Feasibility of Initiating a Commercial Fishery for Paddlefish in Alabama Reservoirs of the Tennessee River

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Abstract: In recent years, commercial paddlefish harvesters have renewed their requests for opening a potential commercial paddlefish (*Polyodon spathula*) season in Alabama reservoirs of the Tennessee River, including part of Pickwick Reservoir, all of Wilson and Wheeler reservoirs, and the majority of Guntersville Reservoir. These reservoirs of the Tennessee River once supported robust stocks of paddlefish; however, beginning in the 1940s overexploitation became evident as the number of paddlefish harvested declined. Because of this widespread overharvest, a commercial and recreational moratorium on paddlefish possession and harvest in all Alabama waters went into effect in November 1988. We report on recent paddlefish sampling efforts in Alabama reservoirs of the Tennessee River to evaluate if paddlefish stocks have recovered to the point that sustainable commercial harvest is feasible. We used gill nets with various configurations and expended a total of 3125.4 h of gillnetting effort from all four reservoirs combined from October 2016 to January 2021. We captured 17 paddlefish conferring an overall CPUE of 0.005 fish h^{-1}. Standardizing gill-net effort across configurations resulted in CPUEs ranging from 0.00 to 0.05 fish m^{-2} per 24-hr soak time. Biological data obtained from 10 of the 17 paddlefish collected during gillnetting indicated these 10 fish were sexually mature with ages ranging from 8 to 16 years. Only two female paddlefish were harvested during an experimental commercial paddlefish season from Guntersville Reservoir in 2017. Due to extremely low CPUEs, results of this study indicate Tennessee River paddlefish stocks in Alabama would not support a sustainable commercial fishery at this time. We recommend continuation of the paddlefish moratorium and monitoring of the population using a standardized design based on gear and effort. We further recommend consulting with adjoining state resource agencies to seek a moratorium on commercial paddlefish harvest in shared waters of Guntersville Reservoir in the Tennessee River.

Key words: commercial harvest, CPUE, age structure, moratorium

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Paddlefish (*Polyodon spathula*) are found in the Tennessee River and Mobile River basins of Alabama (Boschung and Mayden 2004, Mettee et al. 2009). The Tennessee River basin encompasses an area of 105,905 km^2, including parts of Virginia, North Carolina, Tennessee, Georgia, Alabama, and Mississippi; the river finally discharges into the Ohio River in Kentucky. The Mobile River basin is the largest drainage on the Gulf Coast east of the Mississippi River and encompasses 113,900 km^2 in Georgia, Tennessee, Alabama, and Mississippi. Six major river systems compose the basin, including the Black Warrior, Tombigbee, Alabama, Cahaba, Coosa, and Tallapoosa rivers, joining to flow into Mobile Bay and the Gulf of Mexico. Historically, rivers in the Tennessee and Mobile River basins sustained abundant paddlefish populations that supported recreational and commercial fisheries (Gengerke 1986). Nonetheless, the legacy of commercial paddlefish harvest in Alabama has been one of overexploitation with limited to no regulations (Rider et al. 2019). Overexploitation of paddlefish was evident in the Tennessee River by the early 1940s, as harvest with snag lines declined 84% from 323,865 kg in 1941 to 52,011 kg in 1946 (Pasch and Alexander 1986). Despite this drastic decline in abundance, the Alabama legislature legalized the use of nets in 1946 to encourage increased harvest of paddlefish as demand surged for meat and roe after World War II (Pasch and Alexander 1986). Accordingly, paddlefish harvest increased in 1947 to 68,745 kg but by 1954 had declined to 53,751 kg. Increasing roe prices in the late 1970s resulted in paddlefish harvest peaking at approximately 150,000 kg in 1980 (Gengerke 1986). Through the 1980s, Tennessee River paddlefish stocks farther north in Kentucky and Tennessee also declined due to overfishing, and commercial harvesters then redirected their efforts to Alabama, increasing additional pressure on already depleted stocks (Rider et al. 2019). The additional fishing effort resulted in a severe decline in paddlefish abundance and sizes; therefore, the Alabama Division of Wildlife and Freshwater Fisheries (ADWFF) placed a recreational and commercial moratorium on

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the capture, possession, and harvest of paddlefish in Alabama waters beginning November 1988 (Rider et al. 2012).

By early 1993, ADWFF managers sought a current population assessment to determine if paddlefish stocks had recovered in Alabama reservoirs of the Tennessee River since the moratorium. From November 1993 to June 1994, a total of 346 gillnetting and 20 electrofishing h of effort failed to capture a single paddlefish in this area (Hoxmeier and DeVries 1996). However, these sampling efforts were not extensive. Additional paddlefish sampling was conducted from February to March 2012 in Guntersville Reservoir in consultation with a commercial harvester who had targeted paddlefish before the moratorium. No paddlefish were collected with 72 h of sampling effort; however, the flow was high which made sampling difficult (S. Rider, ADWFF, unpublished data).

By the early 2000s, studies in the Mobile River basin indicated paddlefish abundance in the Alabama River had increased since the moratorium (Rider 2006, Mettee et al. 2009). By 2012, sampling revealed this stock had a robust population with older age classes along with many prime spawning fish present (Scarnecchia et al. 2007, Rider et al. 2012). Therefore, the ADWFF proposed a "provisional" fishery using a proactive approach (Rider et al. 2019) and informed commercial harvesters this approach would allow ADWFF to evaluate the fishery for future seasons. A commercial paddlefish season opened in 2013, but the season was suspended indefinitely in 2018 due to numerous and flagrant violations by commercial paddlefish harvesters (ADWFF 2018).

Despite the indefinite closure of commercial paddlefish harvest in the Alabama River, commercial paddlefish harvesters have continued to voice their support for a commercial paddlefish season in Alabama reservoirs of the Tennessee River, claiming that paddlefish stocks have recovered to the point such a fishery is warranted. In addition, the Tennessee Wildlife and Resources Agency (TWRA) allows commercial paddlefish harvest below Nickajack Lock and Dam, at the headwaters of Guntersville Reservoir. This fishery exists only 14.5 km above where the Tennessee River crosses into Alabama. This limited commercial fishery just upstream of Alabama waters bolstered the commercial paddlefish harvesters' convictions that a commercial fishery downstream in Alabama is warranted. Therefore, our objective was to determine whether paddlefish relative abundance (CPUE) was sufficient to allow commercial harvest in Alabama reservoirs of the Tennessee River.

Study Area

Paddlefish sampling was conducted in Alabama waters of the Tennessee River in Guntersville, Wheeler, Wilson, and Pickwick reservoirs (Figure 1). Guntersville Reservoir has a surface area of 27,478 ha and stretches over 135.2 km from Nickajack Dam in southeastern Tennessee to Guntersville Dam. Wheeler Reservoir begins immediately below Guntersville Dam and flows northwest for 119.3 km, encompassing 27,142 ha. Wilson Reservoir is the smallest of the four reservoirs (6,273 ha), beginning below Wheeler Dam and flowing west for 24.9 km. Pickwick Reservoir begins immediately below Wilson Dam and flows in a southwestern to northwestern direction for 84.3 km, encompassing 17,442 ha. Pickwick Reservoir is a multi-jurisdictional reservoir shared by Mississippi and Tennessee, with most of Guntersville, and all of Wheeler and Wilson entirely in Alabama. Collectively, these four reservoirs have a total surface area of 78,335 ha and encompass 350.4 km of the Tennessee River.

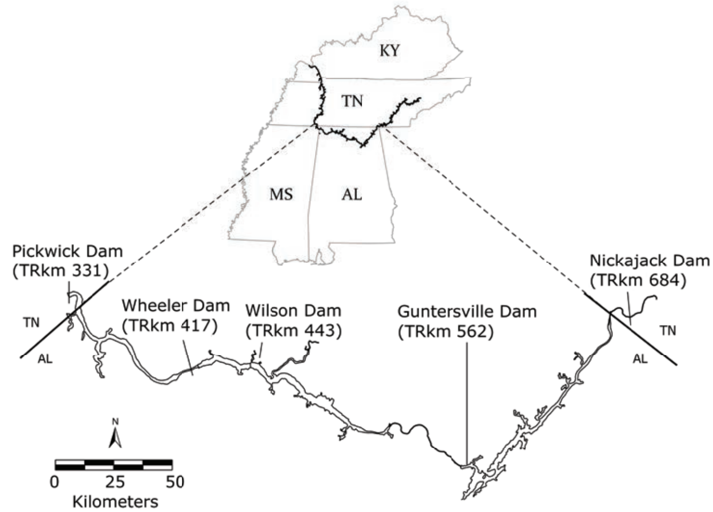

Figure 1. Map of the five mainstem reservoirs that consist of Alabama waters of the Tennessee River where sampling for paddlefish was conducted from October 2016 to January 2021.

Methods

Paddlefish sampling was conducted using gill nets of various configurations, materials, mesh sizes, depths, and lengths in the four reservoirs at varying times from 2016 to 2021. Mono-twist gill nets were 61 m long, 4.9 or 5.5 m deep with 152-mm mesh. Monofilament untied gill nets (i.e., non-hobbled) ranged in lengths of 46, 61, and 91 m, depths of 1.8, 2.4, 3.0, 3.6, 4.3, and 5.5 m, with square (bar measure) meshes sizes of 25, 38, 52, 64, 76, 89, 102, 127, and 152 mm. We also deployed tied-down (i.e., hobbled) gill nets. These nets run a string every 1.8 m along length of the gill net that is attached from the float line to the lead line to reduce the depth of the net. This results in a bag of webbing being formed at the bottom of the net where paddlefish are entangled. Gill nets of this configuration capture more fish from entanglement rather than being wedged in the mesh (Hamley 1980). The use of tied-down gill nets is common with commercial paddlefish harvesters where legal (Hoffnagle and Timmons 1989, Scholten and Bettoli 2007, Geik 2016; Risley et al. 2016). Our monofilament tied-down gill nets were 91 m long and either 3.6 m deep tied-down to 3.0 m or 7.3 m deep tied-down to 5.5 m with square mesh sizes of 76, 102, 127, and 152 mm. Multifilament untied gill nets ranged in lengths of 46 and 61 m with a depth of 3 m and square mesh sizes of 127, 152, and 203 mm; whereas tied-down multifilament gill nets were 61 m long, 3.7 m deep, and tied-up to 1.8 m with square mesh sizes of 76, 102, 127, and 152 mm. Gill nets were either sinking or floating style with floating nets set below the water surface approximately 1 m to prevent passing boats from becoming entangled. Sinking gill nets were set on the bottom of the water body or in the mid-water column. We deployed gill nets in the afternoon to early evening and pulled the following morning with set times ranging from 15 to 21 h. Sample locations were determined using commercial harvester input based on historical catches and more recent bycatches of paddlefish.

The number of hours to collect paddlefish was an important statistic requested by ADWFF biologists and administrators. Therefore, CPUE was calculated across all net configurations as paddlefish h^{-1} of gill-net effort and was reported to the nearest 0.001 to emphasize the amount of time needed to catch paddlefish. We realized this value may not reflect an accurate CPUE as gill nets deployed were of different configurations as described above and were fished for various soak times. Therefore, we also provided standardized CPUE calculated as paddlefish 100 m^{-2} of gill net per 24-h soak time by mesh size (Paukert and Fisher 1999). Effort did not meet the assumption of normality; therefore, we examined differences in paddlefish hourly CPUE among reservoir and collection date, reservoir combined by collection dates, and standardized CPUE by gill net meshes using a Kruskal-Wallis one-way ANOVA on ranks. All statistical analyses were conducted using the statistical software package SigmaStat 3.5 (Systat Software Inc., San Jose, California) with significance determined using $P \leq 0.05$.

Biological data were obtained from all paddlefish collected in Guntersville Reservoir and one paddlefish in Wheeler Reservoir. We did not obtain any biological data from the remaining three and four paddlefish collected from Wheeler and Pickwick reservoirs, respectively, because these fish were released after capture as the crews did not have the space required to keep them. Paddlefish were measured from anterior orbit of the eye along curvature of the body to the fork of the caudal fin (curved eye-to-fork; CEFL) to the nearest mm (Rider et al. 2019). Total fish weights were measured to the nearest 0.2 kg. Gonads were excised, separated from the gonadal fat, and weighed to the nearest 0.1 g; sex was determined visually from the excised gonads (Scarnecchia et al. 2007). We used the gonadosomatic index (GSI) which was calculated for each individual with the following equation: GSI = 100 x gonad weight (g)/body weight (g) and reproductive staging guides to assign reproductive maturity (Crim and Glebe 1990, Scarnecchia et al. 2007, Webb et al. 2019). To determine age, the left lower dentary bone was excised, processed, and sectioned as described in Scarnecchia et al. (1996) and ages assigned by counting annuli (Scarnecchia et al. 2006).

In 2017, the ADWFF initiated a seven-week experimental commercial paddlefish harvest season in the upper reaches of Guntersville Reservoir to provide current commercial catch data (ADWFF 2017). Commercial paddlefish harvest numbers and statistics were obtained from the Alabama Daily Commercial Paddlefish Harvester and Dealer's Report (Rider et al. 2019). Commercial paddlefish harvesters were required by regulation to submit these reports on a weekly basis (ADWFF 2017). For each harvested female, the CEFL, total fish weight, total egg weight, and total screened egg weight were required. The harvesters also provide their start and ending fishing times and number of gill nets fished each day. In addition to the data provided by commercial paddlefish harvesters, fisheries biologists with the River and Stream Fisheries Program of ADWFF obtained paddlefish harvest data via check stations. Independent biological data from harvested female paddlefish were obtained to verify biological data provided by commercial paddlefish harvesters.

Because commercial paddlefish harvest remained open and legal in the upper reaches of Guntersville Reservoir in Tennessee during this study, we obtained commercial paddlefish harvest numbers by sex and total egg weights (kg) from below Nickajack Dam in Tennessee from TWRA commercial fish reports (Ganus 2016, 2017, 2018, 2020, 2021). Harvest numbers from 2011 to 2015 were obtained from TWRA's commercial harvest database (J. E. Ganus, TWRA, unpublished data). Reporting commercial paddlefish harvest data was mandated by the State of Tennessee (Rule 1660-1-30) with roe-harvest data collected using Daily Commercial Roe Fish Harvest Reports (WR-0896). The number of female paddlefish harvested met the assumption of normality; therefore, we examined the difference in the number of paddlefish harvested from 2010–2015 compared to 2016–2021 using a two-sample *t*-test with the statistical package SigmaStat 3.5. Significance was determined using $P \leq 0.05$.

Results

We collected 17 paddlefish from the four study reservoirs after expending 3125.4 h of gillnetting effort (Table 1). Overall mean (SD) CPUE was 0.005 (0.006) fish h^{-1} which translates to 200 h of gillnetting effort required to catch one paddlefish. Nine of the 17 paddlefish were collected from Guntersville Reservoir with

Table 1. Total number of gill-net sets, effort (gill net-h), number of paddlefish collected, median and mean CPUE (fish h^{-1}) by reservoir and date from Alabama reservoirs of Tennessee River.

Reservoir	Date	Gill nets	Effort	*n*	Median	Mean
Guntersville	Oct 2016	14	171.7	3	0.0	0.017
Guntersville	Nov 2016	28	504.0	1	0.0	0.002
Guntersville	Jun 2017	20	448.4	5	0.0	0.011
Guntersville	Jul 2017	19	436.1	0	0.0	0.000
Wheeler	Feb 2017	3	54.0	0	0.0	0.000
Wheeler	Nov 2017	10	174.2	1	0.0	0.006
Pickwick	Nov 2017	11	185.0	0	0.0	0.000
Wheeler	Mar 2018	3	54.0	0	0.0	0.000
Pickwick	May 2020	18	216.0	4	0.0	0.019
Wheeler	Jun 2020	18	216.0	3	0.0	0.014
Wilson	Jul 2020	8	96.0	0	0.0	0.000
Pickwick	Oct 2020	12	144.0	0	0.0	0.000
Wilson	Oct 2020	8	96.0	0	0.0	0.000
Wheeler	Oct 2020	12	144.0	0	0.0	0.000
Pickwick	Nov 2020	8	96.0	0	0.0	0.000
Wheeler	Jan 2021	3	90.0	0	0.0	0.000
	Total	195	3125.4	17	0.0	0.005

Table 2. Total number of gill nets, number of paddlefish collected, median and mean paddlefish CPUE by mesh size from Alabama reservoirs of the Tennessee River, 2016 to 2021. CPUE is reported as paddlefish 100 m^{-2} of gill net per 24 h soak time. Mesh size (mm) for paddlefish collected in experimental gill nets (i.e., 76-102-127) was not recorded; therefore, CPUE was calculated per experimental gill net.

Mesh size (mm)	Gill nets	*n*	Median	Mean
89	7	0	0.0	0.00
102	7	0	0.0	0.00
127	10	0	0.0	0.00
152	80	9	0.0	0.02
203	7	0	0.0	0.00
76-102-127	84	8	0.0	0.05
Total	195	17	0.0	0.03

CPUEs ranging from 0.000 to 0.017 fish h^{-1} with a mean of 0.008 (0.008) fish h^{-1}. Four paddlefish were caught in each of Wheeler and Pickwick reservoirs, with CPUEs ranging from 0.000 to 0.019 fish h^{-1} across reservoirs; mean CPUE was 0.003 (0.006) fish h^{-1} at Wheeler Reservoir and 0.005 (0.009) fish h^{-1} from Wheeler and Pickwick reservoirs, respectively. We did not collect any paddlefish from Wilson Reservoir. Paddlefish CPUE was similar across reservoirs and sample dates ($H = 17.9$, df = 15, $P = 0.264$) or among reservoirs when combined by collection date ($H = 1.76$, df = 3, $P = 0.624$).

Standardized CPUEs ranged from 0 to 0.05 paddlefish m^{-2} of gill net per 24-h soak time (Table 2) and was similar among the various mesh sizes used ($H = 2.47$, df = 5, $P = 0.78$). Similar with the hourly CPUE, the standard CPUE indicated it would take excessive effort to collect one paddlefish. For example, using a 91.4-m x 7.3-m gill net it would take 160 h of effort to collect one paddlefish.

For female paddlefish ($n = 4$) CEFL and total weights ranged from 1147 to 1234 mm, and 25.2 to 34.4 kg, respectively (Table 3). All females were age 13 or 14 and were sexually mature individuals based on GSIs and visual inspection of the ovaries. Male paddlefish ($n = 6$) CEFL and total weights ranged from 847 to 1177 mm, and 12.5 to 24.0 kg, respectively. Ages ranged from 8 to 15 years and these males were classified as sexually mature based on visual inspection of the gonads (Table 3).

The 2017 Alabama experimental commercial paddlefish season in Guntersville Reservoir only yielded 2 harvestable female paddlefish, generating a CPUE of 0.02 fish h^{-1} (Table 3). Commercial harvesters caught more paddlefish (males or undersized females) but did not record accurately the total number as required by regulation and only fished 2 of 7 weeks that were open for commercial paddlefish fishing due to high water. The TWRA commercial harvest data documented 117 female paddlefish harvested below

Table 3. Biological data for paddlefish collected by ADWFF biologists or commercial paddlefish harvesters (CPH) from the Alabama reservoirs of the Tennessee River, 2016 to 2017. CEFL is the curved-eye-to-fork length, and GSI is the gonadosomatic index.

Collector	Date collected	CEFL (mm)	Sex	Maturity/ Reproductive condition	Total weight (kg)	Gonad weight (g)	GSI	Age
ADWFF	2 Nov 2016	1125	M	Mature/ Pre-spawn	23.8	371.0	1.6	15
ADWFF	2 Nov 2016	1234	F	Mature/ Gravid	34.4	6370.0	18.5	13
ADWFF	2 Nov 2016	1148	F	Mature/ Gravid	25.8	3970.0	15.4	13
ADWFF	3 Nov 2016	1114	M	Mature/ Pre-spawn	23.4	544.3	2.3	13
ADWFF	19 Jun 2017	1147	F	Mature/ Post-spawn	25.2	888.3	3.5	13
ADWFF	19 Jun 2017	1118	M	Mature/ Post-spawn	24.0	79.4	0.3	14
ADWFF	19 Jun 2017	1185	F	Mature/ Post-spawn	27.4	982.0	3.6	14
ADWFF	19 Jun 2017	965	M	Mature/ Post-spawn	16.9	61.7	0.4	9
ALDWFF	19 Jun 2017	847	M	Mature/ Post-spawn	12.5	42.6	0.3	8
ADWFF	29 Nov 2017	1177	M	Mature/ Pre-spawn	30.2	330.0	1.1	16
CPH	9 Mar 2017	1130	F	Mature/ Gravid	26.3	4.8	18.3	15
CPH	7 Mar 2017	1213	F	Mature/ Gravid	29.5	4.5	15.3	n/a

Table 4. Number of paddlefish harvested by commercial harvesters below Nickajack Dam at the headwaters of Guntersville Reservoir, Tennessee River, Tennessee, 2011 to 2021.

Harvest season	Females	Males	Total	Total egg weight (kg)
2010–2011	29	9	38	44.90
2011–2012	36	1	37	64.70
2012–2013	47	5	52	95.10
2013–2014	39	6	45	89.60
2014–2015	26	4	30	66.80
2015–2016	16	0	16	48.50
2016–2017	5	20	25	20.40
2017–2018	7	0	7	25.80
2018–2019	6	0	6	12.70
2019–2020	4	0	4	13.10
Total	215	45	260	481.6

Nickajack Dam from 2010 to 2015, with catches ranging from 26 to 47 per year. However, the number of female paddlefish harvested from 2016 to 2020 in this area ranged from 4 to 16. On average more female paddlefish were harvested the first five years ($\bar{x} = 35$, $SD = 8$) compared to the last five years ($\bar{x} = 8$, $SD = 5$) ($t = 6.5$, $df = 8$, $P < 0.001$; Table 4).

Discussion

Our results indicate paddlefish populations in the Alabama reservoirs of the Tennessee River are still recovering from past depletion and thus vulnerable to overfishing. For example, CPUEs from paddlefish surveys conducted in the Alabama River (Mobile River basin) from 2005 to 2008 ranged from 0.1 to 2.3 fish h^{-1} with a mean (SD) of 0.70 (0.67) fish h^{-1} before commercial harvest was allowed (Rider 2012). This is a difference in orders of magnitude compared to our results from the Tennessee River. On average it took 1.4 h to catch a paddlefish in the Alabama River; whereas with our sampling in the Tennessee River it took 200 h to catch a paddlefish. Likewise, in the lower Tombigbee River, Alabama, which has been closed to commercial harvest since the 1988 moratorium, gill net CPUEs from 2012 to 2014 ranged from 0 to 14.6 fish h^{-1} with a mean (SD) of 1.15 (3.22) fish h^{-1} (S. Rider, ADWFF, unpublished data). In that system, a total of 0.87 h of effort was required on average to catch one paddlefish. In contrast to the Tennessee River, both the lower Tombigbee and Alabama rivers demonstrated sufficient relative abundance to justify a commercial season, which was initiated in the Alabama River beginning in 2013. However, no such justification was found in the Alabama reservoirs of the Tennessee River, even though legal commercial paddlefish fishing has not been conducted since 1988.

Commercial paddlefish harvest and catch data reflected comparable results as our fishery surveys. Hoxmeier and DeVries (1997) conducted the only other paddlefish survey in Alabama reservoirs of the Tennessee River, which occurred just five to six years after the moratorium went into effect. They failed to collect any paddlefish, although their sampling effort (366 h) was low compared to our sampling effort. However, their results indicated how heavily the paddlefish population was exploited prior to 1988. Likewise, the CPUE recorded for the 2017 experimental commercial paddlefish season in Guntersville was an order of magnitude less than what was observed in the Alabama River, where the mean (SD) CPUE for commercial harvesters from 2013 to 2017 was 0.14 (0.03) fish h^{-1} (S. Rider, ADWFF, unpublished data). Therefore, 30 years after the paddlefish moratorium was authorized in Alabama, the Tennessee River populations there had shown little signs of recovery.

Although a commercial fishery still exists on the Tennessee River upstream of Alabama below Nickajack Dam, the number of paddlefish harvested has also decreased over the last decade. A total of 215 female paddlefish were harvested over 2010–2020 (J. E. Ganus, TWRA, unpublished data; Ganus 2016, 2017, 2018, 2020, and 2021), but most (82.3%) of them were harvested from 2011–2015 and paddlefish harvest decreased 5-fold from 2010–2015 compared to 2015–2020. The commercial paddlefish season in the upper reaches of Guntersville Reservoir of Tennessee may in fact be limiting or suppressing the Reservoir's paddlefish population. Paddlefish are highly migratory and often congregate below dams and other barriers where they become more vulnerable to overfishing (Tripp et al. 2019). The recent decline in paddlefish harvest numbers during 2015–2020 and low relative abundance found in our survey indicate that recruitment overfishing may be occurring in this population. Thus, both Tennessee and Alabama data indicate that paddlefish populations in this section of the Tennessee River have not rebounded and may in fact have declined. We expended a large amount of effort targeting paddlefish in the Alabama reservoirs of the Tennessee River in this study; however, these reservoirs are large, and this effort may still be low relative to their surface area. Thus, increased sampling/monitoring efforts are needed in these reservoirs.

Downstream of our study area in Kentucky Lake, ages of paddlefish in an exploited population ranged from 2 to 16 years old (Hageman et al. 1986, Hoffnagle and Timmons 1989). However, by 2004 the fishery was overfished with no ages over 11 years (Scholten and Bettoli 2005). Hoxmeier and DeVries (1997) examined age structure of the Alabama River population just five to six years after implementation of the statewide harvest moratorium and found that 92% of these fish were age 7 or younger. Similar truncated age structures were found in exploited Louisiana paddlefish populations (Reed et al. 1992). Due to their longevity and late age at maturation, paddlefish populations recovery from overfishing often occurs over decadal time scales and truncated age structures are indicative of heavily exploited populations (Carlson and Bonislawsky 1981, Graham 1997). Conversely, unexploited, or lightly exploited paddlefish populations routinely have fish exceeding 20 years in age (Scarnecchia et al. 1996 for the Yellowstone River, Montana/North Dakota; Runstrom et al. 2001 for the Wisconsin River, Wisconsin; and S. Rider, ADWFF, unpublished data for the Tombigbee River, Alabama). However, despite no harvest being allowed in the Alabama reservoirs of the Tennessee River since 1988, the oldest fish collected during this study was 16 years old (i.e., 2001-year class). Thus, although recruitment is occurring, it seems to be at a lower rate in Alabama reservoirs of the Tennessee River compared to other Alabama river systems. Lower recruitment could be associated with insufficient discharge rates during the spawning period and/or associated physical habitat (Schlosser 1982, Poff and Allan 1995, Ward et al. 1999, Nilsson and Svedmark 2002).

Movement from closed and/or protected areas (i.e., Alabama reservoirs of the Tennessee River) for mobile species like paddlefish has been documented for marine and freshwater fishes (Hayes et al. 1997, Apostolaki et al. 2002, Kerwath et al. 2009, Knip et al. 2012). Our data suggests that low paddlefish abundances in the Tennessee River may reflect fish moving upriver or downriver out of Alabama water where harvest is closed into areas where they could be exploited. However, the large lock and dams found in the Tennessee River constitute substantial barriers to movement. Paddlefish have been documented moving upriver and downriver of low-head dams when inundated; however, movement through these larger dams and locks is substantially less (Moen et al 1992, Zigler et al 2003, Mettee et al. 2009). Also, if this did occur then paddlefish from other reservoirs where exploitable populations exist would also be moving into the closed areas in Alabama. At this time, we cannot determine whether this is occurring, but we believe it is unlikely. Therefore, synchronous regulations are paramount for management and conservation of paddlefish populations in waters shared between states, and we recommend the TWRA and ADWFF seek a joint paddlefish harvest moratorium in Guntersville Reservoir to the headwaters below Nickajack Dam in Tennessee.

The low relative abundance and young ages of this unexploited paddlefish population indicate it is still recovering and recruitment is low compared to other populations in Alabama after the moratorium. The causes of low recruitment are uncertain at this time and additional research is warranted to determine what abiotic and biotic factors are affecting recruitment. Potential causes and/or bottlenecks may be changes to reservoir operations, loss of habitat, illegal harvesting, and continued commercial harvest of paddlefish in shared waters of the Tennessee River. Nonetheless, Alabama reservoirs of the Tennessee River paddlefish stocks have not recovered to date to allow for sustainable commercial harvest.

We propose the following management recommendations to accurately describe the characteristics of the paddlefish populations in the Alabama reservoirs of the Tennessee River.

1) Develop annual stratified-random sampling protocols to ensure all habitats and areas of the reservoir are represented with the appropriate amount of effort.

2) Sample annually during the winter (December–February) and spring (March–May).

3) Use standardized gear configurations for adult and juvenile sampling.

4) Use standardized sampling effort.

5) Implant telemetry tags in paddlefish to discern if movement into and out of these Alabama reservoirs is occurring.

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Literature Cited

Alabama Division of Wildlife and Freshwater Fisheries (ADWFF). 2017. Alabama Administrative Code Regulation 220-2-.158 Guntersville Reservoir paddlefish management area and season established. Montgomery, Alabama.

_____. 2018. Alabama River commercial paddlefish seasons suspended indefinitely. Montgomery, Alabama. <https://www.outdooralabama.com/node/2391>. Accessed 15 July 2021.

Apostolaki, P., E. J. Milner-Gulland, M. K. McAllister, and G. P. Kirkwood. 2002. Modelling the effects of establishing a marine reserve for mobile fish species. Canadian Journal of Fisheries and Aquatic Sciences 59:405–415.

Boschung, H. T. and R. L. Mayden. 2004. Fishes of Alabama. Smithsonian Books, Washington, D. C.

Carlson, D. M. and P. S. Bonislawsky. 1981. The paddlefish (*Polyodon spathula*) fisheries of the midwestern United States. Fisheries 6:17–27.

Crim, L. W. and B. D. Glebe. 1990. Reproduction. Pages 529–533 *in* C. B. Schreck and P. B. Moyle, editors. Methods for fish biology. American Fisheries Society, Bethesda, Maryland.

Ganus, E. 2016. Tennessee's commercial fish and mussel report. Report no. 16-12. Tennessee Wildlife Resources Agency, Fisheries Management Division, Nashville, Tennessee.

_____. 2017. Tennessee's commercial fish and mussel report. Report no. 17-09. Tennessee Wildlife Resources Agency, Fisheries Management Division, Nashville, Tennessee.

_____. 2018. Tennessee's commercial fish and mussel report. Report no. 18-07. Tennessee Wildlife Resources Agency, Fisheries Management Division, Nashville, Tennessee.

_____. 2020. Tennessee's commercial fish and mussel report. Report no. 20-02.

Tennessee Wildlife Resources Agency, Fisheries Management Division, Nashville, Tennessee.

_____. 2021. Tennessee's commercial fish and mussel report. Report no. 21-03. Tennessee Wildlife Resources Agency, Fisheries Management Division, Nashville, Tennessee.

Geik, A. 2016. Movement, habitat use, reproduction, and commercial harvest of paddlefish in Lake Dardanelle, Arkansas. Master's Thesis, Arkansas Tech University, Jonesboro.

Gengerke, T.W. 1986. Distribution and abundance of paddlefish in the United States. Pages 22–35 *in* J.G. Dillard, L.K. Graham, and T.R. Russell, editors. The paddlefish: status, management, and propagation. Special Publication No. 7. American Fisheries Society, North Central Division, Bethesda, Maryland.

Graham, K. 1997. Contemporary status of the North American paddlefish, Polyodon spathula. Environmental Biology of Fishes 48:279–289.

Hageman, J.R., D.C. Timpe, and R.D. Hoyt. 1986. The biology of paddlefish in Lake Cumberland, Kentucky. Proceedings of the Annual Conference of the Southeastern Association of Fish and Wildlife Agencies 40:237–248.

Hamley, J.M. 1980. Sampling with gill nets. Pages 37–53 *in* T. Backiel and R.L. Welcomme, editors. Guidelines for sampling fish in inland waters. Advisory Commission Technical Paper 33. FAO European Inland Fisheries, Rome, Italy.

Hayes, M.C., L.F. Gates, and S.A. Hirsch. 1997. Multiple catches of smallmouth bass in a special regulation fishery. North American Journal of Fisheries Management 17:182–187.

Hoffnagle, T.L. and T.J. Timmons. 1989. Age, growth, and catch analysis of the commercially exploited paddlefish population in Kentucky Lake, Kentucky-Tennessee. North American Journal of Fisheries Management 9:316–326.

Hoxmeier, R.J. and D.R. Devries. 1996. Status of paddlefish in the Alabama waters of the Tennessee River. North American Journal of Fisheries Management 16:935–938.

Kerwath, S.E., E.B. Thorstad, T.F. Næsje, P.D. Cowley, F. Økland, C. Wilke, and C.G. Attwood. 2009. Crossing invisible boundaries: the effectiveness of the Langebaan Lagoon Marine Protected Area as a harvest refuge for a migratory fish species in South Africa. Conservation Biology 23:653–661.

Knip, D.M., M.R. Heupel, and C.A. Simpfendorfer. 2012. Evaluating marine protected areas for the conservation of tropical coastal sharks. Biological Conservation 148:200–209.

Mettee, M.F., P.E. O'Neil, and S.J. Rider. 2009. Paddlefish movements in the lower Mobile River basin, Alabama. Pages 63–81 *in* C.P. Paukert and G.D. Scholten, editors. Paddlefish management, propagation, and conservation in the 21st century. American Fisheries Society, Bethesda, Maryland.

Moen, C.T., D.L. Scarnecchia, and J.S. Ramsey. 1992. Paddlefish movements and habitat use in Pool 13 of the upper Mississippi River during abnormally low river stages and discharges. North American Journal of Fisheries Management 12:744–751.

Nilsson, C. and M. Svedmark. 2002. Basic principles and ecological consequences of changing water regimes: riparian plant communities. Environmental Management 30:468–480.

Pasch, R.W. and C.M. Alexander. 1986. Effects of commercial fishing on paddlefish populations. Pages 46–53 *in* J.G. Dillard, L.K. Graham, and T.R. Russell, editors. The paddlefish: status, management, and propagation. Special Publication No. 7. American Fisheries Society, North Central Division, Bethesda, Maryland.

Paukert, C.P. and W.L. Fisher. 1999. Evaluation of paddlefish length distributions and catch rates in three mesh sizes of gill nets. North American Journal of Fisheries Management 19:599–603.

Poff, N.L. and J.D. Allan. 1995. Functional organization of stream fish assemblages in relation to hydrological variability. Ecology 76:606–627.

Reed, B.C., W.E. Kelso, and D.A. Rutherford 1992. Growth, fecundity, and mortality of paddlefish in Louisiana. Transactions of the American Fisheries Society 121:378–384.

Rider, S.J. 2006. Population status of paddlefish (*Polyodon spathula*) in the Alabama River. Interim project report, 2005. Alabama Division of Wildlife and Freshwater Fisheries, River and Stream Fisheries Program, Montgomery, Alabama.

_____, T.R. Powell, and T.W. Ringenberg. 2012. Assessment of an unexploited paddlefish population in the Alabama River. Report ARP-1104. Alabama Division of Wildlife and Freshwater Fisheries, River and Stream Fisheries Program, Montgomery, Alabama.

_____, D.K. Riecke, and D.L. Scarnecchia. 2019. Proactive harvest management of commercial paddlefish fisheries. Pages 267–297 *in* J.D. Schooley and D.L. Scarnecchia, editors. Paddlefish: ecological, aquacultural, and regulatory challenges of managing a global resource. American Fisheries Society, Bethesda, Maryland.

Risley, J.T., R.L. Johnson, and J.W. Quinn. 2016. Evaluation of the commercially exploited paddlefish fishery in the lower Mississippi River of Arkansas. Journal of the Southeastern Association of Fish and Wildlife Agencies 4:52–59.

Runstrom, A.L., B. Vondracek, and C.A. Jennings. 2001. Population statistics for paddlefish in the Wisconsin River. Transactions of the American Fisheries Society 130:546–556.

Scarnecchia, D.L., L.F. Ryckman, Y. Lim, G.J. Power, B.J. Schmitz, and J.A. Firehammer. 2007. Life history and the costs of reproduction in northern Great Plains paddlefish (*Polyodon spathula*) as a potential framework for other Acipenseriform fishes. Reviews in Fisheries Science 15:211–263.

_____, _____, _____, _____, _____, and V. Riggs. 2006. A long-term program for validation and verification of dentaries for age estimation in the Yellowstone-Sakakawea paddlefish stock. Transactions of the American Fisheries Society 135:1086–1094.

_____, P.A. Stewart, and G.J. Power. 1996. Age structure of the Yellowstone–Sakakawea paddlefish stock, 1963–1993, in relation to reservoir history. Transactions of the American Fisheries Society 125:291–299.

Schlosser, I.J. 1982. Fish community structure and function along two habitat gradients in a headwater stream. Ecological Monographs 52:395–414.

Scholten, G.D. and P.W. Bettoli. 2005. Population characteristics and assessment of overfishing for an exploited paddlefish population in the lower Tennessee River. Transactions of the American Fisheries Society 134:1285–1298.

_____ and _____. 2007. Lack of size selectivity for paddlefish captured in hobbled gillnets. Fisheries Research 83:355–359.

Tripp, S.J., B.C. Neely, and R.J. Hoxmeier. 2019. Paddlefish migrations and movements: a review of tagging and telemetry studies. Pages 49–65 *in* J.D. Schooley and D.L. Scarnecchia, editors. Paddlefish: ecological, aquacultural, and regulatory challenges of managing a global resource. American Fisheries Society, Bethesda, Maryland.

Ward, J.V., K. Tockner, and F. Schiemer. 1999. Biodiversity of floodplain ecosystems: ecotones and connectivity. Regulated Rivers: Research and Management 15:125–139.

Webb, M.A.H., J.P. Van Eenennaam, J.A. Crossman, and F.A. Chapman. 2019. A practical guide for assigning sex and stage of maturity in sturgeons and paddlefish. Journal of Applied Ichthyology 35:169–186.

Zigler, S.J., M.R. Dewey, B.C. Knights, A.L. Runstrom, and M.T. Steingraeber. 2003. Movement and habitat use by radio-tagged paddlefish in the upper Mississippi River and tributaries. North American Journal of Fisheries Management 23:189–205.