Harvest Potential of Paddlefish Stocks in Watts Bar Reservoir, Tennessee

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Abstract: Mark-recapture techniques were used during spring 1982 and 1983 to estimate the abundance of harvestable size paddlefish (*Polyodon spathula*) in Watts Bar Reservoir, Tennessee. Results indicated a harvestable population in 1982 of 3,421 fish (95% confidence interval of 2,184 to 6,665). Aging studies indicated a relatively young population with an abrupt decrease in survival after the ninth year. This decrease was attributed to extreme fishing mortality on these older age classes before July 1980 when Watts Bar Reservoir was closed to net fishing. Estimated annual growth of adult paddlefish was 27.4 mm for males and 31.2 mm for females. Age at maturity was estimated at 5 to 6 years for males and 8 years for females. Males constituted 76% and 60% of the sample in 1982 and 1983, respectively. Fort Loudoun tailwater was identified as the probable spawning area for most Watts Bar Reservoir paddlefish.

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Commercial exploitation of paddlefish stocks in Tennessee reservoirs increased dramatically during the 1970s and early 1980s (Pasch and Alexander 1983). By the mid-1970s commercial harvest of paddlefish from the Tennessee and Cumberland Rivers in Tennessee, Alabama, and Kentucky comprised 50% of the nation's commercial paddlefish harvest (Carlson and Bonislawsky 1981). This increase in harvest was prompted by an escalation in the value of paddlefish roe to over $25 per pound by spring 1980 (Pasch and Alexander 1983). Effects of continued and increasing exploitation of paddlefish stocks in the Tennessee and Cumberland Rivers were not known and caused concern among fisheries biologists in the region.

By spring 1979, the potential for over exploitation of this valuable resource was recognized, and regulations were proposed to deal specifically with management of paddlefish in Tennessee waters (Harned 1979). On 1 July 1980, the Tennessee Wildlife Resources Agency (TWRA) closed Watts Bar Reservoir to netting to protect a put-grow-and-take striped bass (*Morone saxatilis*) fishery. Although harvest of paddlefish by sport snagging and commercial snagline has been allowed, closure of Watts Bar Reservoir to netting has afforded adequate protection to paddlefish until assessment studies could be completed.

A study to gain information required for developing rational management plans for Watts Bar Reservoir paddlefish stocks began during spring 1982 and was completed in the spring of 1983. The objectives of this study were: to assess the harvest potential of existing paddlefish stocks in Watts Bar Reservoir and to develop management plans for these stocks. Estimates of the number of harvestable size paddlefish, population age structure, and other vital statistics were used for this assessment.

Methods

Watts Bar Reservoir, a mainstream impoundment of the Tennessee River, was formed in 1942 by completion of Watts Bar Dam at Tennessee River mile 529.9, approximately 11.3 kilometers southeast of Spring City, Tennessee. At full pool the reservoir covers 15,783 ha with 1,241 km of shoreline. Watts Bar Reservoir's upstream boundaries are Fort Loudoun Lock and Dam, Tellico Dam, and Melton Hill Lock and Dam. The Emory River, another major tributary to Watts Bar Reservoir, is unimpounded with no apparent upstream boundary to fish migration. These 3 tributaries have the general habitat characteristics described as necessary for paddlefish spawning (Pasch et al. 1980, Purkett 1963). The most obvious difference is that the Tennessee River is larger, maintains a higher flow, and is more turbid than the other 2 tributaries.

Paddlefish were collected during 2 spawning seasons with sampling centered on the 3 major tributaries in the upper reaches of Watts Bar Reservoir during 1982 and confined to the Fort Loudoun tailwater in 1983. Paddlefish were tagged during the spawning run in 1982 and recaptured the following spring. This allowed marked fish to randomly mix with unmarked fish and reduced bias of localized sampling.

In 1982, samples were taken on 21 nights beginning 2 March and ending 3 June. Twenty-nine net hours were fished on the Emory River, 113.5 on the Clinch River, and 434.4 on the Tennessee River arm of Watts Bar Reservoir. Fish were captured with 91.2-m × 2.4-m, 12.7-cm bar mesh floating and sinking gill nets and 91.2-m × 4.4-m (hobbled to 3.7 m) 15.2-cm, 17.8-cm, and 20.3-cm bar mesh floating gill nets. Netting was conducted at night in order to maximize catch per effort and to be compatible with power generation schedules (no flow periods) below Fort Loudoun and Melton Hill Dams. Nets were pulled and reset at intervals of less than 2 hours whenever possible. Captured paddlefish were placed in a holding tank in the boat until the net was pulled and reset. Weight, body length (anterior orbit of eye to fork of tail), and sex of paddlefish were recorded. Sex was determined using criteria described by Alexander and Peterson (1982).

Prior to release paddlefish were tagged with sequentially numbered Peterson disc tags attached on the left mandible with nylon electrical wire straps. A thin section (approximately 3 mm) of the right mandible was excised for aging. Cuts were made with a high speed Dremmel tool. Sections were taken in the mesial bend as described by Adams (1942). Tag numbers of recaptured paddlefish were recorded and fish released. The number of individuals of other species captured was also recorded.

In addition to netting, 2 methods were used to locate paddlefish in the Emory River arm of Watts Bar Reservoir: (1) electrofishing the mid-channel area at night (2) and by creating a large wake in the mid-channel at night. Although not reported, these techniques were useful in locating paddlefish on Norris Reservoir (Alexander and Peterson 1982). Paddlefish would run, often leaping from the water, when disturbed by either method.

Recapture sampling was done during 10 nights (160.8 net hours) beginning 4 April 1983 and ending 5 May 1983. Fish were captured with 91.2-m × 4.4-m, 15.2-cm bar mesh floating gill nets. Procedures described for 1982 were used and data from all recaptures were recorded and these fish released.

Abundance of harvestable size paddlefish was estimated using Chapman's modification (Ricker 1975) of Peterson's single census method:

$$N = \frac{(M+1)(C+1)}{R+1}$$

The upper and lower confidence limits were calculated using values from Ricker's (1975) table for the Poisson distribution since <10% of the marked fish were recaptured (Lackey and Hubert 1977). To eliminate the effect of recruitment on the population estimate, all paddlefish collected in 1983 less than the age to recruitment (i.e., vulnerable to fishery) were not considered in the population estimate. Survival was estimated by constructing catch curves of gill net captured paddlefish after recruitment (Ricker 1975).

Individual paddlefish were aged using methods similar to those described by Adams (1942). Annuli were counted on the mesial lobe using a dissecting microscope (12X to 25X) equipped with polarized light.

Regression analysis was used to determine relationships between length at age and weight at age (Neter and Wasserman 1974). The slope of these regressions were used to estimate annual incremental growth.

The length-weight relationship usually represented by $A = aL^b$ was logarithmic transformed to obtain a straight line relationship with the equation (Lagler 1973): $\log W = a + b \log L$. Regression analysis (SAS 1982) was used to estimate length-weight relationships for paddlefish by sex. Differences between sexes were tested by analysis of covariance for parallel slopes and adjusted mean weights. Condition of paddlefish was calculated using the coefficient of condition of K factor (Lagler 1973):

$$K = \frac{W(10^5)}{L^3}$$

The condition factor was tested for significant differences between years and between tagged and untagged paddlefish by sex using the Student's *t*-test. Significance testing was done at $P = 0.05$ error level.

Results and Discussion

During spring 1982, 382 paddlefish were tagged and released in Watts Bar Reservoir. All but 1 (from the Emory River) were captured and released in the Tennessee River arm. This distribution was consistent with observations by TWRA biologists while collecting striped bass broodstock in the Clinch and Tennessee River arms over the past few years (unpubl. data). Although spawning was not documented, the distribution of adult paddlefish during spring sampling suggests the Fort Loudoun Dam tailwater and the Tennessee River downstream for some distance to be the primary spawning area for the Watts Bar Reservoir paddlefish population. Therefore, sampling was restricted to the Tennessee River arm during spring 1983.

A total of 138 paddlefish was captured during the 1983 sampling period. Fourteen were recaptured from the 1982 tagging. In addition, vital statistics were collected from 2 paddlefish tagged in 1982 that were caught by sport snag fishermen. These 2 fish were not considered in the population estimate.

Weighted mean weight for 331 male and 152 female paddlefish captured during both years was 10.6 kg and 18.5 kg, respectively. (Table 1). Mean weights for paddlefish from Cherokee Reservoir were males = 20.6 kg and females = 26.0 kg (Peterson and Alexander 1984); from Norris Reservoir, males were 13.8 kg and females 24.5 kg (Alexander and Peterson 1982). This observed size difference was in general agreement with differences between population age structure for Cherokee and Watts Bar Reservoirs; however, no age analysis is available for Norris Reservoir paddlefish.

Age was determined for 332 and 92 paddlefish collected in 1982 and 1983, respectively. These data are presented by sex due to differences in age distribution (Fig. 1). Male paddlefish ranged between 3 and 10 years old, while females ranged between 6 and 12 years old. Male paddlefish were distributed around an age mode of 7 years during 1982, and 8 years during 1983. Female paddlefish also showed modal shift in age between years from 8 years in 1982 to 9 years in 1983. Although there was a 1 year difference in the most abundant age class of male and female

Table 1. Mean weight and length of paddlefish collected from Watts Bar Reservoir in 1982 and 1983 (sample size in parenthesis).

	Mean Weight (kg)		Mean Body Length (mm)	
	Male	Female	Male	Female
1982	10.52 (269)	18.38 (87)	890.28 (269)	1,041.15 (87)
1983	10.92 (62)	18.64 (65)	914.05 (62)	1,054.09 (65)
Weighted Mean	10.59 (331)	18.49 (152)	894.73 (331)	1,046.68 (152)

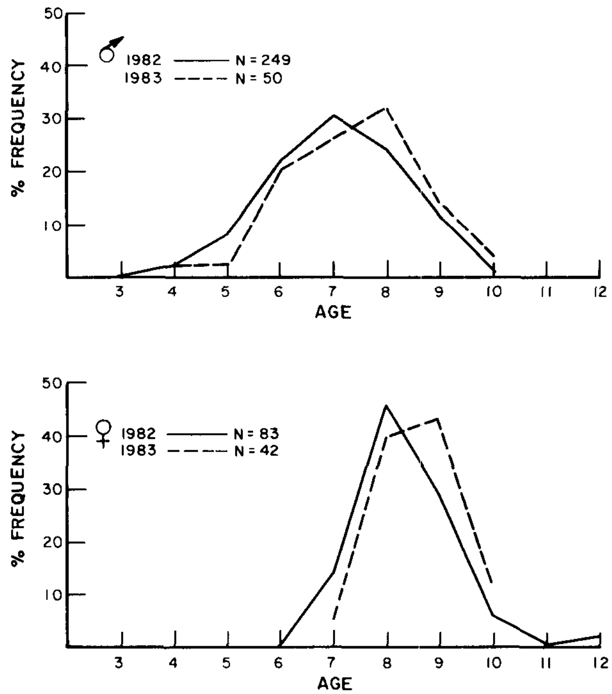

Figure 1. Age frequency by sex of paddlefish captured from Watts Bar Reservoir during spring 1982 and 1983.

paddlefish, the distinct modal shift seen in these data indicated low recruitment between the 2 years sampled. The difference in the most abundant age class by sex was probably due to error in aging, possibly caused by a spawning check in females.

Accuracy of ages determined from dentary bones of paddlefish is open to some speculation. Differences between authors in interpreting annual rings and false annuli make it very difficult to compare age-and-growth studies. Dentary bones were examined from fish tagged in 1982 and recaptured 1 year later. Although these paddlefish were assigned ages by the same individual, only 4 of 10 were aged 1 year apart, while 5 of 10 were assigned the same age for both years. These data demonstrate the difficulty of aging paddlefish with great accuracy. However, inconsistencies in aging were not great, and it is reasonable to conclude that the Watts Bar Reservoir paddlefish population consists of unusually young fish.

Regression analysis was used to compare length to age and weight to age. Although length and weight were positively correlated with age, neither was a good predictor of age due to the variance of these characters within an age group.

Absence of smaller/younger paddlefish in these samples was expected since sampling occurred during the spawning season in an area that appeared to be the primary spawning area. Also, large mesh sizes of the nets used could have limited collection of smaller paddlefish. Although gill net size selectivity could also affect capture of larger/older specimens, their absence from Watts Bar collections was apparently due to their low abundance.

Male paddlefish were more abundant than females, constituting 76% of the sample during 1982 and 60% during 1983. The occurrence of a greater proportion of males on the spawning run is common in paddlefish populations as well as other species and may be explained in part by differences in age to maturity by sex. Male paddlefish appeared to mature in Watts Bar Reservoir during their fifth or sixth year. Numbers of males began to comprise a greater proportion of the sample at this age (Fig. 1). Female paddlefish appeared to reach sexual maturity during their eighth year and were abundant in samples at this age.

Age at maturity was also illustrated by the change in annual growth by sex (Fig. 2). Mean growth of male paddlefish was > 50 mm annually until age 5. Beyond the fifth year, the increase in body length slowed to about 30 mm annually. This decreased growth rate can be seen at about the eighth year in female paddlefish and was assumed to be related to energy expended during gondal development. This

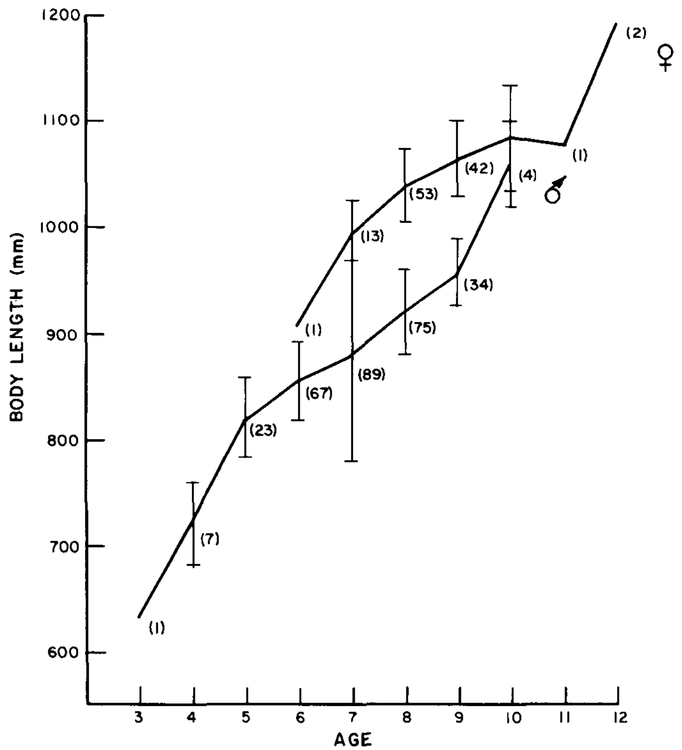

Figure 2. Mean body length at age for paddlefish captured from Watts Bar Reservoir during spring 1982 and 1983. Bars are one standard deviation from the mean.

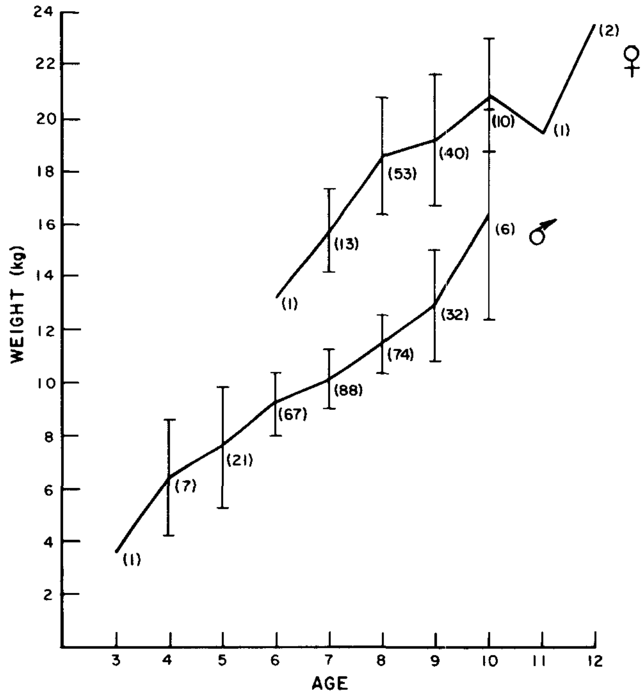

Figure 3. Mean weight at age for paddlefish captured from Watts Bar Reservoir during spring 1982 and 1983. Bars are one standard deviation from the mean.

trend appeared to occur in annual weight increments for females but not for males (Fig. 3). Because male paddlefish appeared on the spawning run at a younger age than females, greater numbers were expected given equal total annual mortality before being effected by fishing mortality. This may be masked during some years by fluctuations in year-class strength.

Age distribution of Watts Bar paddlefish indicated an unusually young population with most fish (97%) ≤ 9 years. Age frequency information reported for other populations shows the most abundant age groups were < 10 years (Meyer 1960, Gengerke 1978, Rosen et al. 1982). However, in these studies, a greater proportion of individuals > 9 years were reported than were seen in Watts Bar collections. The absence of these older specimens from the samples may have been due to heavy exploitation before gill nets were banned in Watts Bar Reservoir in July 1980. This was illustrated by the change in estimated survival by year after recruitment (Fig. 4). Catch curves showed poor survival for both sexes after the ninth year (males 0.14, females 0.24). This may have been due to heavy fishing mortality before the regulation change. In addition, poor survival of male paddlefish (0.49) could be seen between the eighth and ninth year. This was thought to reflect the exploitation by sport and commercial snagging after 1980 and may have indicated

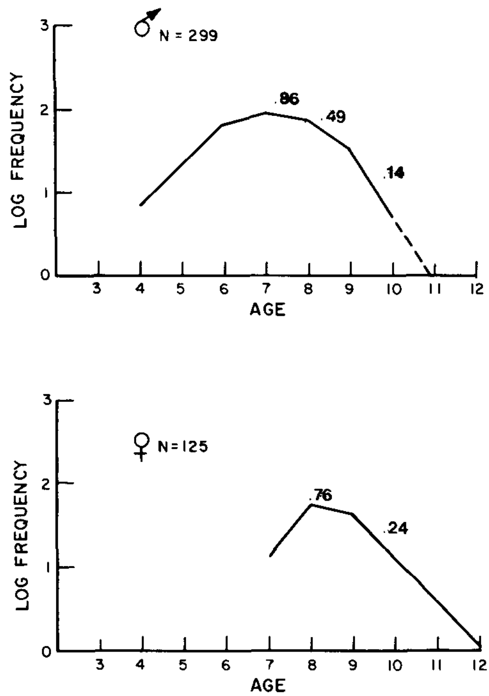

Figure 4. Catch curves for paddlefish of Watts Bar Reservoir 1982 and 1983.

excessive harvest. However, age-groups much older than those in the samples may have been affected by poor recruitment due to low reproduction or survival (Alexander and McDonough 1983).

Annual growth, as increase in body length (BL), was estimated by sex (Fig. 2). Although increase in length is not a linear relationship throughout the entire life of a fish, these data were little affected by small fast-growing and large slow-growing fish in the population since neither of these groups were well-represented in the samples. Therefore, the slope of a simple linear regression was used to estimate the mean annual increase in BL. Male paddlefish between 600 and 1,050 mm BL grew approximately 27.4 mm annually, while female paddlefish between 900 and 1,200 mm BL grew approximately 31.2 mm annually. Growth rate for males appeared reasonable when compared to the mean growth of 11 male paddlefish measured both years (32.7 mm with a standard deviation of 18.4). Growth estimates for male paddlefish in Watts Bar Reservoir were similar to estimates in Norris Reservoir (Alexander and Peterson 1982). Estimates of growth for female paddlefish could not be confirmed by measuring recaptured fish. Two of the 3 female paddlefish recaptured had negative growth in length and all 3 decreased in weight. Of the 16 paddlefish measured both years, 3 were recorded as decreasing in body length. It was surmised that an error in measurement of body length (front of the eye to the tip of the tail rather than to fork of tail) made the first year caused this decrease in length.

Eight of the 16 paddlefish weighed both years decreased in weight. Condition factors for these fish were significantly lower ($P \leq .05$) during the second year. This suggested that handling, tagging, and taking dentary bone sections during 1982 may have impacted the "well being" of these fish. However, a comparison by sex (due to differences in body shape) of condition of all paddlefish captured in 1982 to all paddlefish captured in 1983 revealed significantly ($P \leq 0.05$) lower K values in 1983. Additionally, there was no significant difference between tagged and untagged fish captured in 1983 when tested by sex. Therefore, poorer condition of the 1983 fish was probably related to environmental factors affecting these stocks.

Analysis of the length-weight relationship for paddlefish 900 to 1,200 mm BL indicated no significant difference between sexes for the regression coefficient ($P >$ .05). Testing adjusted mean weights indicated significant differences ($P \leq .05$) between sexes of fish over 900 mm BL with females being heavier than males of the same length.

The equations best describing predicted weight by sex are:

$$\log W = -6.2343 + 3.4758 \log BL \text{ (females)}$$
$$\log W = -5.6465 + 3.2735 \log BL \text{ (males)}.$$

This analysis supports the use of sex-related differences in body shape as 1 criteria for determining the sex of mature paddlefish (Alexander and Peterson 1982). Before female paddlefish reach sexual maturity at age 8 and about 1,000 mm there was little difference in the length-weight relationship between sexes. This pointed out that immature females might not be distinguishable by body morphology from males. However, this does not constitute a real problem because immature females are not usually captured on the spawning run (Russel 1972).

To ensure the population estimate was not diluted by the addition of a large number of recruits during the second year of sampling, male paddlefish ≤ 5 years and female paddlefish ≤ 7 years were not considered in the estimate. This resulted in removal of only 5 fish. These ages were selected based on age to maturity estimates and the percent occurrence in the sample for both years indicating most males were recruited by age 6 and females at age 8. This seems to be a conservative approach because 4- and 5-year-old males and 7-year-old females were captured during both years indicating at least partial recruitment of their respective year-classes. Size selectivity of nets affected these data. In addition, the smaller sample size in 1983 would tend to decrease the number of fish at the size extremes, both large and small.

The number of harvestable size paddlefish (>700 mm BL) in Watts Bar Reservoir in spring 1982 was estimated based on 382 marked fish in 1982 and 14 recaptures from 133 fish in 1983. This resulted in an estimate of 3,421 with a 95% confidence interval of 2,184 to 6,665. When compared to population estimates for other bodies of water (Gengerke 1978, Aggus et al. 1979, Alexander and Peterson 1982, Combs 1982), this estimate was smaller than expected, which may be a result of heavy commercial exploitation during spring 1979 and 1980 just prior to closure of net fishing. This was a period of escalating roe prices and heavy exploitation in the Tennessee Valley which can rapidly reduce adult paddlefish stocks (Pasch and Alexander 1983).

Paddlefish are harvested below Fort Loudoun Dam by a well-established sport snag fishery. Although the sport snagging of paddlefish was not creeled, observations made during netting operations are worthy of mention. On each night of netting the number of fishermen snagging below the dam was observed, with interviews obtained occasionally. Intuitive estimates from these interviews of the number of fishermen per night during April and May would be 5 to 20. The number of fish harvested probably ranged from 0 to 20 each night with 200 to 500 removed annually. These estimates were not confirmed, but they approach an exploitation rate (15% to 20%) that has been suggested as optimum by some researchers (Gengerke 1978, Alexander and Peterson 1982) and should be considered in management plans.

This study has shown that Watts Bar Reservoir does not have an adequate number or age structure of harvestable size paddlefish to justify any increase in harvest. Abundance estimates, both number and weight, appear to be below carrying capacity as suggested by comparison to estimates for other reservoirs supporting paddlefish populations. It has been shown that paddlefish stocks can be overexploited in a relatively short time when commercially harvested with nets (Pasch and Alexander 1983). It is apparent the Watts Bar population needs continued protection from a commercial net fishery until numbers and biomass increase to acceptable levels. Acceptable levels, in turn, depend on each fishery manager's perspective and goals.

At present, the exploitation rates for the sport snagging and commercial snagline fishery have not been adequately determined, but are considered to be important components of the fishery. A localized intensive creel survey to determine harvest and pressure for each fishery should be conducted.

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