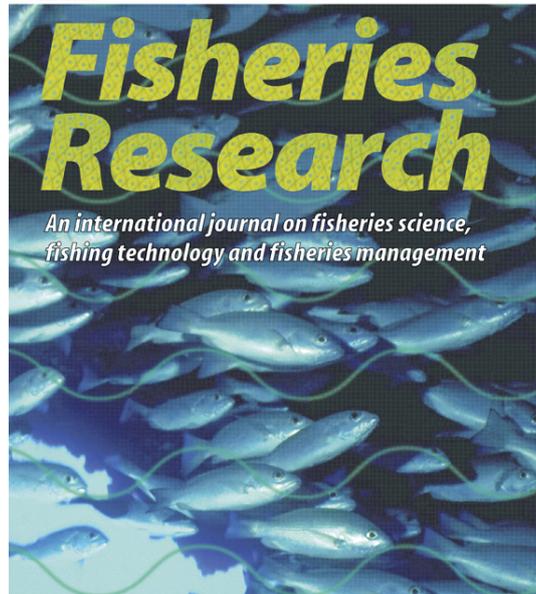


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Short communication

Lack of size selectivity for paddlefish captured in hobbled gillnets

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Abstract

A commercial fishery for paddlefish *Polyodon spathula* caviar exists in Kentucky Lake, a reservoir on the lower Tennessee River. A 152-mm (bar-measure) minimum mesh size restriction on entanglement gear was enacted in 2002 and the minimum size limit was increased to 864 mm eye-fork length to reduce the possibility of recruitment overfishing. Paddlefish were sampled in 2003–2004 using experimental monofilament gillnets with panels of 89, 102, 127, 152, 178, and 203-mm meshes and the efficacy of the mesh size restriction was evaluated. Following the standards of commercial gear used in that fishery, nets were “hobbled” (i.e., 128 m × 3.6 m nets were tied down to 2.4 m; 91 m × 9.1 m nets were tied down to 7.6 m). The mean lengths of paddlefish ($N_{\text{total}} = 576$ fish) captured in each mesh were similar among most meshes and bycatch rates of sublegal fish did not vary with mesh size. Selectivity curves could not be modeled because the mean and modal lengths of fish captured in each mesh did not increase with mesh size. Ratios of fish girth to mesh perimeter ($G:P$) for individual fish were often less than 1.0 as a result of the largest meshes capturing small paddlefish. It is unclear whether lack of size selectivity for paddlefish was because the gillnets were hobbled, the unique morphology of paddlefish, or the fact that they swim with their mouths agape when filter feeding. The lack of size selectivity by hobbled gillnets fished in Kentucky Lake means that managers cannot influence the size of paddlefish captured by commercial gillnet gear by changing minimum mesh size regulations.

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1. Introduction

Minimum mesh-size restrictions in commercial gillnet fisheries are routinely proposed to increase yield-per-recruit (Ehrhardt and Die, 1988), re-structure predator-prey interactions (Schindler et al., 1998), reduce bycatch discard rates (Gray et al., 2005), or protect stocks from recruitment overfishing by delaying the size and age of recruitment to the fishery (Jude et al., 2002). Failure to protect some spawners in a heavily exploited stock will increase the likelihood of recruitment overfishing which, if left unchecked, can lead to stock collapse. Using that rationale, the Tennessee Wildlife Resources Commission in 2002 established a minimum bar measure of 152-mm for any entanglement gear used by commercial fishers to capture paddle-

fish *Polyodon spathula*. The minimum size limit was also raised from 813 to 864 mm eye-fork length (EFL). A recent assessment of the fishery concluded that the stock was routinely being fished at an unsustainable rate and that recruitment overfishing was a distinct possibility (Scholten and Bettoli, 2005). Commercial fishers usually target paddlefish for their roe, which currently sells for US\$ 154–198/kg wholesale (US\$ 385–845/kg retail), but the flesh can also be sold for US\$ 1/kg to wholesale fish markets. Several high-profile convictions in 2004 for interstate trafficking in illegal paddlefish roe also heightened efforts to protect that valuable resource and the new mesh size restriction met with virtually no opposition.

Imposing minimum mesh-size requirements for gillnets often does not meet with the same opposition that can accompany other ways of reducing fishing mortality such as limited entry or closed seasons (e.g., Huhmarniemi and Salmi, 1999). Perhaps a more important rationale for proposing mesh size regulations is the fact that gillnets are usually highly size-selective (Hamley, 1980) and it is usually possible to reduce the bycatch of smaller fish by increasing the minimum mesh size. The degree to which

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particular gillnet meshes select for different sizes of fish of many species has been the subject of numerous investigations (e.g., Hamley, 1975; Hansen et al., 1997; Carlson and Cortés, 2003) and the best approach to indirectly measure size selectivity has been debated (e.g., Millar, 2000; Bromaghin, 2005).

Many marine and freshwater fish species have been the subject of gillnet selectivity studies, but few studies have explicitly examined selectivity in a paddlefish fishery. Paukert and Fisher (1999) reported that mean lengths of paddlefish caught in three different mesh sizes increased with increasing mesh size in an Oklahoma reservoir, but mesh size selectivity was not modeled. Preliminary observations we made while retrieving more than 150 experimental gillnets in 2003–2004 suggested that unlike most species, little size-selectivity was evident for paddlefish. The problem facing managers of paddlefish fisheries is compounded because paddlefish caught as bycatch in gillnets (i.e., sublegal fish) can experience high rates of mortality (Bettoli and Scholten, 2006). Thus, our objectives were to test the following null hypotheses:

- (1) Mean lengths of paddlefish captured in experimental gillnets would not vary with mesh size.
- (2) The proportion of the catch in each mesh that was bycatch (i.e., sublegal fish less than 864 mm EFL) would not vary with mesh size.
- (3) Selectivity curves for each mesh would broadly overlap.
- (4) Fish girth:mesh perimeter ratios would be similar in each mesh.

Failure to reject the first three hypotheses would indicate that mesh size restrictions could not be used to increase the size-structure of the commercial catch and, subsequently, reduce bycatch and protect some mature paddlefish from harvest. Rejection of the fourth hypotheses would likewise indicate that paddlefish of varying lengths (and girths) were susceptible to capture by a wide range of mesh sizes.

2. Study area

Kentucky Lake is a mainstream impoundment of the Tennessee River located in western Tennessee and Kentucky. Impounded in 1944 by Kentucky Dam at Tennessee River km (TR km) 35, Kentucky Lake is a eutrophic impoundment that covers 64,870 ha and has a mean depth of 5.4 m. Water flows north through this 296-km long reservoir, with Pickwick Dam forming the upstream boundary at TR km 331. Kentucky and Pickwick dams have power generators controlled by the Tennessee Valley Authority and navigation locks controlled by the U.S. Army Corps of Engineers.

Since 1999, annual paddlefish harvest (as reported by commercial fishers) from Kentucky Lake has ranged from 4590 to 11,863 fish ($\bar{X} = 7458$), with 39–54 commercial fishers reporting that they fished this reservoir. Annual roe harvest has been steadily increasing from a reported 13,426 kg during the 2002 season to 44,544 kg during the 2005 season. Approximately 7–10 dealers purchase and process this roe into caviar that they sell to domestic consumers, other Tennessee dealers, and large-

scale distributors (who sell it domestically or export it from the U.S.). Much of the caviar that is exported from the United States originates from Tennessee waters (personal communication; M. Maltese, Office of Scientific Authority, U.S. Fish and Wildlife Service, Washington, DC), particularly from Kentucky Lake on the lower Tennessee River.

3. Methods

3.1. Data collection

Paddlefish were collected in 2003 and 2004 in Kentucky Lake before (5 September–2 November 2003) and after (20 April–3 May 2004) Tennessee's commercial fishing season. We used clear monofilament (0.40–0.57 mm diameter) gillnets (3.6 m × 128 m, hobbled to 2.4 m, and 9.1 m × 91 m, hobbled to 7.6 m) that were constructed to the same standards as those deployed by commercial fishers on Kentucky Lake, except our nets were experimental and consisted of six panels of 89, 102, 127, 152, 178, and 203 mm bar-measure meshes. Nets were hung on a 1/2 basis and panels were joined using 1.5 mm twine. Mesh panels were tied between a 12.7 mm foam core line (top) and a 5 mm (weight = 5 kg per 100 m) lead core line (bottom). Gillnets used by commercial fishers were almost exclusively single-panel nets with 152-mm mesh panels, and some fishers used multi-filament netting. Hobbling gill nets that are suspended off the bottom was a ubiquitous technique that fishers in Tennessee and elsewhere used to increase their catch rates in moving waters. All mesh sizes in our experimental nets had equal fishing power (i.e., the number of panels and area fished by each mesh were similar), which is a key assumption in gillnet selectivity studies. The eye-to-fork length (EFL, mm) was recorded for each paddlefish, as well as the mesh in which they were captured. Maximum girth measurements were taken for 403 paddlefish.

3.2. Data analysis

Mean lengths among meshes were compared using one-way analysis of variance (ANOVA). The assumption of homogenous variances ($P > 0.05$) was tested using Levene's test. If the global null hypothesis was rejected, mean lengths were compared using Tukey's test. We used the χ^2 -statistic and a 2×6 contingency table to test whether mesh sizes and the proportion of legal-sized paddlefish (≥ 864 mm EFL) caught in each mesh were associated. The percentage of the total catch that was bycatch (i.e., shorter than the minimum size limit) was regressed against mesh size to determine whether the bycatch decreased with increasing mesh sizes.

We attempted to fit selectivity curves following the method described by Kirkwood and Walker (1986), who used bootstrapping techniques to fit a gamma distribution to the lengths of fish captured in each mesh. Length at maximum selectivity was assumed to be proportional to mesh size; therefore modal lengths in each mesh must increase in order to fit the model.

Maximum girth was measured for 403 paddlefish but girth measurements were not available for 173 paddlefish collected before the fishing season began. Simple linear models were used

to assign girth measurements to fish for which girth was not measured based on their EFL and sex. The relation between EFL and girth for 56 pre-season females ($r^2 = 0.90$; $P < 0.001$) was used to predict girth measurements for 108 other pre-season females. Similarly, the EFL-girth relation for 58 pre-season males ($r^2 = 0.74$; $P < 0.001$) was used to predict girth measurements for 65 other pre-season males. For many species, maximum gillnet selectivity corresponds to $G:P$ ratios centered around 1.1–1.4 (e.g., Spangler and Collins, 1992; Van Den Avyle et al., 1995) and some authors have concluded that the optimum girth is about $1.25 \times$ the mesh perimeter (e.g., Hamley, 1980). We created frequency-distributions of $G:P$ ratios in each mesh to see whether the ratios fell within expected ranges. Mean $G:P$ ratios among meshes were also compared using one-way ANOVA and Tukey's multiple comparison test. If Levene's test indicated that variances were dissimilar ($P \leq 0.05$), the data were transformed using natural logarithms.

4. Results

The variances associated with paddlefish lengths were homogenous among mesh sizes (Levene's test; $P = 0.112$) and

the mean lengths (EFL) of paddlefish captured in each mesh of the experimental gillnets were marginally different ($F = 2.20$; d.f. = 5, 570; $P = 0.053$; Fig. 1). The mesh size effect was attributed to the fact that the mean length of paddlefish captured in the 89-mm mesh ($\bar{X} = 824$ mm) differed from the mean length of fish in the 127-mm mesh ($\bar{X} = 860$ mm). However, the length distributions of fish captured in those two meshes overlapped broadly. Mean EFLs of paddlefish were statistically similar among all other meshes. The means varied over a narrow range (824–860 mm EFL) and modal length classes were 800 or 825 mm EFL for all meshes. With the exception of the smallest mesh, the EFL-frequency distributions were not strongly positively or negatively skewed for any mesh. The parameters of the gamma distribution could not be estimated, and selectivity curves for each mesh could not be created, because modal lengths of captured paddlefish did not increase with mesh size.

The sublegal bycatch of paddlefish in each mesh ranged from 53 to 70% but did not decrease with increasing mesh size. The proportion of the total catch in each mesh that was sublegal was not related to mesh size (linear regression; $F = 1.11$; d.f. = 1,4; $P = 0.350$; $r^2 = 0.22$) and the χ^2 -test of association between the percentage of legal and sublegal fish captured in each mesh size was not significant ($\chi^2 = 9.2$; d.f. = 5; $P = 0.103$).

The similarity in lengths of paddlefish collected in each mesh, coupled with the linear relation between lengths and

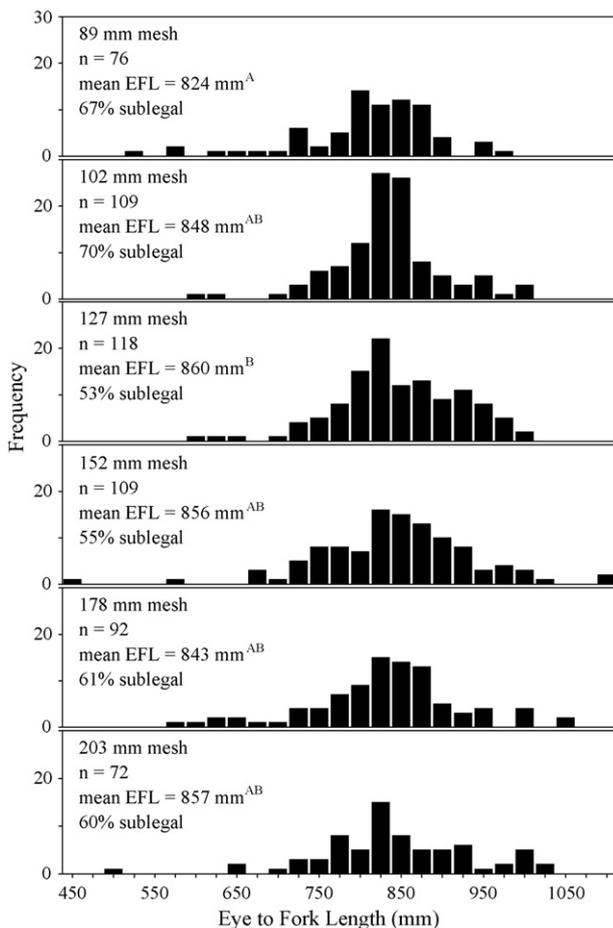


Fig. 1. Length-frequency distributions for paddlefish captured in experimental gillnets in Kentucky Lake, Tennessee/Kentucky. Means sharing the same letter were not significantly different (Tukey's test; $P = 0.05$). Percentage of sublegal fish (<864 mm eye-fork length) is indicated for each mesh panel.

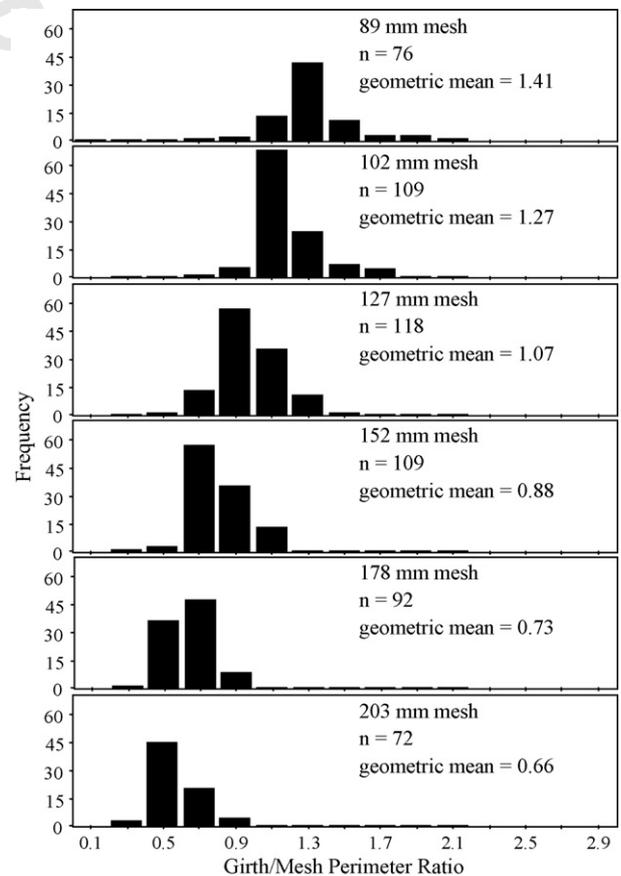


Fig. 2. Fish girth:mesh perimeter ratios by mesh size for paddlefish collected in Kentucky Lake, Tennessee/Kentucky, 2003–2004. All geometric means were significantly different from one another (Tukey's test; $P = 0.05$).

girth, resulted in declining $G:P$ ratios with increasing mesh size (Fig. 2). The variances associated with the $G:P$ ratios were dissimilar (Levene's test; $P=0.001$); therefore, the data were \log_e -transformed. The geometric mean $G:P$ ratios for all meshes differed (ANOVA, $F=324.8$; d.f. = 5, 570; $P<0.0001$) and declined from 1.41 in the smallest mesh to 0.66 in the largest mesh. $G:P$ ratios above ~ 1.5 in the smallest mesh represented large fish that were entangled (as opposed to wedged) in that mesh. The low (≤ 0.7) $G:P$ ratios in the three largest meshes also represented fish that were entangled because they were too small in girth to be caught by wedging in the large meshes.

5. Discussion

We collected few ($n=32$) paddlefish shorter than 700 mm EFL, which suggests that the experimental gillnets we fished were selective for fish longer than 700 mm EFL. However, the low catch of small fish may have occurred because (1) we did not fish our gear in habitats (e.g., inshore or shallow backwaters) that might have harbored smaller paddlefish, (2) recent year classes may have been weak, or (3) a combination of these factors. Excessive bycatch of small (<700 mm EFL) paddlefish is not a concern in Tennessee waters (or elsewhere, as far as we know); thus, we will limit our discussion to the larger sizes of paddlefish routinely collected in commercial and research gillnets.

It is unclear what factors were most responsible for the lack of gillnet size selectivity for paddlefish longer than 700 mm EFL. A casual observer might conclude that the long, narrow rostrum of a paddlefish, which is no wider than ~ 1 cm on a large (>20 kg) fish, might render large fish vulnerable to entanglement in small meshes; however, the absence of size selectivity was due more to capturing small fish in large meshes than capturing large fish in small meshes. Small paddlefish were routinely captured in meshes with large perimeters that should have allowed them to easily pass through the netting without becoming entangled or wedged. Paukert and Fisher (1999) also noted that the smallest paddlefish in their study were collected in the largest mesh (203 mm). Hoffnagle and Timmons (1989) speculated that small paddlefish were caught in large meshes due to entanglement of their rostrums when they turned upon encountering a net. Perhaps a more plausible reason why we did not observe any size selectivity is the way in which paddlefish move through the water column. As early as the 1920s, ichthyologists noted that paddlefish swim with their large mouths open to filter-feed and that they use their heterocercal tails to propel themselves, with "head and paddle thrown alternately to the right and left, the tip of the paddle thus covering a considerable space on each side of the line along which it is swimming" (Forbes and Richardson, 1920). Swimming with their mouths agape would undoubtedly increase the likelihood that small paddlefish might become entangled by their mouthparts; likewise, moving through the water with a pronounced side-to-side motion of the rostrum and head would likely contribute to higher entanglement rates when a paddlefish encountered a gillnet. The combination of unique morphology and behavior might be responsible for different meshes in hobbled gillnets capturing paddlefish over wide, but similar, size ranges.

The hobbled nature of the nets may have confounded the normally strong relationship between lengths of fish captured and mesh size, which has been observed for most species of fish. Hamley (1980) noted that nets hung more loosely tended to capture more fish through entanglement, rather than wedging. The extreme $G:P$ ratios we observed for paddlefish may have resulted from the loose netting that characterizes a hobbled gillnet. Commercial fishers we accompanied and those who assisted our netting operations insisted that tying down their nets and creating a loose bag of netting was an essential design element when gillnets are fished for paddlefish in moving water. The comparative capture efficiencies and size selectivity of hobbled versus standard gillnets is unknown and should be investigated.

Our results would appear to contradict the findings of Paukert and Fisher (1999), who reported that the mean lengths of paddlefish captured in hobbled gillnets increased with increasing mesh size in an Oklahoma reservoir. However, the range of fish lengths in each of the three meshes they fished overlapped so broadly as to render any attempts to significantly alter the size structure of the catch difficult, if not impossible. Although Paukert and Fisher (1999) noted that bycatch could be reduced by using larger-mesh nets, they were referring to the bycatch of other species such as blue catfish *Ictalurus furcatus*, striped bass *Morone saxatilis*, and bigmouth buffalo *Ictiobus cyprinellus*, not sublegal paddlefish.

The lack of size selectivity by hobbled gillnets fished in Kentucky Lake means that managers cannot influence the size of paddlefish captured by commercial gillnet gear by changing minimum mesh size regulations. The inability to delay the size at recruitment to the gear would not be problematic if bycatch rates or bycatch mortality were low. However, bycatch rates exceed 90% when fishers were targeting mature females and predicted initial mortality (i.e., paddlefish are dead when nets are retrieved) can exceed 33% at water temperatures of 15 °C (Bettoli and Scholten, 2006). Managers of this commercial fishery should implement regulations that will minimize bycatch mortality (e.g., bycatch quotas, confine netting to cool water periods) because this study indicates that mesh restrictions will not reduce the amount of bycatch.

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