Characteristics of Commercial Paddlefish Harvest from a Provisional Fishery in the Alabama River, Alabama

Steven J. Rider[1], *Alabama Division of Wildlife and Freshwater Fisheries, River and Stream Fisheries Program, 3608 Fairground Road, Montgomery, AL 36110*

Travis R. Powell, *Alabama Division of Wildlife and Freshwater Fisheries, River and Stream Fisheries Program, 3608 Fairground Road, Montgomery, AL 36110*

Abstract: Due to overharvest of paddlefish (*Polyodon spathula*) throughout Alabama, the Alabama Division of Wildlife and Freshwater Fisheries (ADWFF) approved a moratorium prohibiting the recreational and commercial catch, possession, and harvest of paddlefish beginning November 1988. However, due to increased demand for paddlefish eggs, a provisional fishery for commercial paddlefish harvest was approved beginning March 2013 in the Alabama River, Mobile River Basin, Alabama. As part of this provisional fishery, a new reporting form was required of all commercial paddlefish harvesters to record their daily harvest and effort. We summarized and quantified commercial paddlefish harvest and harvester data from these reports to examine spatial and temporal harvest patterns from 2013 to 2017 and compare to data collected by ADWFF biologists in 2016. A total of 4861 female paddlefish were harvested in all commercial years combined. The number of paddlefish harvested yearly increased from 191 in 2013 to 1457 in 2017 due to increased fishing effort commensurate with demand and price of eggs. Based on standardized effort from gill nets across a range of commercial configurations, median CPUEs increased from 2013 (0.7 fish net-day^{-1}) to 2017 (5.7 fish net-day^{-1}) with an overall median CPUE of 2.0 fish net-day^{-1}. Overall median harvested female curved eye-to-fork length was 927 mm with a median weight of 10.9 kg. Total and screened egg weights from all 5 years combined were 10,867 and 9021 kg, respectively. On average, a harvested female paddlefish yielded 2.3 and 1.9 kg of total egg and screened egg weights, respectively. Overall harvester effort (i.e., number of gill nets, fishing hours available, gill netting, and catch-per-unit-effort) increased annually, resulting in greater numbers of paddlefish harvested. However, harvesters never used the maximum amount of potential effort available to them. Although the fishery was suspended indefinitely in 2018 due to numerous violations, these data provide important insights into commercial paddlefish harvester and harvest characteristics for future management options if a commercial paddlefish fishery reopens in Alabama.

Key words: *Polyodon spathula*, harvester, eggs, gill net, CPUE

Journal of the Southeastern Association of Fish and Wildlife Agencies 10:17–26

The paddlefish (*Polyodon spathula*) is native to the Tennessee River and Mobile River basins of Alabama (Smith-Vaniz 1968, Mettee et al. 1996). The Mobile River Basin is the largest drainage (113,900 km^2) on the Gulf Coast east of the Mississippi River and drains into Mobile Bay, Alabama. The Tennessee River Basin drains into the Ohio River, then ultimately into the Mississippi River; hence, the populations found in this basin are considered part of the Mississippi River Basin paddlefish populations. Mobile River Basin paddlefish populations are genetically unique, smaller in size and weight, and not as long-lived as Mississippi River Basin paddlefish populations (Hoxmeier and DeVries 1997, Heist and Mustapha 2008, O'Keefe and Jackson 2009, Scarnecchia et al. 2011). Although biological and genetic differences exist between populations from these two basins, both populations have been subjected to historical and contemporary overharvest in Alabama (Pasch and Alexander 1986, Rider et al. 2019). Due to a severe decline in paddlefish abundance and sizes in the 1980s, the Alabama Division of Wildlife and Freshwater Fisheries (ADWFF) placed a recreational and commercial moratorium on the capture, possession, and harvest of paddlefish in Alabama waters beginning in November 1988 (Rider et al. 2019, 2021).

In the early 2000s, due to increased market value, demand for paddlefish eggs steadily increased in states where harvest was legal. Commercial paddlefish harvesters sought additional waters to harvest paddlefish and pressured states that did not allow harvest to open additional fisheries. In Alabama, paddlefish population assessments from 2006 to 2012 in the Alabama River indicated paddlefish abundance had increased and contained older age classes of prime spawning females (Rider 2006, Scarnecchia et al. 2007, Mettee et al. 2009, Rider et al. 2012). Thus, ADWFF decided to open a "provisional" commercial fishery in 2013 with a proactive approach to support a long-term sustainable fishery (Rider et al.

1. E-mail: Steve.Rider@dcnr.alabama.gov

2019). After five to seven years, the provisional fishery would be evaluated to determine if it should continue, be suspended, or terminated. Part of this proactive approach included development of a new reporting method for the provisional paddlefish fishery; therefore, ADWFF established the Alabama Daily Commercial Paddlefish Harvester and Dealer's Report (hereafter, the Report). All harvesters and dealer/buyers were required by regulation to complete and submit the Report on a weekly basis. These self-reported commercial data allowed ADWFF to track harvest and effort data and compare those to data collected independently by ADWFF fisheries biologists. The objectives of this study were to 1) summarize and quantify spatial and temporal commercial paddlefish harvest and effort data from the Alabama River provisional commercial paddlefish fishery from 2013 to 2017, 2) compare length data obtained from harvested fish processed at fish houses to length data provided in the Report, and 3) evaluate how river stage was related to commercial paddlefish harvest.

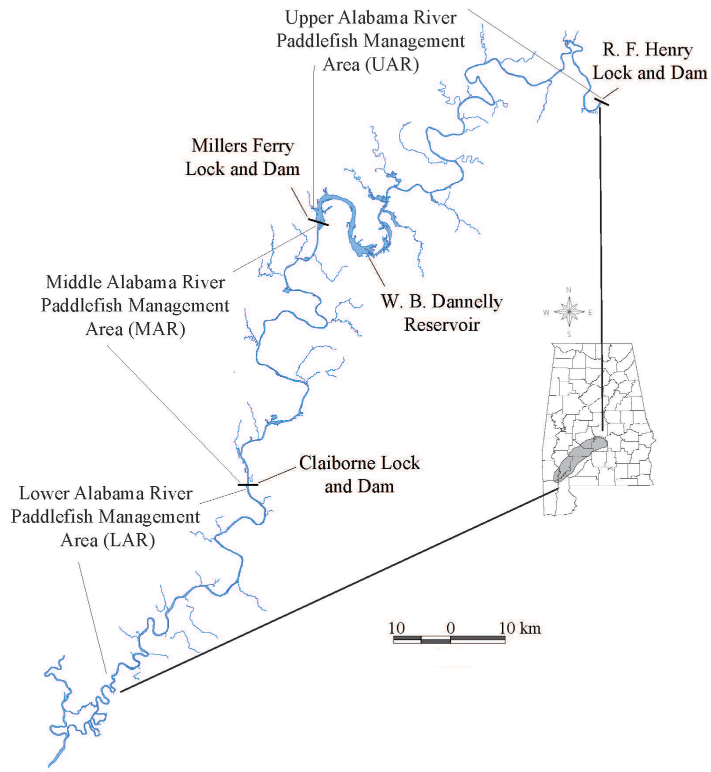

Figure 1. Alabama River Paddlefish Management Areas (mainstem river only; tributaries prohibited) for the provisional commercial paddlefish fishery from 2013 to 2017.

Study Area

The Alabama River is formed by the confluence of the Tallapoosa and Coosa rivers near Fort Toulouse, about 24 km north of Montgomery. The river flows 161 km in a westerly direction through Selma, then southwesterly 338 km until it merges with the Tombigbee River to form the Mobile River (Figure 1). The Alabama River watershed comprises an area of 15,600 km^2 and drains 57,415 square km^2 in 18 counties. Three sets of locks and dams operated by the U. S. Army Corps of Engineers (USACE) are located at river kilometer (rkm) 380.1 (Robert F. Henry Lock and Dam), rkm 213.9 (Millers Ferry Lock and Dam), and rkm 116.8 (Claiborne Lock and Dam) (Figure 1).

Commercial paddlefish harvest was allowed for three areas in the Alabama River designated as Paddlefish Management Areas (PMAs): the Upper Alabama River (UAR; below Robert F. Henry Lock and Dam), Middle Alabama River (MAR; below Millers Ferry Lock and Dam), and Lower Alabama River (LAR; below Claiborne Lock and Dam) PMAs. The UAR comprised the mainstem portion of the river (all tributaries excluded) from 379 to 333.1 and 317.2 to 267.2 rkm. The MAR and LAR comprised the mainstem (all tributaries excluded) from 211.8 to 137.8 and 115.6 to 44.1 rkm, respectively. In all, a total of 241.4 rkm of the Alabama River was open to commercial paddlefish harvest.

Methods

Commercial paddlefish harvest and harvester data were obtained from the Report (Rider et al. 2019). Before the fishery opened each year a meeting was held with all commercial harvesters that held a permit for that particular year to explain the regulations and reporting requirements and to answer any questions or concerns from harvesters. These requirements for each harvester included recording start and end fishing time each day (i.e., total hours fished), number of gill nets used per day, number of gill nets set (i.e., the number times all gill nets were set and checked each day), and number of paddlefish released. Each legally harvested fish was required to be tagged with an individually numbered carcass tag attached to the dorsal fin (Rider et al. 2019). Data required for each harvested fish were curved eye-to-fork length (CEFL; measured from anterior orbit of the eye along curvature of the body to the fork of the caudal fin), total fish weight, total egg weight, and total screened egg weight (Rider et al. 2019). Screened egg weight is the total weight after the eggs have been processed or gently massaged through a screen mesh to remove and separate the eggs from the ovary epithelium and connective tissue. Additionally, ADWFF fisheries biologists visited fish houses on several occasions in 2016 where paddlefish dealers and buyers were processing harvested fish to verify and compare collected data with commercial reported data. In 2013, both male and female paddlefish over 864 mm (34 in) CEFL were legal for harvest. However, ADWFF met with all harvesters prior to the opening in 2014, and based on harvesters' recommendation and support, this regulation was revised to allow only egg-bearing females over 864 mm CEFL to be eligible for harvest. For this paper, only egg-bearing female harvest and effort data are presented.

Harvesters were limited to the following gill net requirements: total length not to exceed 61 m, total depth not to exceed 7.3 m, minimum mesh size of 152 mm bar measure (i.e., knot to knot), no hobbled nets, and a maximum of five nets could be fished concurrently each day. All harvesters reported fishing nets with lengths of 61 m and mesh of 152 mm. Gill-net depth was not required for the Report, but after intercepting harvesters on the water and at boat ramps we asked depth of nets used, which varied from 3.7 to 7.3 m. Thus, we calculated CPUE as the number of paddlefish harvested per gill net (GN) fishing day. A fishing day was defined as one full day of fishing effort, approximately 10 h; fishing was permitted only on weekdays (i.e., Monday to Friday) from legal sunrise to 1600 hours. Total harvester effort was defined as the number of harvesters × number of days open to fishing × number of hours per day to fish × the number of gill nets.

Neither raw nor transformed harvest and effort data met assumptions of normality. Therefore, we examined differences in daily effort, number of gill nets, CEFL, fish weight, egg weight, and screened egg weight among years using a Kruskal-Wallis one-way ANOVA on ranks with significance determined at $P \leq 0.05$ (Daniel 1990). If differences were detected, then a Dunn's pairwise comparison using a Bonferroni adjustment was applied to isolate differing groups (Bland and Altman 1995). Means were calculated for daily effort, daily gill nets used, CEFL, weight, egg weight, screened egg weight, and CPUE by PMA and year.

To better understand the potential effects of size-selective removal and to provide additional data for minimum-length limit (MLL) and/or slot limit evaluation, we examined the size structure of commercially harvested paddlefish (Neumann and Allen 2007). Specifically, we constructed length-frequency distributions (25-mm size bins) by harvest year. River stage, which is the water level above a defined point with zero height near the river bottom, was compared to mean daily CPUE to better understand how river stage affects commercial paddlefish harvest and effort by PMA. River stage data were obtained from the United States Geological Survey (USGS) gauging stations 02428400 (Claiborne Lock and Dam), 02427506 (Millers Ferry Lock and Dam), and 02421352 (Robert F. Henry Lock and Dam). The relation between mean daily CPUE and mean daily river stage was examined using Pearson correlation.

In 2016, we visited several dealer fish and egg processing facilities to measure recently harvested fish prior to processing. This was done to compare harvested paddlefish CEFLs provided by harvesters on their Reports to CEFLs collected by ADWFF biologists. We used a Mann-Whitney Rank Sum test to compare CEFL medians between the two groups with significance determined at $P \leq 0.05$ using a Bonferroni adjustment. Length-frequency distributions (25-mm size bins) were constructed from CEFLs collected by ADWFF and those provided by harvesters on the Reports. A Kolmogorov-Smirnov two-sample test was used to compare CEFL frequency distributions between length data provided by harvesters vs. collected by ADWFF biologists. All statistical analyses were conducted using SigmaStat 3.5 (Systat Software, Inc. 2007).

Results

A total of 15 commercial paddlefish harvester (hereafter referred to as harvester) permits were available each year. Twelve permits were purchased in 2013 and 2014; thereafter, all permits were claimed from 2015 to 2017 (Table 1). For 2013, a season of 25 days of fishing was approved. However, due to high rain events causing the river to reach flood stage for a prolonged time, the fishery opening date was delayed from 25 February to 11 March. From 2014 to 2017, 35 fishing days (36 days in 2016 as it was a leap year) were approved from February 1 to March 21 of each year. The number of gill nets used tripled from 2013 to 2014, then doubled again from 2015 to 2016 with a decrease in 2017 (Table 1). Based on the number of permits available, days of fishing, and maximum number of gill nets allowed, harvesters used only 11% (2013) to 57% (2016) of the available gill nets. Overall, 12,450 gill nets could have been used, but harvesters used only 4197 (34%) (Table 1). Likewise, harvesters used 16–51% of the available hours to fish. The number of gill-net sets and number of paddlefish released are not presented as these data were determined unreliable. Annual total harvester effort never exceeded 44% of available hours by year, and overall total harvester effort was 28% of total effort available during 2013 to 2017 (Table 2). Harvester median daily effort increased from 2013 to 2017 ($H = 176.5$, df = 4, $P < 0.001$). The number of gill nets used daily differed among years ($H = 80.7$,

Table 1. Number of permitted commercial paddlefish harvesters, number of days open, dates opened, total number of gill nets used, and total hours fished by year from the Alabama River provisional fishery, 2013 to 2017. Values in parentheses indicate the maximum number of harvesters, gill nets, and hours allowed by year.

Year	Harvesters	Days	Dates	Gill nets	Total
2013	12 (15)	25	11 Mar–12 Apr	216 (1875)	601 (3750)
2014	12 (15)	35	3 Feb–21 Mar	606 (2625)	1099 (5250)
2015	15 (15)	35	2 Feb–20 Mar	703 (2625)	2259 (5250)
2016	15 (15)	36	1 Feb–21 Mar	1532 (2700)	2755 (5400)
2017	15 (15)	35	1 Feb–21 Mar	1140 (2625)	1890 (5250)
Total	69 (75)	166		4197 (12,450)	8604 (24,900)

df = 4, $P < 0.001$); use was similar in 2013, 2015, 2016, and 2017, but was lower in 2014 than in later years (Table 2).

Overall, 4861 female paddlefish were harvested for the 5 years combined, with yearly harvests of 191–1457 females (Table 3). The median CEFL ranged from 914 mm in 2016 to 940 mm in 2013 and 2017 and varied among years ($H = 98.3$, df = 4, $P < 0.001$); overall median CEFL was 927 mm (Table 3; Figure 2). Accordingly, median harvested female weights followed a similar trend and differed ($H = 100.9$, df = 4, $P < 0.001$) among years (Table 3).

Total egg and total screened egg weights for all harvested female paddlefish ranged from 441 and 399, respectively, in 2013 to 3459 and 2868 kg, respectively, in 2017 (Table 4). The overall total egg and screened egg weights from harvested female paddlefish were 10,867 and 9021 kg, respectively (Table 4). Median egg and screened egg weights followed trends similar to median CEFL and weights. Significantly greater median egg ($H = 182.8$, df = 4, $P < 0.001$) and screened egg weights ($H = 156.5$, df = 4, $P < 0.001$) were observed in 2013 and 2017 compared to those from 2014 to 2016 (Table 4).

Paddlefish CPUE was similar among PMAs in 2013 ($H = 2.20$, df = 2, $P = 0.33$ (Table 5). Higher CPUEs occurred in LAR followed

Table 2. Total harvester effort, median and mean (SE) daily fishing effort (h), and median and mean daily gill nets set by year from the Alabama River provisional paddlefish fishery, 2013 to 2017. Values in parentheses for effort indicate the maximum effort allowed. Median daily effort and daily gill nets with different letters are significantly different ($P \leq 0.05$).

		Daily effort		Daily gill nets	
Year	Total effort	Median	Mean	Median	Mean
2013	1196 (18,750)	6.3^{b}	6.5 (0.2)	5.0^{ab}	3.8 (0.1)
2014	3937 (26,250)	6.5^{b}	6.3 (0.1)	4.0^{b}	3.8 (0.1)
2015	9498 (26,250)	7.5^{b}	6.6 (0.2)	5.0^{a}	4.1 (0.1)
2016	11,831 (27,000)	8.0^{a}	7.0 (0.1)	5.0^{a}	4.0 (0.1)
2017	8751 (26,250)	8.8^{a}	7.9 (0.1)	5.0^{a}	4.6 (0.1)
Overall	35,213 (124,500)	7.8	7.1 (0.1)	5.0	4.1 (0.1)

Table 3. Total number, total weight (kg), median and mean (SE) curved eye-to-fork length (CEFL; mm), and median and mean weight (kg) of harvested female paddlefish from the Alabama River provisional fishery, 2013 to 2017. Median CEFL and weight with different letters are significantly different ($P \leq 0.05$).

	Total		CEFL		Weight	
Year	Number	Weight	Median	Mean	Median	Mean
2013	191	2241	940^{a}	944 (3.7)	11.3^{a}	11.7 (0.2)
2014	620	6994	914^{b}	930 (2.0)	10.9^{b}	11.3 (0.1)
2015	1209	13,649	927^{ab}	935 (1.5)	10.9^{b}	11.3 (0.1)
2016	1384	14,503	914^{b}	922 (1.3)	10.4^{c}	10.5 (0.1)
2017	1457	16,085	940^{a}	940 (1.3)	11.3^{a}	11.0 (0.1)
Overall	4861	53,472	927	932 (0.8)	10.9	10.9 (0.1)

Table 4. Total egg weight (kg), total screened egg weight (kg), median and mean (SE) egg weights (kg), median and mean screened egg weights (kg), and number of samples for median and mean egg weights of harvested female paddlefish from the Alabama River provisional fishery by year, 2013 to 2017. Median egg and median screened egg weights with different letters are significantly different ($P \leq 0.05$).

	Egg weight						
Year	Total	Total screened	Median	Mean	Median screened	Mean screened	*n*
2013	441	399	2.5^{a}	2.6 (0.07)	2.2^{a}	2.2 (0.05)	104
2014	1315	1018	2.1^{c}	2.1 (0.03)	1.7^{c}	1.8 (0.02)	613
2015	2646	2211	2.2^{b}	2.3 (0.02)	1.9^{b}	1.8 (0.02)	1135
2016	3006	2525	2.2^{b}	2.2 (0.01)	1.8^{b}	1.9 (0.01)	1309
2017	3459	2868	2.4^{a}	2.5 (0.02)	2.0^{a}	2.1 (0.02)	1406
Overall	10,867	9021	2.4	2.3 (0.01)	1.9	1.9 (0.01)	4567

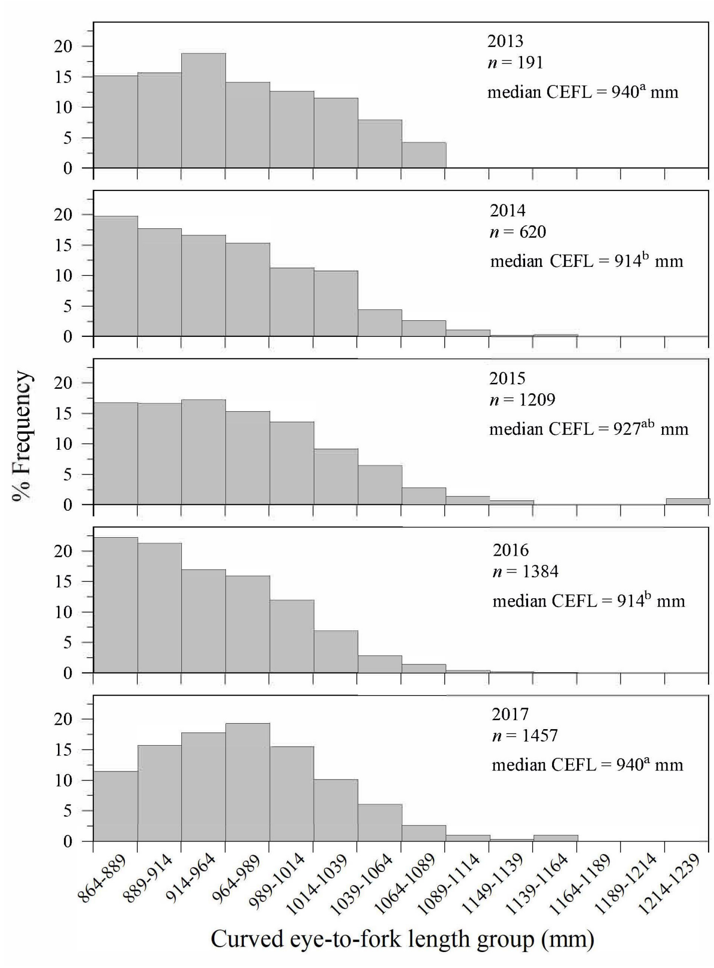

Figure 2. Length-frequency distributions (25-mm size bins) for commercial harvested female paddlefish by year from the Alabama River provisional fishery, 2013 to 2017. Median values followed by different letters for each year are significantly ($P \leq 0.05$) different.

Table 5. Number (N), median and mean (SE) catch-per-effort-unit (CPUE; fish net-day^{-1}) by year and paddlefish management area (PMA) from the Alabama River provisional fishery, 2013 to 2017. Median CPUE with different letters after values (a–d; within columns) among years for each PMA are significantly different ($P \leq 0.05$). Median CPUE with different preceding letters (x, y; within rows) among PMAs for each year are significantly different ($P \leq 0.05$).

	UAR			MAR			LAR			Total		
Year	N	Median	Mean	N	Median	Mean	N	Median	Mean	N	Median	Mean
2013	24	$^{z}0.7^{c}$	1.5 (0.3)	10	$^{z}0.7^{b}$	0.9 (0.2)	15	$^{z}0.7^{c}$	0.8 (0.1)	49	0.7^{c}	1.2 (0.2)
2014	38	$^{y}0.4^{c}$	0.7 (0.1)	78	$^{z}1.8^{b}$	2.4 (0.3)	56	$^{z}1.0^{c}$	1.5 (0.2)	172	1.0^{c}	1.7 (0.2)
2015	112	$^{y}0.5^{c}$	1.3 (0.2)	70	$^{yz}0.8^{b}$	1.4 (0.2)	143	$^{z}1.1^{c}$	1.3 (0.1)	325	1.0^{c}	1.3 (0.1)
2016	121	$^{z}4.4^{b}$	6.4 (0.5)	112	$^{yz}3.8^{a}$	5.0 (0.4)	107	$^{y}2.5^{b}$	3.7 (0.3)	340	3.5^{b}	5.0 (0.3)
2017	67	$^{z}8.8^{a}$	8.8 (0.8)	90	$^{yz}6.3^{a}$	6.3 (2.6)	77	$^{y}5.0^{a}$	5.0 (3.2)	234	5.7^{a}	7.4 (0.4)
Overall	362	2.5^{a}	5.8 (0.3)	360	2.9^{a}	6.5 (0.4)	398	1.3^{b}	2.9 (0.2)	1120	2.0	4.1 (0.2)

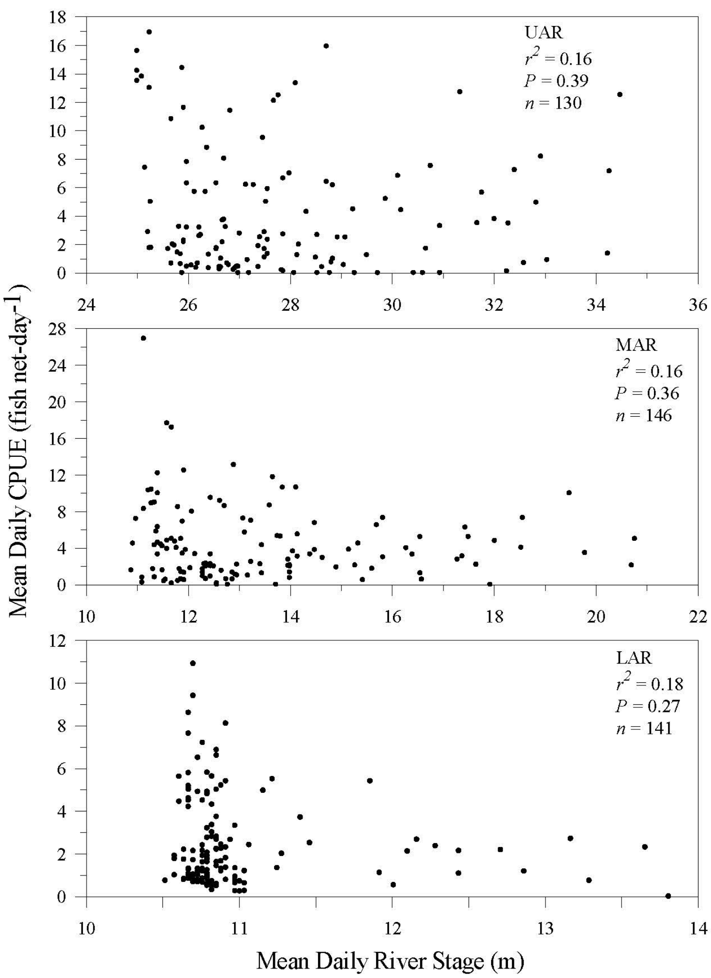

Figure 3. Mean daily river stage (m) versus mean daily catch-per-unit-effort (CPUE; fish net-day^{-1}) for commercially harvested female paddlefish by paddlefish management area (PMA) and date from the Alabama River provisional fishery, 2013 to 2017.

by MAR and then UAR in 2014 ($H = 23.3$, df $= 2$, $P < 0.001$) and 2015 ($H = 13.9$, df $= 2$, $P < 0.001$; Table 5). Conversely, CPUEs were higher for UAR than LAR, but both PMAs were similar to MAR in 2016 ($H = 10.4$, df $= 2$, $P = 0.006$) and 2017 ($H = 12.9$, df $= 2$, $P = 0.002$). Overall, CPUEs were lower in LAR compared to UAR and MAR ($H = 49.8$, df $= 4$, $P < 0.001$; Table 5).

For all three PMAs, CPUEs significantly increased from 2013 to 2017 (UAR: $H = 140.3$, df $= 4$, $P < 0.001$; MAR: $H = 106.9$, df $= 4$, $P < 0.001$; LAR: $H = 111.7$, df $= 4$, $P < 0.001$). Overall, CPUEs for all PMAs combined were higher in 2016 and 2017 compared to previous years ($H = 344.2$, df $= 4$, $P < 0.001$). Median CPUE was 2.0 fish net-day^{-1} and the mean CPUE was 4.1 fish net-day^{-1}, for all years and PMAs combined.

Mean daily CPUE was not related to mean daily river stage for all years combined in any of the PMAs (Figure 3). Although most of the fishing effort was conducted at low river stages, harvesters who fished at higher river stages did catch and harvest paddlefish. Except for 2013, the Alabama River did not approach flood stage for most of each harvest year. This allowed harvesters access to maximum effort allowed.

We measured 159 harvested paddlefish from the dealer processing facilities and compared these lengths to those submitted on the daily harvest reports. Median CEFL was similar ($U = 11251$, $n_1 = 159$, $n_2 = 1384$, $P = 0.16$) as was length-frequency distribution ($D = 0.20$, $n_1 = 159$, $n_2 = 1384$, $P > 0.05$) between harvester-provided and ADWFF-collected lengths (Figure 4). However, we documented eight (5.1%) undersized and illegally harvested fish (Figure 4). These fish ranged in size from 813 to 849 mm CEFL. Extrapolating this finding to the total harvest for 2016, a total of 68 may have been illegally harvested; however, extrapolated to the total number paddlefish harvested from 2013 to 2017, 248 undersized fish may have been harvested.

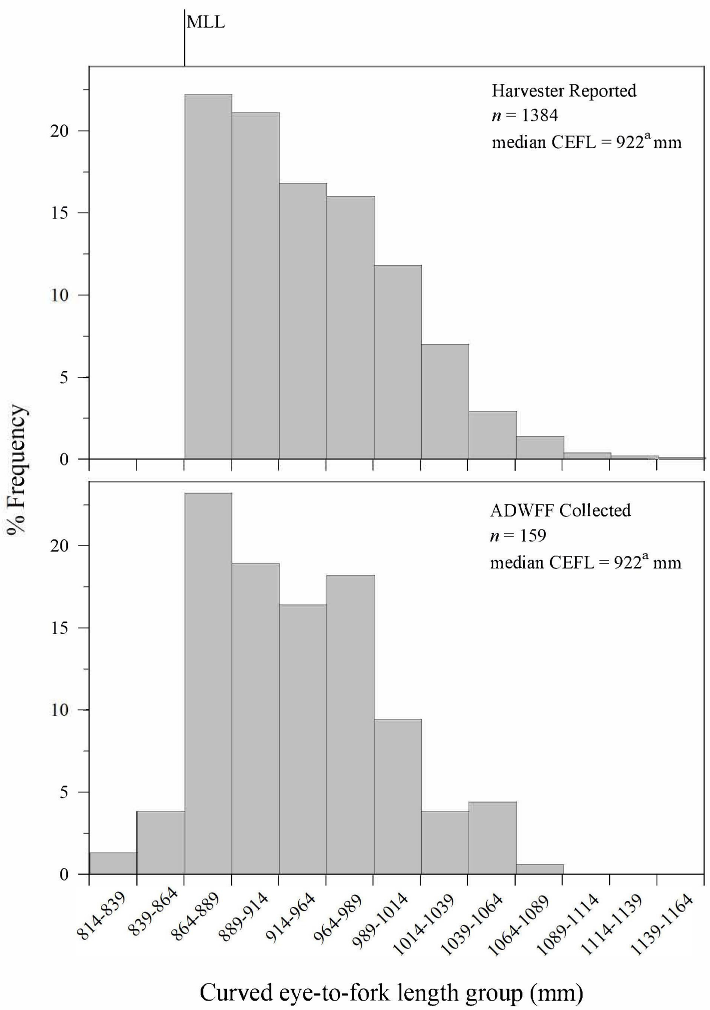

Figure 4. Length-frequency distributions (25-mm size bins) for commercial harvested female paddlefish from harvester daily reports and ADWFF collected data from the Alabama River provisional fishery, 2016. Median values followed by different letters are significantly ($P \leq 0.05$) different. MLL = minimum-length limit.

Discussion

The wholesale price for paddlefish eggs is a major determinant of pressure on paddlefish stocks, and on state wildlife and fisheries agencies to open or expand current commercial fisheries (Quist et al. 2009). Management of these commercial fisheries requires basic harvest data such as catch and effort to understand the fishery and determine if current regulations are effective or regulation revision is needed for sustainability (Demory and Golden 1983). All states that allow commercial paddlefish harvest require harvesters to provide reports of harvest to manage these fisheries (Quinn 2009). At minimum, states require reporting the total number and weight of paddlefish along with the total raw and screened-eggs weights harvested by day or month (MICRA 2022). With recent and ongoing demands, agencies have been examining new and proactive ways to conserve paddlefish stocks (Rider et al. 2019). Therefore, in Alabama, harvesters were required to provide daily effort and catch data along with individually harvested paddlefish data. Biologists required these detailed data to allow a better understanding of commercial paddlefish harvest that would support current and future management of the stocks.

These results provide the first quantitative assessment of a commercial paddlefish fishery in the Mobile River Basin of Alabama. During this provisional fishery, commercial harvesters never utilized the full amount of gill net and fishing day effort that was available to harvest paddlefish. These data provided ADWFF insight into fishing effort by commercial harvesters and the justification to change or update the regulations in a timely manner. Prior to and throughout the provisional fishery harvesters were dissatisfied with the amount of fishing time (days opened) and referenced other states where the commercial paddlefish fisheries were opened longer. In these six other states (i.e., Arkansas, Kentucky, Missouri, Tennessee, Illinois, and Indiana), number of open days each season varied from 142 (Arkansas) to 243 days (Illinois) with a mean of 180 ± 34 days. However, ADWFF allowed fewer days for the fishery to be opened as a precaution to evaluate this new fishery before determining whether to increase fishing days. After examining the total number of gill nets used, total hours fished, and total harvester effort, we concluded harvesters were using less the 45% of the nets, hours, and harvester effort available to fish for paddlefish. We saw little need to increase the gill nets, hours, or harvesters when a substantial amount of allocated effort was unused.

Understanding and using CPUE as an estimate of fish numbers (i.e., relative abundance) is a major component of evaluating fish stocks (Hubert and Fabrizio 2007). The CPUE from commercial fisheries can be used to compare to fishery-independent CPUEs, track harvest over time to understand factors affecting stock fluctuations, and monitor if overharvest is occurring so steps can be taken to conserve these stocks. In examining the first commercial harvest of paddlefish since 1988, the total number of paddlefish harvested each year and CPUE increased annually from 2013 to 2017. Flood conditions in 2013 and cooler water temperatures due to a polar vortex in 2014 (Cohen et al. 2022) hampered fishing efforts for a majority of harvesters during these years. Although most commercial harvesters began with little to no commercial paddlefish experience, with favorable environmental conditions (i.e., low to moderate water levels with warmer water temperatures) in 2015 they began developing the necessary skills to find and capture paddlefish relative quickly. Additionally, harvesters started using side-scan sonar to locate and target paddlefish. This recent advancement in fish finding technology also increases the ability of recreational and for-hire fishing guides to target and catch paddlefish (Scarnecchia and Schooley 2022).

Although mainly focused on populations of marine fishes, research examining the benefit of maintaining older and larger females has indicated their reproductive importance (e. g., Berkeley et al. 2004a, b, Sharpe and Hendry 2009, Stewart 2011, Hixon et al. 2014). Removal of these females can lead to age and size truncation, which may result in stock collapse (Beamish et al. 2006, Levin et al. 2006). Recently, Scarnecchia et al. (2022) demonstrated that large and older female paddlefish from Montana, North Dakota, and Oklahoma have a higher reproductive output than smaller females. Thus, conserving these larger and older females may be warranted. This research led to discussions within ADWFF about using a slot limit to protect these larger and older females from harvest. With the harvester requirement to provide a daily harvest report, we now have biological data for each paddlefish harvested that can be used to assess this potential limit. For example, paddlefish harvested over 1014, 1039, and 1064 mm CEFL constituted 9.3%, 3.9% and 2.0%, respectively, of the total number of commercially harvested paddlefish. If a maximum-size limit of 1014-, 1039-, or 1064-mm CEFL was in effect, then based on the daily harvest records, a total of 451, 189, or 60, respectively, of these larger and older paddlefish could have been conserved and protected from harvest. Because paddlefish are a long-lived and large freshwater fish, protecting these "prime spawners" may sustain and buffer the population from overharvest (Scarnecchia et al. 1989, 2007). Thus, daily harvest reports provided additional data along with fishery-independent data needed for justification.

The ability to rely on individual biological data is valuable since these data are used to ascertain fish growth and condition as well as for stock assessment (Ney 1993). Median lengths, median weights, and total and screened egg weights indicated slightly larger and more fecund females were harvested in the first (2013) and last (2017) years, compared to the other three harvest years. Size truncation was not evident during the five years. These data from the harvester reports can provide the necessary information to ascertain if size truncation is occurring. However, it may take decades to actually detect persistent size truncation (Hamilton et al. 2007, Fisher et al. 2010).

From the beginning of the provisional commercial paddlefish fishery, ADWFF discussed a total allowable catch (TAC), i.e., the maximum number of female paddlefish to be harvested each year that still conserves the stock for long-term sustainability. However, we lacked necessary data to proceed in developing a scientifically based number. Although the commercial paddlefish catch and harvest is indefinitely suspended in Alabama, if the fishery is reopened, a TAC could be developed using data from past daily harvest reports. For example, CPUE trends can be used as one factor to determine if a stock is increasing, decreasing, or stable and, coupled with size structure, can generate estimates of a TAC (Wilson et al. 2010). Biological reference points (BRP) have also been suggested by Sharov et al. (2014) for managing commercial paddlefish stocks that are depauperate in biological data. Although developing a TAC or BRPs are outside the scope of this paper, these are just examples of how fishery-dependent data can be used to understand and manage the resource.

Various factors can affect the commercial catch and harvest of paddlefish, such as river stage and/or discharge, water temperature, habitat, and especially current egg prices (Quist et al. 2009). Harvesters were concerned that if the Alabama River stage increased to flood stage levels due to high rain events, coupled with a short season, they would not have ample time to catch and harvest paddlefish. Our results showed that no relation existed between mean daily CPUE and mean daily river stage, indicating harvesters who did fish at higher river stages caught and harvested paddlefish similar to lower river stages. However, the mean daily CPUE for higher river stages tended to be lower than during lower river stages or non-flooding events, and this was more evident progressing from upriver to downriver PMAs. In the UAR, harvesters tended to fish and catch more during these flood events. This may be because more experienced harvesters who held permits and commercially harvested paddlefish in other states selected the UAR to fish because it was closer to their homes. The inexperienced harvesters tended to hold permits in the MAR and LAR because these PMAs were closer to their homes in south Alabama. Experienced harvesters had the knowledge and skills to find paddlefish during high water, demonstrating that harvest is possible under high-water conditions. Likewise, our sampling efficiency has increased after years of sampling as we developed knowledge and skills to catch paddlefish under various environmental scenarios, including various water levels.

We found that 5% of harvested paddlefish were undersized in 2016. These undersized fish (<864 mm CEFL) are younger and tend to be first-time spawners (Rider et al. 2012). A common goal with maintaining commercial fish stocks is to protect females so they can spawn at least once (Scarnecchia et al. 1989, Froese 2004, Risley et al. 2017). During this fishery, these data initiated increased law enforcement surveillance and monitoring of the fishery. Collecting fishery-independent data is an important component of commercial paddlefish management as it allows managers to compare and verify harvester-provided catch data and identify misreporting or falsification.

Harvesters were also required to report the total number of paddlefish released each day. After several years it was noted the number of paddlefish released reported by some harvesters typically ranged from 125 to 175 fish in a single day. However, during this period ADWFF biologists were collecting paddlefish data via on-the-water intercepts, at boat launching sites, and through independent sampling, but never observed these high catches. Conversations with several harvesters indicated these numbers were falsely inflated; the harvesters believed that if the numbers were high ADWFF would not suspend the commercial season since these data would suggest a more robust population. Besides inflating the number of paddlefish released, some harvesters simply forgot to record the number released. Therefore, these numbers as reported were viewed unreliable and not presented in this paper.

Commercial harvesters were also required to report the number of times they checked (i.e., gill-net sets) their nets each fishing day. By regulation, gill nets were prohibited from being soaked more than 2 h without being pulled and checked. This regulation was to reduce or eliminate bycatch mortality of undersized and male paddlefish and of imperiled species. Even though we discussed the reasoning behind this regulation with all permitted harvesters before the beginning of each season, they continued to inaccurately record the correct number of gill-net sets. Some continued to be confused with how to determine number of sets, some simply did not record the number, and some simply recorded the number of gill nets initially set, not checked. Like the number of paddlefish released value, this value was not calculated due to unreliability of the reporting and misunderstanding of what and how to report.

During 2018, a high number of citations was issued to harvesters for a wide array of violations. Many of the harvesters quit fishing after issuance of these citations and few harvest reports were provided to ADWFF; therefore, we did not consider 2018 data for this paper. These citations and nonreporting resulted in the indefinite suspension of any future commercial paddlefish fishery in Alabama (ADWFF 2018). This suspension is still currently in effect; however, commercial interests continue to campaign for a commercial paddlefish fishery. Several bills were introduced in the Alabama State House of Representatives to reopen commercial paddlefish harvest in the last several years but have garnered little support (Alabama Legislature Services Agency 2022). Given the continued pressure, it is imperative to have a plan and process in place in case commercial paddlefish harvest is opened, such as requiring the daily harvest reports.

Despite historical commercial paddlefish harvest records published for Alabama waters of the Tennessee River Basin (Bryan and Tarzwell 1941, Bryan and White 1958, Pasch and Alexander 1986), results of this study provide the first detailed record of commercial paddlefish harvest and harvester characteristics in a provisional fishery from the Alabama River, Alabama. Having detailed and accurate data available and reported soon after harvest each season can give managers a better understanding of harvest and effort, allowing them to evaluate in a timely manner whether adjustments are needed for the following harvest years as well as guiding future management decisions. However, managers must understand the limitations of self-reported data when interpreting and using these results.

Based on these data provided by commercial harvesters, and our experience and knowledge gained during this provisional commercial fishery, we propose the following recommendations to effectively manage the Alabama River paddlefish fishery if it is reopened in the future.

1) Visit fish processing facilities every year at an increased frequency to gather additional independent data of harvested fish to compare to harvester reported data.

2) Keep the number of fishing days available the same as in the seasons we evaluated, as fishing effort data revealed harvesters did not use all the effort allocated.

3) Evaluate the ability of a harvest slot limit to protect larger, older, and more fecund female paddlefish from harvest.

4) Continue to use the Report with a few minor changes such as adding the requirement to record gill net dimensions.

5) Develop a TAC or use BRPs such as spawning potential ratio (Goodyear 1993) to prevent recruitment overfishing.

6) Continue to educate commercial harvesters on the importance of providing accurate and reliable commercial harvest data.

Acknowledgments

The authors thank Greg Miles and Tom Ringenberg of the ADWFF River and Stream Fisheries Program with assistance during the commercial paddlefish years, several anonymous reviewers, and the associate editor whose comments improved this manuscript.

Literature Cited

Alabama Division of Wildlife and Freshwater Fisheries (ADWFF). 2018. Alabama River commercial paddlefish seasons suspended indefinitely. Montgomery, Alabama. <https://www.outdooralabama.com/node/2391>. Accessed 5 May 2022.

Alabama Legislature Services Agency. 2022. Commercial fishing, paddlefish season, license from Conservation and Natural Resources Department, regulation, fines. <http://alisondb.legislature.state.al.us/ALISON/SearchableInstruments/2022RS/PrintFiles/HB334-int.pdf>. Accessed 5 May 2022.

Beamish, R. J., G. A. McFarlane, and A. Benson. 2006. Longevity overfishing. Progress in Oceanography 68:289–302.

Berkeley, S. A., C. Chapman, and S. M. Sogard. 2004a. Maternal age as a determinant of larval growth and survival in a marine fish, *Sebastes melanops*. Ecology 85:1258–1264.

______, M. A. Hixon, R. J. Larson, and M. S. Love. 2004b. Fisheries sustainability via protection of age structure and spatial distribution of fish populations. Fisheries 29(8):23–32.

Bland, J. M. and D. G. Altman. 1995. Multiple significance tests: the Bonferroni method. British Medical Journal 310:170.

Bryan, P. and C. M. Tarzwell. 1941. A preliminary report on the census of commercial fishing in TVA impoundments. Transactions of the North American Wildlife Conference 6:256–272.

_____ and C. E White. 1958. An economic evaluation of the commercial fishing industry in the TVA lakes of Alabama. Proceedings of the Annual Conference of the Southeastern Association of Game and Fish Commissioners 12:128–132.

Cohen, J., L. Agel, M. Barlow, J. C. Furtado, M. Kretschmer, and V. Matthias. 2022. The "Polar Vortex" Winter of 2013/14. Journal of Geophysical Research: Atmospheres 127:e2022JD036493.

Daniel, W. W. 1990. Applied nonparametric statistics, 2nd edition. PWS-Kent Publishing Company, Boston, Massachusetts.

Demory, R. L. and J. T. Golden. 1983. Sampling the commercial catch. Pages 421–430 *in* L. A. Nielsen and D. L Johnson, editors. Fisheries techniques. American Fisheries Society, Bethesda, Maryland.

Fisher, J. A., K. T. Frank, and W. C. Leggett. 2010. Breaking Bergmann's rule: truncation of Northwest Atlantic marine fish body sizes. Ecology 91: 2499–2505.

Froese, R. 2004. Keep it simple: three indicators to deal with overfishing. Fish and Fisheries 5:86–91.

Goodyear, C. P. 1993. Spawning stock biomass per recruit in fisheries management: foundation and current use. Pages 67–81 *in* S. J. Smith, J. J. Hunt, and D. Rivard, editors. Risk evaluation and biological reference points for fisheries management. Canadian Special Publication of Fisheries and Aquatic Sciences 120. NRC Research Press, Ottawa.

Hamilton, S. L., J. E. Caselle, J. D. Standish, D. M. Schroeder, M. S. Love, J. A. Rosales-Casian, and O. Sosa-Nishizaki. 2007. Size-selective harvesting alters life histories of a temperate sex-changing fish. Ecological Applications 17:2268–2280.

Heist, E. J. and A. Mustapha. 2008. Range wide genetic structure in paddlefish inferred from DNA microsatellite loci. Transactions of the American Fisheries Society 137:909–915.

Hixon, M. A., D. W. Johnson, and S. M. Sogard. 2014. BOFFFFs: on the importance of conserving old-growth age structure in fishery populations. ICES Journal of Marine Science 71:2171–2185.

Hoxmeier, R. J. and D. R. Devries. 1997. Habitat use, diet, and population structure of adult and juvenile paddlefish in the lower Alabama River. Transactions of the American Fisheries Society 126:288–301.

Hubert, W. A. and M. C. Fabrizio. 2007. Relative abundance and catch per unit effort. Pages 279–325 *in* C. S. Guy and M. L. Brown, editors. Analysis and interpretation of freshwater fisheries data. American Fisheries Society, Bethesda, Maryland.

Levin, P. S., E. E. Holmes, K. R. Piner, and C. J. Harvey. 2006. Shifts in a Pacific Ocean fish assemblage: the potential influence of exploitation. Conservation Biology 20:1181–1190.

Mettee, M. F., P. E. O'Neil, and J. M. Pierson. 1996. Fishes of Alabama and the Mobile Bain. Oxmoor House, Birmingham, Alabama.

_____, _____, 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, Symposium 66, Bethesda, Maryland.

Mississippi Interstate Cooperative Resource Association [MICRA]. 2022. Commercial paddlefish fishery regulations. Carbondale, Illinois.

Neumann, R. M. and M. S. Allen. 2007. Size structure. Pages 375–421 *in* C. S. Guy and M. L. Brown, editors. Analysis and interpretation of freshwater fisheries data. American Fisheries Society, Bethesda, Maryland.

Ney, J. J. 1993. Practical use of biological statistics. Pages 137–158 *in* C. C. Kohler and W. A. Hubert, editors. Inland fisheries management in North America. American Fisheries Society, Bethesda, Maryland.

O'Keefe, D. M. and D. C. Jackson. 2009. Population characteristics of paddlefish in two Tennessee-Tombigbee waterway habitats. Pages 83–101 *in* C. P. Paukert and G. D. Scholter, editors. Paddlefish management, propagation, and conservation in the 21st century. American Fisheries Society, Symposium 66, Bethesda, Maryland.

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. American Fisheries Society, North Central Division, Special Publication 7, Bethesda, Maryland.

Quinn, J. W. 2009. Harvest of paddlefish in North America. Pages 203–221 *in* C. P. Paukert and G. D. Scholter, editors. Paddlefish management, propagation, and conservation in the 21st century. American Fisheries Society, Symposium 66, Bethesda, Maryland.

Quist, M. C., M. J. Steuck, and M. M. Marron. 2009. Commercial harvest of paddlefish in the upper Mississippi River. Pages 345–355 *in* C. P. Paukert and G. D. Scholter, editors. Paddlefish management, propagation, and conservation in the 21st century. American Fisheries Society, Symposium 66, Bethesda, Maryland.

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

_____, J. E Ganus, T. P. Powell, and G. T. Miles. 2021. Feasibility of initiating a commercial fishery for paddlefish in Alabama reservoirs of the Tennessee River. Journal of the Southeastern Association of Fish and Wildlife Agencies 9:1–7.

_____, 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.

_____, 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, Symposium 88, Bethesda, Maryland.

Risley, J. T., R. L. Johnson, and J. W. Quinn. 2017. 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.

Scarnecchia, D. L., T. W. Gengerke, and C. T. Moen. 1989. Rationale for a harvest slot limit for paddlefish in the Upper Mississippi River. North American Journal of Fisheries Management 9:477–487.

_____, B. D. Gordon, J. D. Schooley, L. F. Ryckman, B. J. Schmitz, S. E. Miller, and Y. Lim. 2011. Southern and northern Great Plains (United States) paddlefish stocks within frameworks of Acipenseriform life history and the metabolic theory of ecology. Reviews in Fisheries Science 19:279–298.

_____, 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 J. D. Schooley. 2022. Trophies, technology, and timescape in fisheries management, as exemplified through Oklahoma's world record paddlefish (*Polyodon spathula*). Fisheries 47:381–394.

_____, _____, A. Slominski, K. M. Backes, B. Brown, B. D. Gordon, and Y. Lim. 2022. Patterns and scaling of reproductive output in paddlefish (*Polyodon spathula*) and its conservation implications. Transactions of the American Fisheries Society 151:347–355.

Sharov, A., M. Wilberg, and J. Robinson. 2014. Developing biological reference points and identifying stock status for management of Paddlefish

(*Polyodon spathula*) in the Mississippi River basin. U. S. Fish and Wildlife Service, Falls Church, Virginia.

Sharpe, D. M. and A. P. Hendry. 2009. Synthesis: life-history change in commercially exploited fish stocks: an analysis of trends across studies. Evolutionary Applications 2:260–275.

Smith-Vaniz, W. F. 1968. Freshwater fishes of Alabama. Auburn University Agricultural Experiment Station, Auburn, Alabama.

Stewart, J. 2011. Evidence of age-class truncation in some exploited marine fish populations in New South Wales, Australia. Fisheries Research 108:209–213.

Systat Software, Inc. 2007. SigmaStat 3.5. San Jose, California.

Wilson, J. R., J. D. Prince, and H. S. Lenihan. 2010. A management strategy for sedentary nearshore species that uses marine protected areas as a reference. Marine and Coastal Fisheries 2:14–27.