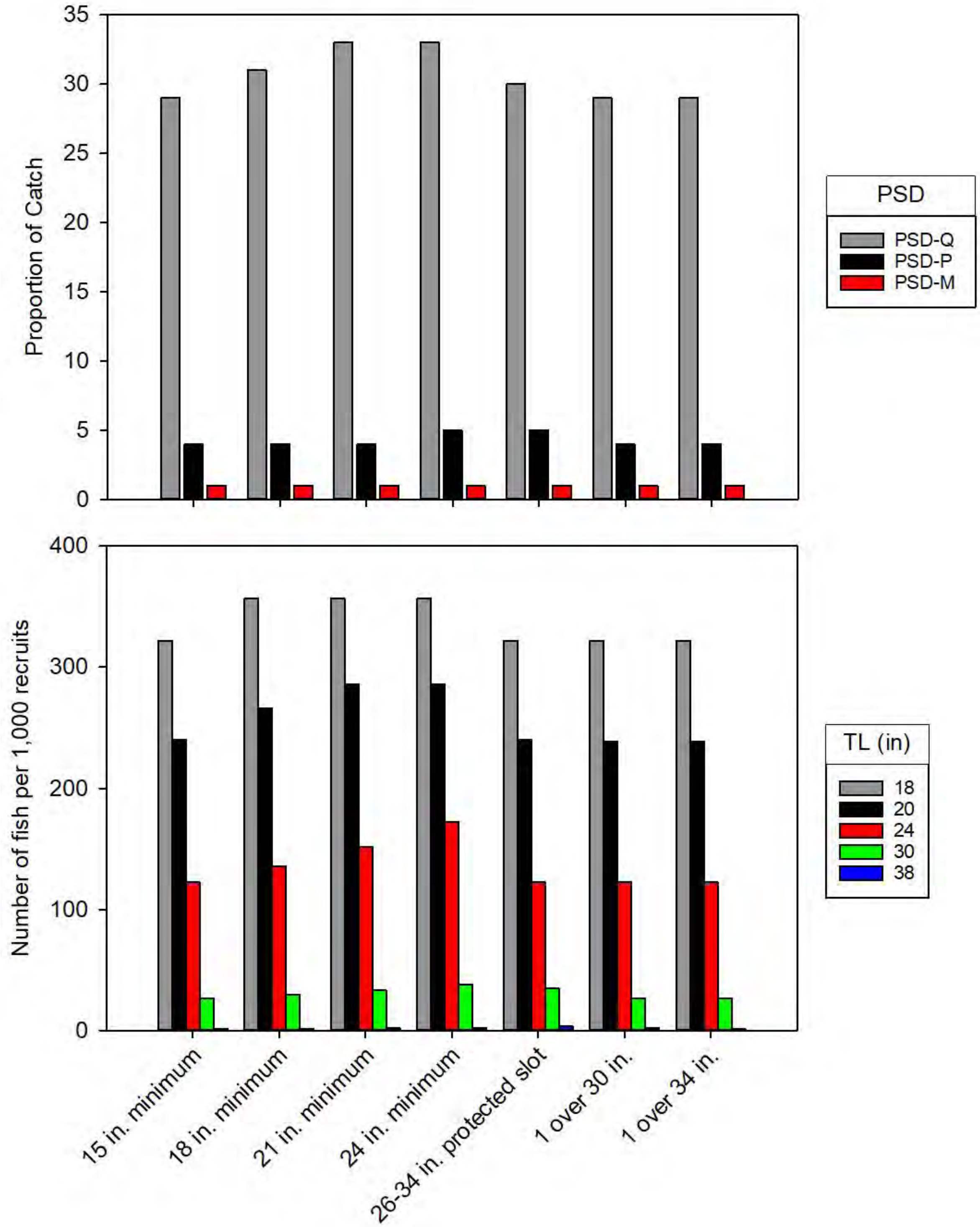

Figure 21. <u>Mississippi River – scenario 1.</u> Comparison of the proportional size distributions (top panel) and number of fish at specific sizes (bottom panel) from the dynamic-pool-model under various harvest regulations.

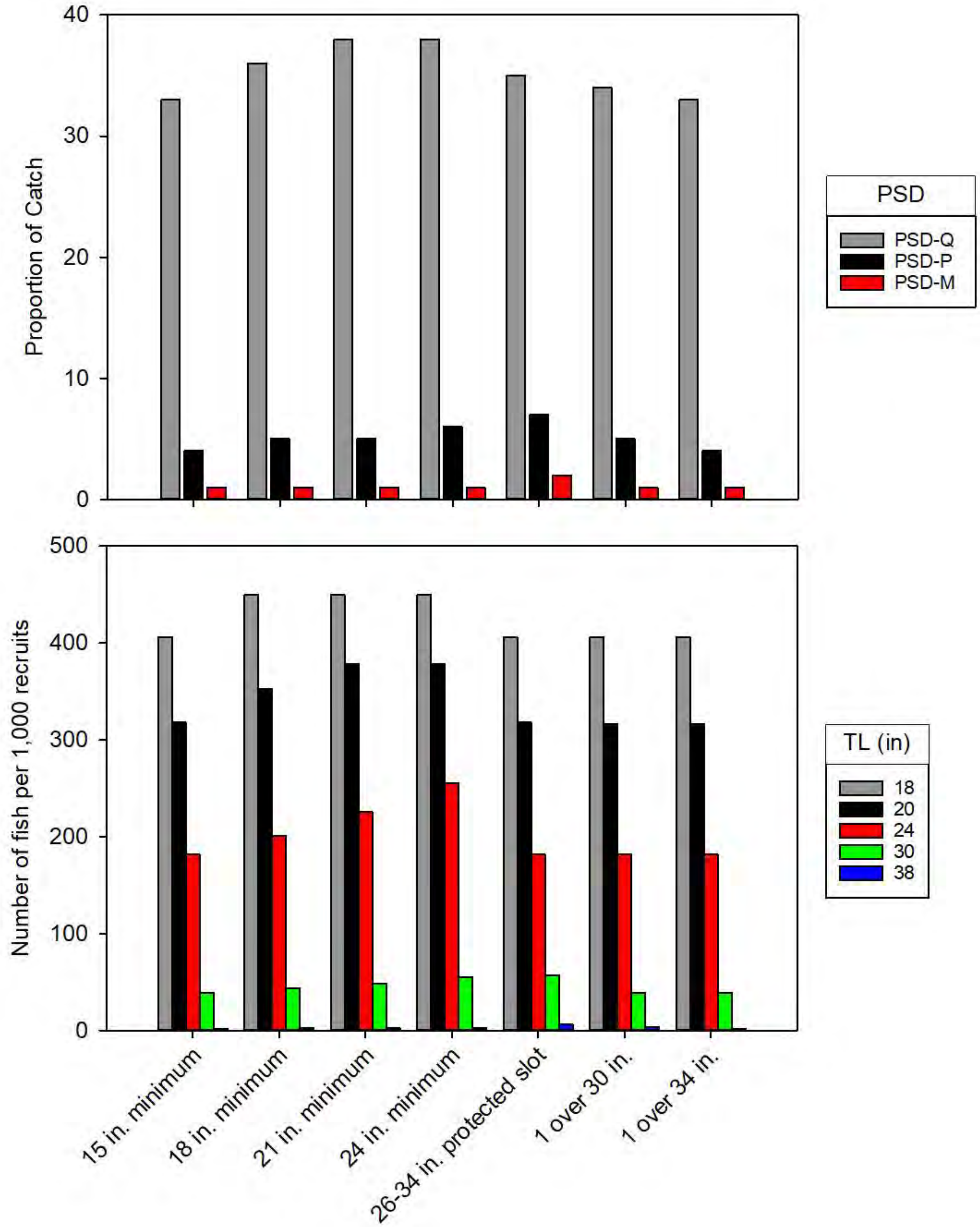

Figure 22. <u>Mississippi River – scenario 2.</u> Comparison of the proportional size distributions (top panel) and number of fish at specific sizes (bottom panel) from the dynamic-pool-model under various harvest regulations.

Appendices

Appendix 1. Sampling Protocols

Electrofishing requires potentially hazardous equipment; at least two crew members must acquire cardiopulmonary resuscitation and first aid certification prior to the commencement of sampling.

A data sheet is completed for each sampling run and habitats are sampled consistently.

Standard Random Sampling

Blue catfish and flathead catfish are collected during the spring and fall, respectively, at water temperatures ranging from ≈13 to 24^{o}C (55 to 75^{o}F). Catfish are collected from the Mississippi and Missouri rivers with low-frequency pulsed-DC (15 Hz; 30 percent duty cycle) boat electrofishing at 8 randomly selected sites during daylight hours. Each site is 32.2 river kilometers (20 river miles), of which, one-quarter (25 percent) will be randomly selected for standard sampling. Overall, 25 percent of all potential sampling run locations are randomly selected for standard sampling each calendar year. Standard sampling runs are temporally distributed so that the total effort equals approximately 90 minutes per week (power on time). Not more than one random sampling event (≈90 minutes shock time/25 percent of runs) will occur within a single week. Random run locations for standard sampling are proportionally distributed among habitat types within each site. Alternative random run locations are available for cases when priority random run locations are inaccessible or present a potentially hazardous situation.

Prior to electrofishing runs, ambient water conductivity is measured, or specific water conductivity and water temperature are measured and ambient water conductivity is calculated as $\mathbf{Ca} = \mathbf{Cs\ x\ 1.02}^{\wedge}(\mathbf{T}-\mathbf{25})$, where Ca is the ambient water conductivity, Cs is the specific water conductivity, and T is the water temperature **in °C**. Ambient water conductivity must be re-measured whenever water temperature changes >3^{o}C or at/near tributary mouths. For each run, the peak voltage goal is determined based on ambient water conductivity in order to standardize fish response (Table 1). The voltage meter readings on some electrofishing control boxes (e.g., VVP-15B) do not match actual peak output; therefore, boat specific meter readings are adjusted to produce actual peak outputs within 2 standard errors of the voltage goal (Table 2). Boats with electrofishing control boxes with accurate peak meter readings (e.g. Infinity, ETS) should be used if available.

The total length (TL) of all blue catfish and flathead catfish collected during standard random sampling is measured (mm) and all fish receiving a reward tag are weighed (g). Ten pectoral spines per length group, per species, per site, per year are obtained for age determination of blue catfish and flathead catfish ≥177 mm (≥7 in) TL (see *Ageing Structure Protocol*). Pectoral spines are collected from blue catfish in the spring only and from flathead catfish in the fall only. Otoliths and pectoral spines are collected from mortalities encountered afield or from harvesters willing to donate structures. Eleven reward tags per length group, per species, per site, per year are affixed to blue catfish and flathead catfish ≥381 mm (≥15 in) TL (see *Reward Tagging Protocol*). Blue catfish receive reward tags in the spring only; flathead catfish receive reward tags in the fall only. All fish ≥177 mm (≥7 in) TL captured during standard random sampling which do not receive a reward tag receive a fin clip to identify recaptures.

One electrofishing boat will shock and collected stunned fish while one chase boat assists with the capture of stunned fish. The electrofishing boat has, at a minimum, a three member crew, one pilot and two netters. The chase boat has, at a minimum, a two member crew, one pilot and one netter. Additional crew members may be utilized but the number of active netters per boat must remain constant. Dip nets must be a minimum of 30-cm (12-in) deep with no larger than 1.3-cm (1/2-in) mesh size on non-conductive handles. Netters collect each catfish as it surfaces, regardless of size or species and place them in holding tanks until the run is terminated. Utilize aerators or regular water exchanges between river and tank to ensure healthy holding conditions for fish. Non-target species are released.

The primary responsibility of the electrofishing boat's crew is to shock each habitat type in a standardized manner while netting catfish that can be captured without drastically deviating from its current position or path to the extent possible. Deviations may be necessary to avoid obstructions or when the chase boat is overwhelmed with the collection of large numbers of surfacing catfish. During a run, the pilot operates the boat at a speed and along a path such that 3 to 10 minutes of effort allows coverage of the approximate sampling area. A timer is used to measure the time spent electrofishing with the power on at each run location. The accessible sampling area of any individual run may vary depending on water level. Portions of the run which may exhibit higher habitat complexity or quality (i.e., large woody debris, brush piles, scours, etc.) are shocked thoroughly until they no longer yield fish. The pilot is free to modify the forward and backward movement of the boat to permit the most effective collection of fish only to the extent that such movement does not interfere with the objective of obtaining 100 percent area coverage with a single 3 to 10 minute run. The primary responsibility of the chase boat's crew is to net as many catfish as possible without interfering with the electrofishing boat.

Sampling is conducted so long as the river stage nearest to a site is below Action Stage. Sampling may be delayed should a site be deemed unsafe to navigate or if a crew's ability to access the river is compromised. Visit the U.S. Geologic Service's National Water Information System at http://waterdata.usgs.gov/nwis/rt or the National Weather Service's Advanced Hydrologic Prediction Services at http://water.weather.gov/ahps/ to check current and projected river stages. To ensure that sampling is completed statewide, each season, it may be necessary to assist crews that are presented with a shorter sampling window due to inhospitable weather and/or river stages.

Non-Random Sampling

Non-random sampling may be necessary to collect adequate numbers of some length groups of blue catfish and flathead catfish for aging and tagging. Non-random sampling methods may include the use of hoop nets, trotlines, gill nets, trammel nets, or targeted electrofishing runs (standard sampling protocols for electrofishing do not need to be followed for non-random sampling. Non-random sampling must occur within the boundaries of a site at water temperatures ranging from 10 to ≈27^{o}C (50 to 80^{o}F). All blue catfish and flathead catfish collected during non-random sampling are measured for total length (TL) (mm). **Catfish collected during non-random sampling do not receive a fin clip.**

Table 1. Peak output voltage goal (VGoal) by ambient water conductivity (Ca). Voltage goals are based on an assumed effective fish conductivity (115 µS/cm) and peak output power levels used during initial pilot sampling. This represents preliminary output goals until further research is done.

Ca	VGoal	+/- 2SE	Ca	VGoal	+/- 2SE
10	2624	74	130	396	11
20	1417	40	140	382	11
30	1014	29	150	371	10
40	813	23	170	352	10
50	693	20	200	331	9
60	612	17	250	306	9
70	555	16	300	290	8
80	512	14	400	270	8
90	478	13	600	250	7
100	451	13	800	240	7
110	429	12	1000	234	7
120	411	12	115	420	12

Table 2. Boat specific (identified by Biologist's last name) voltage meter readings compared to actual peak voltage output for each Biologist's respective control box.

Box Meter Reading Volt Setting	Knuth	Ostendorf	Peper	Dames	Gemming	Allman	Mason
100	109	100	142	105	112	94	139
125	138	125	176	133	138	125	167
150	166	150	210	161	164	156	195
175	195	175	244	188	190	187	223
200	223	200	277	216	216	219	251
225	252	225	311	244	242	250	279
250	281	250	345	272	268	281	307
275	309	275	379	299	294	312	335
300	338	300	413	327	320	343	363
325	366	325	446	355	346	374	390
350	395	350	480	383	371	406	418
375	423	375	514	410	397	437	446
400	452	400	548	438	423	468	474
425	481	425	581	466	449	499	502
450	509	450	615	493	475	530	530
475	538	475	649	521	501	562	558
500	566	500	683	549	527	593	586

Habitat Types and Associated Sampling Techniques

Sampling methods vary by habitat type. Figures 1 through 4 depict where sampling is required (blue arrows) and where sampling is optional (orange arrows), water depths permitting and if safe to do so.

Main Channel Natural Bank: Main channel banklines which are primarily comprised of naturally deposited materials such as clay, silt, sand, gravel, boulders, rock outcroppings, or any combination of these materials. Sampling Method: Begin at the up or downstream boundary of the run. Maneuver the electrofishing boat close and parallel to the bankline and sample slowly and continuously. Maneuver to alternate the boat's position relative to the bankline and pause or slow the boat as needed (Figure 1).

Main Channel Other Structure: Main channel rock structures including chevrons, W-dikes, and multiple roundpoint structures (MRS) but excluding wing dikes and trail dikes. Sampling Method: Begin sampling by positioning the electrofishing boat near the scour hole just downstream of the main channel tip of the structure and remain stationary/near the scour for a minimum of three minutes. Maneuver the electrofishing boat close to the structure and sample along its entire length slowly and continuously. Sample the down then upstream sides of emergent structures. Sample from the downstream side and cross just over submerged structures if possible. Maneuver to alternate the boat's position relative to the structure and pause or slow the boat as needed.

Main Channel Revetted Bank: Homogenous main channel banklines which are covered by an erosion resistant material (e.g., stone rip rap or articulated concrete mattress (ACM)) and are devoid of dikes. Sampling Method: Begin at the up or downstream boundary of the run. Maneuver the electrofishing boat close and parallel to the bankline and sample slowly and continuously. Maneuver to alternate the boat's position relative to the bankline and pause or slow the boat as needed (Figure 1).

Main Channel Sandbar: Main channel sand deposits in proximity to but often disjunct from main channel banklines or structures. Sampling Method: Begin at the up or downstream boundary of the run. Maneuver the electrofishing boat close and parallel to the sandbar and sample slowly and continuously. Maneuver to alternate the boat's position relative to the sandbar and pause or slow the boat as needed. Sample the channel then bankline sides of emergent sandbars, or over submerged sandbars (Figure 1).

Main Channel Trail Dike (L-Dike): Rock trail dikes including all portions of the structure from the bankline to the tip nearest the main channel and a portion of the bankline up and downstream of the foot of the dike (from the foot of the dike upstream 50 meters and downstream to just past the downstream portion of the bank scour). Sampling Method: Begin by positioning the electrofishing boat near the scour hole just downstream of the main channel tip of the structure and remain stationary/near the scour for a minimum of three minutes. Approach the main channel tip of the structure and continue slowly and continuously along the main channel side of the portion of the structure that is approximately parallel to flow, to its most upstream point. Sampling may be continued along the bankline side of the structure, down/upstream of the portion of the structure that is approximately perpendicular to flow to the foot of the dike and along the banklines down/upstream of the structure. If emergent, sample main channel then bankline sides and down then upstream sides of the structure and associated banklines. Sample from the main channel/downstream side and cross just over submerged structures if possible. Maneuver to alternate the boat's position relative to the structure and associated banklines, and pause or slow the boat as needed (Figure 2).

Main Channel Wing Dike: Rock wing dikes including all portions of the structure from the bankline to the tip nearest the main channel and a portion of the bankline up and downstream of the foot of the dike (from the foot of the dike upstream 50 meters and downstream to just past the downstream portion of the bank scour). Sampling Method: Begin sampling by positioning the electrofishing boat near the scour hole just downstream of the main channel tip of the structure and remain stationary/near the scour for a minimum of three minutes. Maneuver the electrofishing boat close to the main channel tip of the structure and continue slowly and continuously along the downstream edge toward the bankline. Sampling may be continued to the foot of the dike and along the banklines down/upstream of the structure. Sample the down then upstream sides of emergent structures and associated banklines. Sample from the downstream side and cross just over submerged structures if possible. Maneuver to alternate the boat's position relative to the structure and banklines, and pause or slow the boat as needed (Figure 3).

Side Channel Natural Bank: Side channel banklines which are primarily comprised of naturally deposited materials such as clay, silt, sand, gravel, boulders, rock outcroppings, or any combination of these materials. Sampling Method: Begin at the up or downstream boundary of the run. Maneuver the electrofishing boat close and parallel to the bankline and sample slowly and continuously. Maneuver to alternate the boat's position relative to the bankline and pause or slow the boat as needed (Figure 1).

Side Channel Revetted Bank: Homogenous side channel banklines which are covered by an erosion resistant material (e.g., stone rip rap or articulated concrete mattress (ACM)) and are devoid of dikes. Sampling Method: Begin at the up or downstream boundary of the run. Maneuver the electrofishing boat close and parallel to the bankline and sample downstream slowly and continuously. Maneuver to alternate the boat's position relative to the bankline and pause or slow the boat as needed (Figure 1).

Side Channel Structure: Side channel rock structures including dikes and closing structures. Sampling Method: Maneuver the electrofishing boat close to the structure and sample along its entire length slowly and continuously. Sample the down then upstream sides of emergent structures. Sample from the downstream side and cross just over submerged structures if possible. Maneuver to alternate the boat's position relative to the structure and pause or slow the boat as needed.

Tailwater Open: Open water within the tailwater of a mainstem dam (from the point of discharge from the dam to 0.5 river miles downstream). Sampling Method: Begin sampling at the main channel side of the earthen dam. Maneuver the electrofishing boat close and parallel to the earthen dam sampling slowly and continuously toward the bankline then back toward the main channel through the deeper scour. Continue sampling downstream of the main dam keeping the boat pointed upstream and moving closely along the dam. Finish the run by sampling the current seam downstream of the main dam-earthen dam connection. Maneuver to alternate the boat's position relative to the dam and banklines and pause or slow the boat as needed.

Tailwater Structure: Rock structures within the tailwater of a mainstem dam (from the point of discharge from the dam to 0.5 river miles downstream) including wing dikes, trail dikes, chevrons, and multiple roundpoint structures (MRS). Sampling Method: Follow methods for Main Channel Wing Dike, Main Channel Trail Dike, or Main Channel Other Structure where appropriate (Figures 2 or 3)

Tributary Mouth: The mouth of tributary streams 4th order or larger, including the main channel or side channel banklines within 50 meters up and downstream of the confluence and the tributary banklines within 200 meters upstream of its mouth. Sampling Method: Begin at the up or downstream boundary of the run. Maneuver the electrofishing boat close and parallel to the bankline and sample slowly and continuously to where the tributary bankline meets that of the main channel. Sample each tributary bankline and finish the run by sampling the remainder of the main channel bankline. Maneuver to alternate the boat's position relative to the banklines and pause or slow the boat as needed (Figure 4).

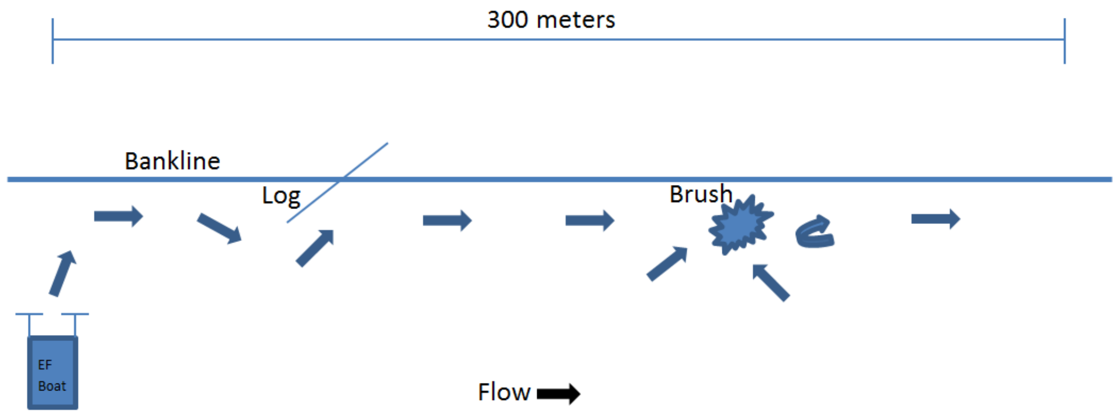

Figure 1: Diagram of electrofishing boat maneuvers for Main Channel Natural Bank, Main Channel Revetted Bank, Side Channel Natural Bank. Main Channel Revetted Bank and Main Channel Sandbar habitats.

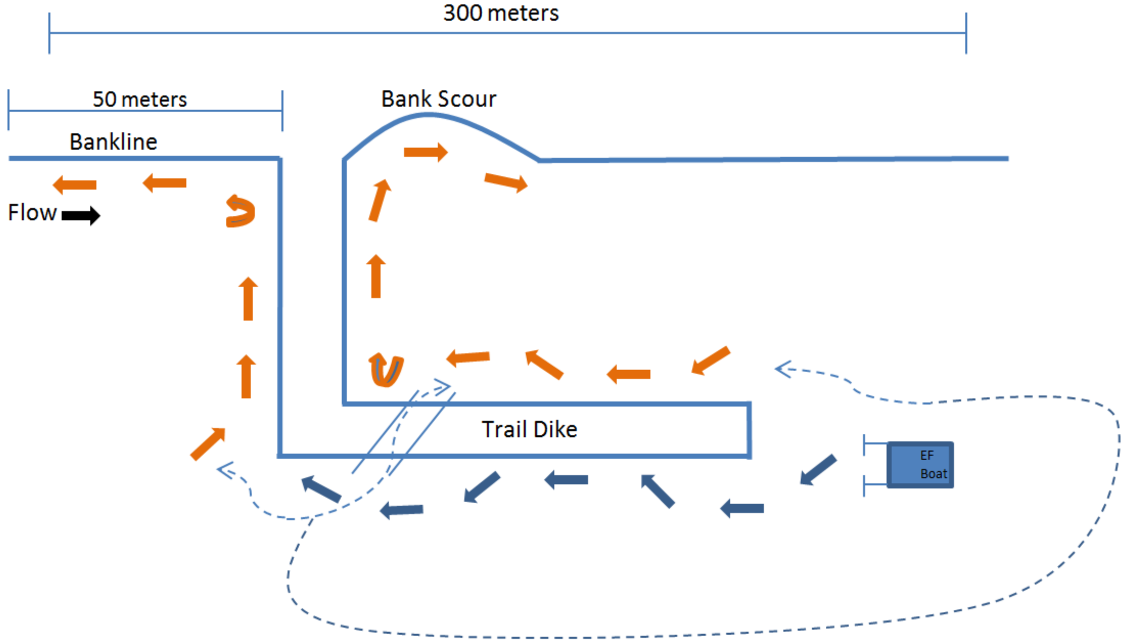

Figure 2: Diagram of electrofishing boat maneuvers for Main Channel Trail Dike (L-Dike) and Tailwater Structure habitats. Blue arrows signify required sampling locations; orange arrows indicate potential sampling locations.

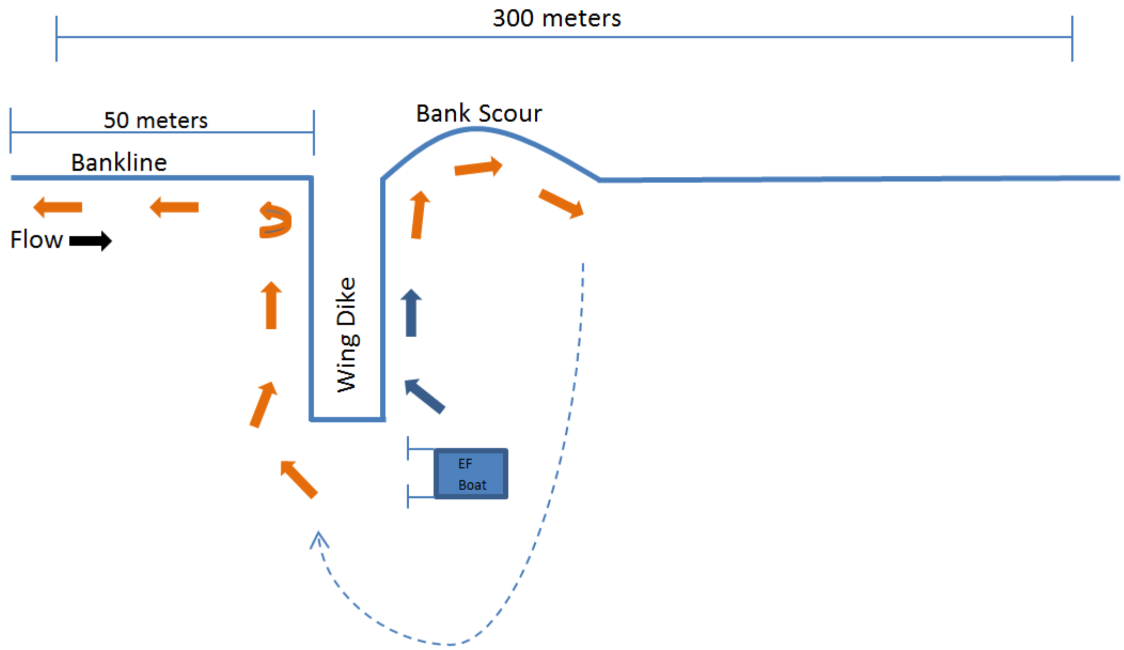

Figure 3: Diagram of electrofishing boat maneuvers for Main Channel Wing Dike, Side Channel Structure and Tailwater Structure habitats. Blue arrows signify required sampling locations; orange arrows indicate potential sampling locations.

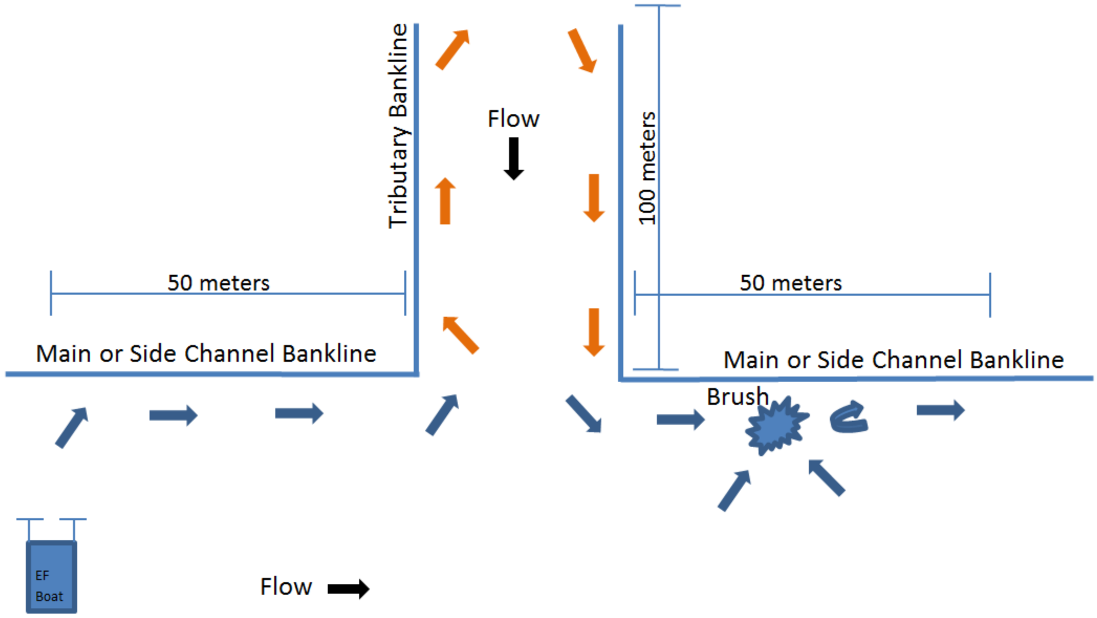

Figure 4: Diagram of electrofishing boat maneuvers for Tributary Confluence habitat. Blue arrows signify required sampling locations; orange arrows indicate potential sampling locations.

Data Sheet Instructions

A data sheet is completed for each run; all fields are required during standard random sampling.

File Name: *Big Rivers Catfish Assessment Data Sheet.pdf*

Location: *SharePoint/Fisheries/Big Rivers/Documents/Big Rivers Catfish Assessment*

SAMPLING DATE: Date that sampling was conducted

SECCHI DISK DEPTH: Water depth of secchi disk measurement. Unit = cm (if not, specify units)

WATER CONDUCTIVITY: Measurement of water conductivity using conductivity meter (RECORD conductivity for each run; re-measure if temperature changes (>3^{o}c) or at/near tributary mouths). Unit = µS/cm. Specify whether measurement is **Specific** - or - **Ambient Conductivity** (circle one) as measured by your conductivity meter (check the instruction manual if needed). Specific Conductivity (σ_s) is adjusted to a specific water temperature **(T_s = 25°C)**. Ambient Conductivity (σ_a) is measured at the ambient (actual) water temperature (T_a). Specific Conductivity can be converted to Ambient Conductivity using the following equation: $\sigma_{a}=\frac{\sigma_S}{1.02^{(T_S-T_a)}}$ (requires temperature in °C) (Equation on p.315 in 3rd Edition of Fisheries Techniques). Electrofishing success depends on ambient conductivity, not specific conductivity. Conductivity changes by 2 percent for every 1°C change in water temperature.

WATER TEMP: Surface water temperature at time of sampling (measure temperature before each run). Unit = °C or °F (circle one)

CONTROL BOX TYPE: Smith-Root VVP-15B, Infinity Box, or ETS Box (circle one)

EF FREQUENCY: Frequency setting on the control box. Use 15 Hz (or pps) as standard setting. Do NOT change setting during a sampling run.

DUTY CYCLE: Duty cycle setting on control box. Use 30-40 percent range as standard setting, other duty cycles can be tried. Do NOT change setting during a sampling run.

EFFORT IN MINUTES: Pedal time (shock time) of sampling run. Unit = minutes (or list seconds off box meter and convert to minutes).

TIME OF DAY: Time when sampling run started.

RIVER STAGE: Stage at nearest river gage. Unit = feet.

GAGE STATION #: The USGS gage station # used to determine river stage. Specify if a NOAA river gage is used rather than USGS

 # OF NETTERS: The number of dip netters used during a run (EF and Chase boat combined). Standard sampling should be a total of 3 netters, 2 on the electrofishing boat and 1 on the chase boat.

EF VOLTS: Voltage setting based on control box output meter – METER READING. Unit = Volts. Do NOT change setting during a sampling run except if necessary to pursue surfacing fish. If adjustments must be made, then return to original settings as soon as possible.

EF AMPS: Amperage based on control box output meter – METER READING. Unit = Amps.

EF POWER (WATTS = V · A): Manual calculation of Volts x Amps = Power – METER READING. Unit = Watts

PROJECT BIOLOGIST: Full name of lead biologist.

RIVER DISCHARGE: Discharge based on nearest river gage station. Unit = cfs.

SITE #: Site number (Table 1 & Figure 1)

RUN #: Consecutive integer identifying the run number. Run number begins at 1 each day of sampling.

 # OF NETTERS: Record the number of netters during non-random electrofishing runs (2 netters per shock boat and 1 netter per chase boat are required for standard random sampling)

START/STOP UTM NORTHINGS (7 DIGITS): Start and Stop UTM Northings for each sampling run.

START/STOP UTM EASTINGS (6 DIGITS): Start and Stop UTM Eastings for each individual sampling run.

HABITAT TYPE: Circle ONE**:** MCNB (Main Channel Natural Bank)**,** MCOS (Main Channel Other Structure)**,** MCRB (Main Channel Revetted Bank)**,** MCS (Main Channel Sandbar)**,** MCTD (Main Channel Trail Dike (L-Dike))**,** MCWD (Main Channel Wing Dike)**,** SCNB (Side Channel Natural Bank)**,** SCRB (Side Channel Revetted Bank)**,** SCS (Side Channel Structure)**,** TO (Tailwater Open)**,** TS (Tailwater Structure)**,** TM (Tributary Mouth).

RANDON/NON-RANDOM: Circle ONE**:** R – Random, N – Non-Random. Identify whether the subsample is for a randomly selected run or is for a non-random (i.e. targeted) run.

GEAR TYPE: Circle ONE: EF (Electrofishing), HN (Hoop Net), GN (Gill Net), TN (Trammel Net), TL (Trotline), OTHER. Provide details in the NOTES field concerning the method of collection if "Other" is selected.

SPECIES: BCF = blue catfish, FHC = flathead catfish, NFS = No Fish.

LENGTH: Measure and record the total length of all catfish >=177 mm. Units = millimeters.

WEIGHT: Measure and record the WEIGHT of each catfish that receives a reward tag. Units = grams, (if not, specify units).

TAG NUMBER: Includes 2 letter tag prefix (FS, FH, BS or BH) plus the 4-digit number following it.

TAG M/R: M – Mark (initial tagging), N – No Mark, R – Recapture (recaptured tag), S – Shed Tag.

FIN CLIP: M – Mark, N – No Mark, R – Recapture (previously fin clipped).

AGING STRUCTURE: P – Pectoral Spine, O – Otolith, N – None, PO – Pectoral Spine and Otolith.

COMMENTS: Any additional comments specific to a fish record (e.g. deformed spine, CHEP tag number).

OTHER NOTES: List any other unique information specific to a sampling run.

PAGE______ OF______: List the number of data sheets used to record data for each sampling run

Ageing Structure Protocol

Each year of sampling, pectoral spines (Figure 5) are collected from blue catfish (spring only, N=1,280) and flathead catfish (fall only, N=1,280) ≥177 mm (7 inches) for aging (Table 3). Collected spines will be equally divided among species and sites; 160 spines from each species will be collected from each site, each year. Collected spines will be distributed among ten 50 mm length groups for fish from 177-890 mm (7-34.9 in). Fish larger than 889 mm (34.9 in) are divided into two length groups, 890-1015 mm (35-39.5 in) and ≥1016 mm (≥40 in). Ten pectoral spines are collected from each length group.

Disarticulate the pectoral spine by gently twisting it downward and around when the fish is relaxed and the spine is not locked in joint at the articulating process. Remove the spine with a sharp scalpel and place the structure in an envelope. Fill out the information on the envelope and freeze it as soon as possible.

Otoliths and pectoral spines are collected from mortalities that are encountered afield or from harvesters willing to donate ageing structures. Tools needed to remove otoliths include a hacksaw (fillet knife or scalpel for small fish), wire cutters and forceps. Otoliths are in pockets along the sides of the cranium below the posterior portion of the brain (Figures 7 & 8). To remove the otoliths dorsally, extend the pectoral spines (Figure 9), cut 3-5 mm anterior to a line that connects them (Figure 10) and push the skull downward to force open the cut (Figure 11). Glide the forceps along each side of the braincase until you feel the pocket in which each otolith is located; grasp and remove each otolith (Figure 7). If you are unable to locate the otoliths use a wire cutter to remove the top of the skull. To remove the otoliths ventrally, cut the isthmus (Figure 12), remove gills and scrape the skin from the otic capsule. Cut the otic capsule with wire cutters (Figure 13) and break it open; grasp and remove otoliths (Figure 14).

Figure 5: Catfish pectoral spine.

Table 3: Pectoral spine collections by length group.

Length Group	Pectoral Spines
177-227 mm (≈7-8.9 in)	10
228-278 mm (≈9-10.9 in)	10
279-329 mm (≈11-12.9 in)	10
330-380 mm (≈13-14.9 in)	10
381-431 mm (≈15-16.9 in)	10
432-482 mm (≈17-18.9 in)	10
483-533 mm (≈19-20.9 in)	10
534-584 mm (≈21-22.9 in)	10
585-635 mm (≈23-24.9 in)	10
636-686 mm (≈25-26.9 in)	10
687-737 mm (≈27-28.9 in)	10
738-788 mm (≈29-30.9 in)	10
789-839 mm (≈31-32.9 in)	10
840-890 mm (≈33-34.9 in)	10
891-1015 mm (≈35-39.9 in)	10
≥1016 mm (≈≥40 in)	10

Figure 6: Location of otoliths.

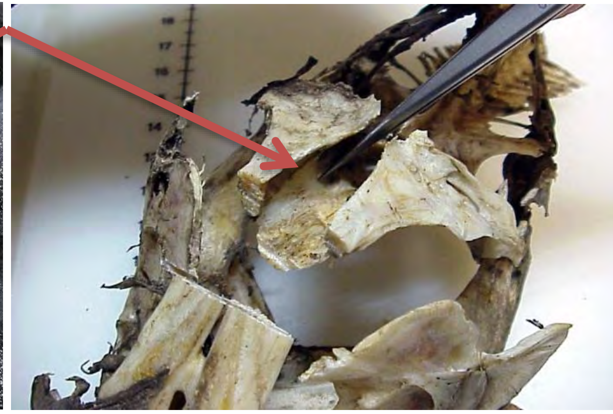

Figure 7: Location of otoliths.

Dorsal otolith removal:

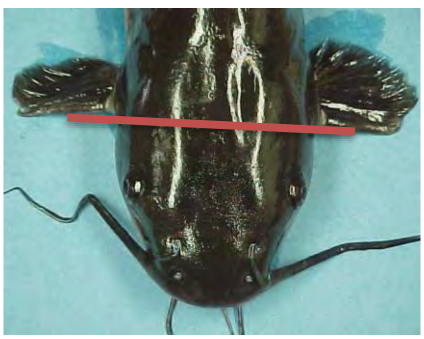

Figure 8: Extend pectoral spines.

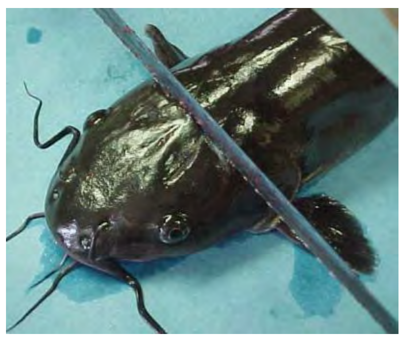

Figure 9: Cut the skull.

Figure 10: Push skull down.

Ventral otolith removal:

Figure 11: Cut the isthmus.

Figure 12: Cut the otic capsule.

Figure 13: Remove the otolith.

Reward Tagging Protocol

Each year of sampling, blue catfish (N=1,088) and flathead catfish (N=1,088) ≥381 mm (15 inches) will be tagged using uniquely numbered Carlin dangler tags with reward values of either $25 (standard reward value) or $150 (high reward value) to estimate tag reporting and exploitation rates (Table 6). Tags will be equally divided among species and sites; 136 fish of each species will be tagged from each site, each year. Carlin dangler tags will be distributed among ten 50 mm length groups for fish from 381-889 mm (15-34.9 in), each group randomly receiving 8 low reward tags and 3 high reward tags. Fish larger than 889 mm (34.9 in) are divided into two length groups, 890-1015 mm (35-39.5 in) and ≥1016 mm (≥40 in), each group randomly receiving 6 low reward tags and 5 high reward tags.

Following each run, blue catfish (spring only) and flathead catfish (fall only) are marked with individually numbered Carlin dangler tags attached to the middle of a stainless steel wire. To tag catfish, secure the fish (Figure 15) insert the double hypodermic needles through the fish under the dorsal fin between dorsal pterygiophores being sure to maintain ≈0.5 inch spacing between the needles (Figure 16). The two wire ends must encompass at least one dorsal pterygiophore to ensure that the tag is properly secured. Insert the wires into the protruding needles (Figure 17) then pull the needles out leaving behind the double wires (Figure 18). Insert spacer sticks between the two wires, one on each side of the fish (Figure 19), to prevent tearing the flesh if the wires are over tightened. Twist wires together with hemostat pliers (Figure 20), cut off excess wire (Figure 21), ensure that the tag is secure and push both ends of it toward the dorsal end of the fish (Figure 22). Fish are released within the site and near the run they were collected from.

Table 4: Reward tag allocations by length group.

Length Group	Low Reward ($25)	High Reward ($150)	Total
381-431 mm (≈15-16.9 in)	8	3	11
432-482 mm (≈17-18.9 in)	8	3	11
483-533 mm (≈19-20.9 in)	8	3	11
534-584 mm (≈21-22.9 in)	8	3	11
585-635 mm (≈23-24.9 in)	8	3	11
636-685 mm (≈25-26.9 in)	8	3	11
686-736 mm (≈27-28.9 in)	8	3	11
737-787 mm (≈29-30.9 in)	8	3	11
788-838 mm (≈31-32.9 in)	8	3	11
839-889 mm (≈33-34.9 in)	8	3	11
890-1015 mm (≈35-39.9 in)	6	5	11
1016+ mm (≈40+ in)	6	5	11

Figure 14. Secure the fish

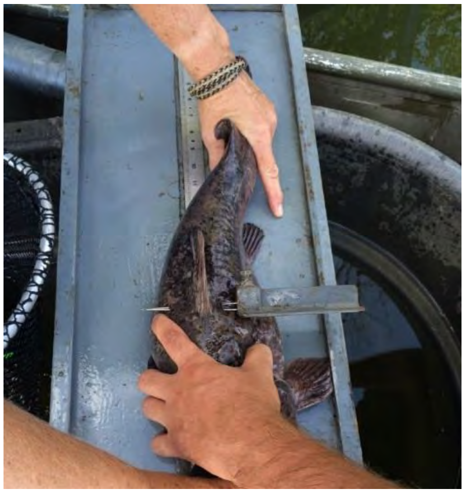

Figure 15. Insert the double hypodermic needles through the fish under the dorsal fin between dorsal pterygiophores with ≈ 0.5” spacing between needles. The two wire ends of the tag must encompass at least one dorsal pterygiophore to ensure that the tag is properly secured.

Figure 16. Insert the wires of the tag into the tips of the protruding needles.

Figure 17. Pull the needles out of the fish leaving behind the wires and tag.

Figure 18. Insert spacer sticks between the two wires, one on each side of the fish, to prevent tearing the flesh if the wires are over tightened.

Figure 19. Twist wires together with hemostat pliers

Figure 20. Cut off excess wire.

Figure 21. Ensure that the tag is secure and push both ends of it toward the posterior end of the fish.

Appendix 2. Tagging and capture data.

Tag Number	Length (in)	Tagging Site	Tagging Date	Capture Date	Days at Large	Distance Traveled (River Miles)
BS 0536	24.4	6	4/6/2015	5/28/2017	783	230.3
BS 0541	19.5	6	4/6/2015	8/1/2017	848	4.2
BS 0549	31.2	6	4/6/2015	6/5/2015	60	27.7
BS 0552	20.1	6	4/6/2015	7/9/2017	825	46.2
BH 6229	21.5	6	4/6/2015	7/26/2015	111	10.9
BH 6230	15.5	6	4/6/2015	9/17/2015	164	0.4
BH 6235	24.2	6	4/6/2015	7/18/2015	103	9.3
BH 6236	25.7	6	4/6/2015	5/20/2017	775	0.6
BS 0095	46.3	2	4/8/2015	5/7/2016	395	0.0
BS 0098	30.6	2	4/8/2015	6/30/2016	449	2.9
BS 0509	25.0	6	4/10/2015	8/21/2016	499	6.0
BS 0517	24.9	6	4/10/2015	11/2/2018	1302	4.8
BS 0523	16.4	6	4/10/2015	4/10/2015	0	0.0
BH 6222	23.1	6	4/10/2015	12/10/2017	975	1.2
BH 6227	25.9	6	4/10/2015	12/20/2015	254	19.0
BS 0185	26.4	3	4/14/2015	8/24/2015	132	0.9
BS 0186	22.8	3	4/14/2015	10/22/2015	191	1.5
BS 0187	24.2	3	4/15/2015	5/21/2018	1132	56.8
BS 0198	23.5	3	4/15/2015	8/27/2016	500	2.6
BS 0199	28.5	3	4/15/2015	5/23/2016	404	0.7
BS 0204	36.4	3	4/15/2015	7/11/2015	87	218.3
BS 0206	40.3	3	4/15/2015	6/1/2015	47	148.3
BS 0211	35.5	3	4/15/2015	7/31/2016	473	5.0
BS 0215	35.5	3	4/15/2015	4/13/2016	364	149.3
BH 6086	29.0	3	4/15/2015	4/1/2018	1082	26.3
BH 6089	35.9	3	4/15/2015	6/11/2017	788	129.2
BS 0220	37.2	3	4/15/2015	8/29/2015	136	1.3
BS 0439	21.6	5	4/17/2015	5/1/2015	14	3.3
BS 0456	23.4	5	4/17/2015	4/1/2016	350	76.4
BH 6163	23.1	5	4/17/2015	6/10/2016	420	0.8
BS 0647	27.2	8	4/21/2015	8/4/2016	471	108.3
BS 0369	24.8	5	4/22/2015	7/2/2016	437	1.1
BH 6219	29.7	6	4/22/2015	10/11/2016	538	208.1
BH 6220	27.9	6	4/22/2015	6/17/2017	787	2.4
BS 0373	17.0	5	4/24/2015	4/23/2016	365	1.1
BH 6165	15.6	5	4/24/2015	5/23/2015	29	1.8
BH 6169	26.5	5	4/24/2015	5/10/2015	16	41.5
BH 6194	33.4	5	4/24/2015	5/26/2018	1128	7.6
BS 0489	31.6	6	4/28/2015	2/15/2016	293	1.9
BS 0490	31.6	6	4/28/2015	6/3/2016	402	18.1
BS 0491	30.1	6	4/28/2015	2/17/2016	295	0.7
BS 0562	23.1	7	4/28/2015	7/1/2016	430	144.6
BH 6216	37.4	6	4/28/2015	5/24/2015	26	38.0

Tag Number	Length (in)	Tagging Site	Tagging Date	Capture Date	Days at Large	Distance Traveled (River Miles)
BH 6217	29.6	6	4/28/2015	7/29/2015	92	4.0
BH 6241	17.9	7	4/28/2015	6/10/2016	409	1.1
BH 6243	24.0	7	4/28/2015	9/4/2017	860	109.4
BH 6246	24.4	7	4/28/2015	8/5/2016	465	12.3
BH 6248	27.5	7	4/28/2015	7/2/2017	796	0.1
BS 0574	19.4	7	4/29/2015	9/30/2018	1250	89.0
BS 0575	27.0	7	4/29/2015	8/1/2015	94	145.0
BS 0576	25.4	7	4/29/2015	4/16/2017	718	21.4
BS 0578	20.5	7	4/29/2015	7/1/2017	794	23.7
BS 0592	28.5	7	4/29/2015	5/4/2016	371	40.3
BH 6087	23.0	3	4/29/2015	5/23/2016	390	23.2
BH 6103	25.5	3	4/29/2015	5/1/2016	368	15.0
BH 6254	25.0	7	4/29/2015	10/14/2017	899	50.7
BS 0241	23.7	3	4/29/2015	8/26/2018	1215	111.8
BS 0248	21.4	3	4/29/2015	6/15/2018	1143	1.5
BS 0250	22.6	3	4/29/2015	2/2/2016	279	2.8
BH 6114	25.0	3	4/29/2015	2/2/2016	279	2.8
BS 0236	26.9	3	4/29/2015	9/5/2018	1225	0.3
BS 0483	38.7	6	4/30/2015	8/13/2016	471	4.7
BS 0486	38.2	6	4/30/2015	10/19/2017	903	2.1
BS 0487	30.5	6	4/30/2015	5/27/2015	27	0.9
BH 6214	32.0	6	4/30/2015	5/24/2015	24	1.4
BS 0107	23.1	2	4/30/2015	6/27/2015	58	5.2
BH 6055	20.5	2	4/30/2015	8/6/2015	98	0.2
BS 0131	23.4	2	5/1/2015	5/8/2015	7	111.4
BS 0129	22.6	2	5/1/2015	5/8/2015	7	1.7
BS 0065	27.6	1	5/5/2015	9/14/2015	132	298.3
BS 0090	23.7	1	5/5/2015	8/16/2015	103	9.4
BS 0474	33.3	6	5/5/2015	5/30/2015	25	26.6
BS 0475	31.4	6	5/5/2015	5/10/2015	5	1.3
BS 0481	31.0	6	5/5/2015	5/20/2015	15	23.6
BS 0600	27.9	7	5/5/2015	5/26/2017	752	87.1
BS 0601	25.9	7	5/5/2015	5/9/2015	4	0.0
BS 0602	28.2	7	5/5/2015	8/23/2016	476	0.1
BS 0614	33.1	7	5/5/2015	6/4/2016	396	0.1
BH 6067	39.8	2	5/5/2015	4/16/2016	347	206.9
BH 6068	29.5	2	5/5/2015	6/10/2017	767	430.4
BH 6207	33.8	6	5/5/2015	1/30/2016	270	11.2
BH 6210	45.6	6	5/5/2015	5/3/2016	364	45.2
BH 6212	36.4	6	5/5/2015	12/5/2015	214	0.1
BH 6259	44.5	7	5/5/2015	5/16/2015	11	11.9
BH 6263	26.9	7	5/5/2015	11/18/2016	563	77.4
BH 6267	30.5	7	5/5/2015	8/9/2015	96	1.0
BS 0056	27.9	1	5/5/2015	11/18/2018	1293	105.4
BS 0062	22.2	1	5/5/2015	6/15/2015	41	8.0
BS 0064	27.3	1	5/5/2015	6/15/2015	41	8.0

Tag Number	Length (in)	Tagging Site	Tagging Date	Capture Date	Days at Large	Distance Traveled (River Miles)
BS 0067	22.6	1	5/5/2015	1/15/2017	621	157.0
BS 0077	28.6	1	5/5/2015	7/20/2016	442	15.5
BS 0079	21.2	1	5/5/2015	8/21/2015	108	6.4
BS 0080	22.4	1	5/5/2015	6/15/2015	41	6.0
BS 0082	23.1	1	5/5/2015	6/2/2015	28	39.8
BS 0088	25.5	1	5/5/2015	7/8/2015	64	36.1
BS 0139	18.9	2	5/5/2015	4/13/2016	344	8.2
BS 0141	35.4	2	5/5/2015	11/10/2015	189	2.8
BS 0146	28.1	2	5/5/2015	7/31/2016	453	2.7
BS 0148	26.0	2	5/5/2015	6/6/2015	32	48.3
BH 6027	20.9	1	5/5/2015	6/15/2015	41	8.0
BH 6031	23.3	1	5/5/2015	9/26/2016	510	26.5
BH 6033	25.2	1	5/5/2015	6/15/2015	41	5.8
BH 6036	25.6	1	5/5/2015	6/18/2016	410	121.2
BH 6038	18.9	1	5/5/2015	7/2/2016	424	117.8
BH 6039	26.6	1	5/5/2015	10/1/2015	149	2.5
BH 6040	25.0	1	5/5/2015	4/23/2016	354	8.8
BH 6064	35.8	2	5/5/2015	5/13/2017	739	186.7
BS 0041	22.6	1	5/6/2015	3/15/2018	1044	296.8
BS 0431	26.0	5	5/6/2015	6/30/2015	55	0.0
BH 6020	31.9	1	5/6/2015	6/17/2015	42	190.3
BH 6192	24.3	5	5/6/2015	5/26/2015	20	4.3
BH 6201	33.7	6	5/6/2015	6/10/2016	401	12.1
BS 0028	17.7	1	5/6/2015	6/15/2015	40	3.1
BS 0034	18.6	1	5/6/2015	11/14/2016	558	14.2
BH 6026	27.1	1	5/6/2015	5/8/2016	368	43.2
BS 0017	36.0	1	5/7/2015	7/4/2015	58	2.5
BH 6005	41.2	1	5/7/2015	6/15/2015	39	2.5
BH 6019	16.1	1	5/7/2015	5/29/2015	22	0.4
BS 0461	41.0	6	5/11/2015	7/31/2015	81	68.2
BS 0464	40.5	6	5/11/2015	5/19/2016	374	250.6
BS 0422	28.6	5	5/12/2015	6/2/2015	21	42.2
BH 6186	35.4	5	5/12/2015	10/24/2015	165	1.9
BH 6188	28.5	5	5/12/2015	5/15/2017	734	58.2
BH 6189	28.7	5	5/12/2015	4/16/2017	705	1.8
BS 0009	33.4	1	5/12/2015	7/12/2015	61	129.2
BS 0010	34.5	1	5/12/2015	7/30/2015	79	4.6
BS 0154	31.9	2	5/12/2015	7/7/2018	1152	122.8
BS 0155	34.4	2	5/12/2015	5/4/2017	723	22.8
BS 0160	28.9	2	5/12/2015	7/5/2015	54	7.5
BH 6009	37.2	1	5/12/2015	6/13/2016	398	79.2
BH 6011	33.0	1	5/12/2015	6/15/2015	34	7.8
BH 6071	29.6	2	5/12/2015	5/25/2017	744	0.2
BH 6072	28.7	2	5/12/2015	3/16/2016	309	9.1
BS 0379	29.1	5	5/13/2015	12/10/2015	211	0.4
BS 0410	31.4	5	5/13/2015	5/22/2016	375	10.9

Tag Number	Length (in)	Tagging Site	Tagging Date	Capture Date	Days at Large	Distance Traveled (River Miles)
BH 6171	29.0	5	5/13/2015	4/30/2016	353	121.5
BH 6284	38.1	8	5/13/2015	9/2/2017	843	2.0
BH 6286	29.7	8	5/13/2015	7/8/2017	787	0.0
BH 6287	27.2	8	5/13/2015	8/24/2017	834	62.4
BS 0170	35.4	2	5/14/2015	6/7/2015	24	262.9
BS 0006	44.1	1	5/14/2015	11/16/2016	552	16.7
BS 0280	30.3	4	5/18/2015	8/2/2015	76	2.1
BS 0281	18.8	4	5/19/2015	1/26/2016	252	18.7
BS 0231	26.6	3	5/19/2015	5/23/2015	4	0.1
BS 0256	25.1	3	5/19/2015	6/7/2015	19	0.0
BS 0260	17.1	3	5/19/2015	8/6/2016	445	11.7
BH 6118	28.8	3	5/19/2015	7/13/2015	55	3.2
BS 0262	29.6	3	5/20/2015	10/3/2015	136	1.5
BS 0265	27.9	3	5/20/2015	7/18/2015	59	270.5
BH 6117	34.3	3	5/20/2015	8/15/2015	87	202.6
BH 6156	28.5	4	5/28/2015	7/29/2015	62	2.2
BH 6148	29.7	4	6/1/2015	9/2/2018	1189	32.0
BH 6301	30.0	8	6/1/2015	8/2/2016	428	2.3
BH 6305	19.7	8	6/1/2015	5/23/2018	1087	36.0
BH 6307	30.6	8	6/1/2015	8/19/2018	1175	153.4
BS 0657	31.9	8	6/2/2015	9/27/2015	117	0.2
BS 0658	30.8	8	6/2/2015	4/19/2016	322	51.4
BS 0661	36.0	8	6/2/2015	9/11/2015	101	0.4
BS 0708	33.1	8	6/2/2015	6/26/2015	24	1.2
BH 6290	37.5	8	6/2/2015	8/30/2015	89	29.4
BS 0712	30.5	8	6/8/2015	9/16/2016	466	0.2
BH 6313	28.5	8	6/8/2015	8/6/2016	425	11.5
BH 6314	32.4	8	6/8/2015	10/25/2015	139	6.8
BH 6315	25.6	8	6/8/2015	4/14/2016	311	21.3
BH 6316	24.5	8	6/8/2015	7/15/2017	768	3.7
BS 0668	26.5	8	6/10/2015	9/25/2015	107	172.7
BS 0669	34.0	8	6/10/2015	8/6/2016	423	22.8
BS 0677	32.1	8	6/10/2015	7/3/2015	23	2.2
BS 0732	23.6	8	6/10/2015	5/30/2016	355	211.6
BS 0733	33.6	8	6/10/2015	5/14/2017	704	73.4
BS 0735	26.4	8	6/10/2015	6/5/2016	361	128.9
BH 6296	36.5	8	6/10/2015	9/4/2016	452	47.5
BS 0402	37.1	5	6/26/2015	9/5/2016	437	45.7
BS 0681	25.7	8	6/29/2015	5/29/2016	335	102.5
BS 0685	33.4	8	7/1/2015	7/26/2015	25	87.2
BS 0383	29.8	5	7/6/2015	4/26/2017	660	22.9
BS 0384	33.4	5	7/8/2015	7/16/2017	739	566.6
BS 0686	33.5	8	7/8/2015	5/26/2018	1053	0.1
BS 0687	34.9	8	7/9/2015	8/1/2015	23	0.3
BS 0382	32.1	5	7/14/2015	6/10/2018	1062	416.9
BS 0616	25.9	7	7/14/2015	7/24/2016	376	4.0

Tag Number	Length (in)	Tagging Site	Tagging Date	Capture Date	Days at Large	Distance Traveled (River Miles)
BS 0619	32.0	7	7/14/2015	8/1/2016	384	3.6
BH 6270	32.4	7	7/14/2015	6/10/2018	1062	111.8
BH 6446	27.0	5	3/28/2016	5/28/2016	61	161.9
BH 6363	36.2	2	4/5/2016	5/23/2016	48	133.8
BS 1115	31.6	5	4/18/2016	8/5/2016	109	0.2
BS 1118	31.8	5	4/18/2016	6/21/2016	64	0.2
BS 1120	26.4	5	4/18/2016	4/21/2016	3	3.9
BS 1125	26.1	5	4/18/2016	6/30/2017	438	96.7
BS 1126	33.4	5	4/18/2016	6/21/2016	64	0.6
BS 0833	27.2	2	4/18/2016	5/11/2018	753	31.2
BS 0834	45.5	2	4/18/2016	8/4/2018	838	18.5
BS 0835	44.1	2	4/18/2016	11/2/2016	198	9.8
BH 6369	25.9	2	4/18/2016	8/3/2017	472	23.7
BS 1152	22.8	5	4/19/2016	10/12/2016	176	1.2
BS 1361	23.4	7	4/19/2016	6/6/2018	778	44.9
BS 1366	34.5	7	4/19/2016	8/5/2016	108	4.5
BH 6457	30.7	5	4/19/2016	6/12/2016	54	147.8
BH 6503	22.9	7	4/19/2016	5/24/2017	400	0.0
BS 0867	26.1	2	4/19/2016	6/24/2016	66	2.7
BS 0872	25.6	2	4/19/2016	9/27/2016	161	18.3
BH 6383	46.7	2	4/19/2016	5/22/2016	33	119.4
BH 6389	23.7	2	4/19/2016	3/5/2017	320	3.4
BS 1201	23.4	6	4/20/2016	3/25/2018	704	4.8
BS 1212	23.7	6	4/20/2016	7/2/2016	73	0.9
BH 6516	19.6	6	4/20/2016	6/3/2017	409	9.6
BH 6518	29.5	6	4/20/2016	5/18/2016	28	11.1
BH 6524	22.8	6	4/20/2016	7/31/2016	102	0.5
BH 6527	22.7	6	4/20/2016	5/21/2017	396	26.0
BH 6379	34.4	2	4/20/2016	8/3/2017	470	24.6
BS 1240	25.8	6	4/21/2016	7/21/2018	821	268.2
BS 1257	29.8	6	4/21/2016	5/14/2016	23	0.6
BH 6530	28.4	6	4/21/2016	8/20/2017	486	3.8
BH 6537	29.1	6	4/21/2016	5/26/2018	765	0.9
BS 0881	25.2	2	4/21/2016	7/30/2018	830	9.5
BH 6121	17.9	4	4/22/2016	5/23/2016	31	0.0
BH 6334	35.5	1	4/22/2016	6/19/2016	58	5.8
BS 0744	19.3	1	4/22/2016	8/2/2016	102	24.9
BS 0745	27.6	1	4/22/2016	9/18/2016	149	281.8
BS 0751	22.5	1	4/22/2016	8/15/2016	115	98.4
BS 0759	20.1	1	4/22/2016	6/30/2016	69	6.8
BH 6339	25.7	1	4/22/2016	5/28/2016	36	7.5
BS 0901	17.0	2	4/26/2016	6/21/2016	56	15.7
BS 0935	26.8	3	4/26/2016	6/1/2018	766	2.3
BS 0937	31.7	3	4/26/2016	6/30/2018	795	25.2
BS 0938	17.3	3	4/26/2016	5/6/2018	740	9.8
BH 6412	25.6	3	4/26/2016	1/13/2017	262	2.7

Tag Number	Length (in)	Tagging Site	Tagging Date	Capture Date	Days at Large	Distance Traveled (River Miles)
BS 1264	33.1	6	4/27/2016	5/2/2016	5	0.9
BS 0903	31.8	2	4/28/2016	7/14/2018	807	470.9
BS 0941	30.8	5	4/28/2016	12/10/2017	591	78.0
BS 0942	30.1	5	4/28/2016	9/17/2017	507	2.2
BS 0774	17.8	1	4/28/2016	6/22/2018	785	9.4
BS 1021	19.7	4	4/29/2016	9/22/2017	511	18.6
BS 1023	27.5	4	4/29/2016	8/15/2016	108	0.7
BS 0800	17.7	1	5/3/2016	8/14/2018	833	13.9
BH 6380	19.8	2	5/3/2016	8/12/2017	466	73.3
BS 1167	33.1	5	5/4/2016	7/30/2016	87	1.1
BS 1168	29.0	5	5/4/2016	9/24/2016	143	3.2
BS 0946	28.8	3	5/5/2016	12/9/2017	583	5.2
BS 1383	27.6	8	5/18/2016	7/17/2016	60	0.1
BS 1384	27.2	8	5/18/2016	2/22/2017	280	19.0
BS 1386	27.2	8	5/18/2016	7/15/2016	58	4.6
BS 1025	19.0	4	5/23/2016	8/13/2018	812	56.2
BH 6351	35.1	1	5/23/2016	6/3/2018	741	305.0
BH 6344	41.7	1	5/23/2016	7/16/2016	54	40.8
BS 0956	26.1	3	5/24/2016	8/26/2017	459	1.4
BS 0957	19.2	3	5/24/2016	8/4/2018	802	16.3
BS 0959	19.9	3	5/24/2016	6/18/2017	390	0.7
BH 6423	29.0	3	5/24/2016	5/9/2017	350	144.5
BS 0982	37.3	3	5/26/2016	5/23/2017	362	213.3
BS 1175	31.2	5	5/26/2016	7/1/2016	36	2.9
BH 6425	43.2	3	5/26/2016	5/26/2017	365	192.6
BS 1177	35.3	5	5/27/2016	3/4/2017	281	19.6
BS 0817	37.2	1	5/31/2016	10/5/2018	857	169.2
BS 1028	27.1	4	5/31/2016	5/21/2017	355	83.9
BS 0819	38.0	1	5/31/2016	5/12/2017	346	90.0
BH 6359	47.3	1	6/1/2016	7/22/2018	781	522.9
BS 1029	18.9	4	6/2/2016	8/15/2017	439	0.9
BH 6130	21.4	4	6/2/2016	6/5/2016	3	2.4
BS 1394	28.3	8	6/7/2016	8/20/2016	74	0.9
BS 1395	24.2	8	6/7/2016	9/3/2016	88	11.6
BS 1398	32.6	8	6/7/2016	7/31/2016	54	3.4
BS 1404	34.5	8	6/7/2016	6/10/2018	733	2.9
BS 1409	32.5	8	6/7/2016	8/4/2017	423	32.3
BH 6559	41.4	8	6/7/2016	9/3/2016	88	14.0
BH 6562	27.6	8	6/7/2016	7/8/2017	396	0.2
BH 6563	28.3	8	6/7/2016	4/29/2018	691	14.8
BS 1423	31.6	8	6/8/2016	7/23/2016	45	2.5
BS 1427	18.9	8	6/8/2016	8/21/2016	74	1.2
BS 1432	30.5	8	6/8/2016	8/4/2017	422	5.4
BS 1436	35.4	8	6/8/2016	8/21/2016	74	2.1
BS 1438	32.5	8	6/8/2016	8/13/2016	66	0.9
BH 6573	32.2	8	6/8/2016	7/9/2016	31	7.0

Tag Number	Length (in)	Tagging Site	Tagging Date	Capture Date	Days at Large	Distance Traveled (River Miles)
BH 6577	22.0	8	6/8/2016	11/4/2016	149	54.9
BH 6579	33.5	8	6/9/2016	8/18/2016	70	1.0
BS 1342	29.9	7	6/13/2016	8/13/2016	61	3.0
BS 1343	31.3	7	6/13/2016	7/1/2017	383	2.1
BH 6497	26.0	7	6/13/2016	5/1/2018	687	168.6
BH 6498	23.4	7	6/13/2016	6/16/2018	733	11.9
BH 6499	26.2	7	6/13/2016	2/25/2018	622	0.1
BS 1320	31.2	7	6/14/2016	6/25/2016	11	24.2
BS 1321	27.6	7	6/14/2016	7/24/2016	40	110.9
BS 1323	31.5	7	6/14/2016	6/18/2017	369	0.6
BS 1325	26.8	7	6/14/2016	7/19/2016	35	0.4
BS 1328	27.2	7	6/14/2016	7/19/2016	35	16.0
BH 6489	33.8	7	6/14/2016	10/15/2016	123	0.4
BH 6495	30.0	7	6/14/2016	10/2/2016	110	5.7
BS 1452	36.0	8	6/15/2016	5/27/2017	346	2.7
BS 1269	37.1	6	6/16/2016	5/26/2018	709	2.0
BS 1270	36.4	6	6/16/2016	7/28/2018	772	12.8
BS 1273	31.5	6	6/16/2016	8/13/2016	58	2.7
BH 6539	49.8	6	6/16/2016	7/9/2016	23	6.2
BH 6540	35.6	6	6/16/2016	8/6/2016	51	1.7
BH 6542	45.8	6	6/16/2016	6/26/2016	10	2.4
BH 6544	42.5	6	6/16/2016	11/27/2016	164	1.5
BS 1277	32.1	6	6/17/2016	7/10/2016	23	0.6
BH 6547	31.0	6	6/17/2016	6/24/2017	372	0.3
BH 6548	35.6	6	6/17/2016	10/2/2016	107	2.2
BH 6549	35.4	6	6/20/2016	8/3/2016	44	31.3
BH 6550	34.4	6	6/20/2016	11/26/2017	524	26.9
BH 6552	33.8	6	6/28/2016	2/11/2017	228	1.1
BS 1316	30.2	7	6/29/2016	6/25/2018	726	57.0
BH 6485	31.2	7	6/29/2016	7/1/2017	367	0.2
BH 6486	44.9	7	6/29/2016	8/29/2018	791	51.3
BH 6488	30.0	7	6/29/2016	7/30/2016	31	0.0
BS 1315	29.8	7	7/7/2016	9/24/2017	444	101.3

Appendix 3. Length frequency distributions of blue catfish collected during low-frequency electrofishing sampling on the Mississippi River during 2015 and 2016 (grey bars) and commercial harvest creel data from the Mississippi River within our study sites during 2015 and 2016 (red bars).