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Bycatch rates and initial mortality of paddlefish in a commercial gillnet fishery

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Abstract

Tennessee is one of seven states in the U.S. that allows commercial fishing for paddlefish, *Polyodon spathula*. Although there is a small market for the flesh, most fishers target paddlefish for their valuable roe, which currently brings as much as US$143/kg wholesale. We deployed experimental monofilament and multifilament gillnets in Kentucky Lake, Tennessee-Kentucky, and accompanied commercial gillnet fishers during the 2003–2004 and 2004–2005 commercial fishing seasons (November 15 to April 23) to estimate the bycatch of sublegal (<864 mm eye-fork length) paddlefish, legal males, and legal, but immature, females. Variation in initial mortality (i.e., dead in the nets) was modeled as a function of mesh size, fish length, water temperature, soak time, and twine type using multiple logistic regression. The bycatch rate of sublegal fish in the commercial catch was 60%. Mature females represented only 8% of the catch; thus, the bycatch rate was 92% for fishers targeting egg-laden fish. Most (71%) of the paddlefish were dead in the nets when water temperatures exceeded 17 °C. Mesh size and fish length were not significant ($P \geq 0.098$) predictors of initial mortality. The probability of initial mortality was significantly ($P \leq 0.004$) and directly related to soak time and water temperature and fish were more likely to be dead in monofilament nets than multifilament nets. The results of this research prompted the state regulatory authority to end the commercial season 8 days sooner (on April 15 each year) to avoid warm water temperatures; however, a proposed ban on monofilament netting met with stiff opposition from commercial fishing interests and the ban was not enacted.

Keywords: Paddlefish; Gillnet; Bycatch mortality; Bycatch rate; Monofilament; Multifilament

1. Introduction

The Magnuson-Stevens Fishery Conservation and Management Act of 1994 (amended 1996) mandated reductions in marine bycatch where practicable; however, no such legislation protects freshwater fish stocks in the United States. Bycatch becomes problematic when the survival of released organisms is poor. For instance, if sublegal Pacific halibut, *Hippoglossus stenolepis*, caught in longline fisheries are not carefully released, mortality can be extremely high (50–75%; Kaimmer and Trumble, 1997) and Clark and Hare (1998) reported that bycatch and subsequent mortality of sublegal Pacific halibut reduced recruitment by about 10%. More than a decade ago, it was estimated that commercial marine fishers annually discarded about 25% of what they caught, or ~27 million metric tonnes of fish and wildlife (Alverson et al., 1994). In 2000, commercial fishers in US marine fisheries discarded about 2.3 billion pounds of wildlife (i.e., birds, marine mammals, turtles, fish) as bycatch (Pew Oceans Commission, 2003) and reducing bycatch in global fisheries is still the subject of intense study (e.g., Hall and Mainprize, 2005). The total elimination of bycatch in any commercial fishery may be unrealistic (U.S. Commission on Ocean Policy, 2005); however, a consensus has emerged in recent years that bycatch

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should be minimized to levels approaching insignificance (Crowder and Murawski, 1998).

Unlike marine fisheries, a depauperate literature exists for bycatch in freshwater fisheries and most information pertains to commercial fisheries in coastal rivers targeting anadromous fishes. For instance, shortnose sturgeons, *Acipenser brevirostrum,* and Atlantic sturgeon, *A. oxyrinchus,* were commonly observed as bycatch in gillnet fisheries targeting migrating American shad, *Alosa sapidissima* (Collins et al., 1996). Armstrong and Hightower (2002) discussed the ramifications of bycatch mortality in efforts to recover Atlantic sturgeon in a coastal North Carolina river. Hale et al. (1996) estimated that freshwater game fish bycatch in Florida's St. John's River striped mullet, *Mugil cephalus,* fishery accounted for less than 1% of the total catch by number.

In the inland waters of Alberta, Canada, commercial fisheries for lake whitefish, *Coregonus clupeaformis,* were managed with a quota and a walleye, *Sander vitreus,* bycatch quota (Sullivan, 2003). Efforts to improve recreational walleye fisheries resulted in uneconomical commercial fisheries because commercial fishers often exceeded their walleye bycatch quota before they realized their lake whitefish quota. Paddlefish, *Polyodon spathula,* bycatch rates were described in a Missouri River hoopnet fishery targeting buffalo, *Ictiobus* spp., and exotic carps (Dieterman et al., 2000); those authors predicted one paddlefish would be caught and killed for every 37 net-days of fishing effort. We are unaware of any published reports on bycatch rates for commercially exploited paddlefish (i.e., the number of paddlefish discarded), nor are we aware of any studies describing rates of bycatch mortality for paddlefish captured in gillnets.

Under certain conditions, paddlefish can be overfished in a commercial gill net fishery. Paddlefish are especially vulnerable when they congregate in spawning areas downstream of dams (Pasch and Alexander, 1986). High flows induce paddlefish to migrate to spawning areas (Paukert and Fisher, 2001), but it is difficult for fishers to deploy and retrieve gillnets in high flows. Regularly alternating periods of high and low discharge in a regulated system such as Kentucky Lake on the lower Tennessee River create conditions that are favorable to commercial fishing with gillnets. Based on yield modeling and spawning potential ratios, Scholten and Bettoli (2005) concluded that the Kentucky Lake paddlefish stock is overfished, particularly during droughts, when gillnets can be easily deployed during the winter and spring spawning migration. Paddlefish are listed as an Appendix II species by CITES (i.e., Convention on International Trade in Endangered Species of Wild Fauna and Flora) and Tennessee is one of only seven states in the U.S. that allows commercial harvest of paddlefish, the others being Arkansas, Illinois, Indiana, Kentucky, Mississippi, and Missouri. Exact figures on the total nationwide harvest of paddlefish are not available, but it is known that Tennessee usually leads the nation in the amount of paddlefish caviar exported overseas (Marie Maltese, Division of Scientific Authority, U.S. Fish and Wildlife Service, personal communication).

Markets are developing for paddlefish flesh, but most fishers target paddlefish exclusively for their eggs because of high prices received for roe. In 2005, wholesale prices for paddlefish roe in Tennessee approached US$143/kg; the processed caviar subsequently fetches upwards of US$845/kg in some markets. A large female carrying 3.5 kg of roe was worth at least US$424 (wholesale) during the 2004–2005 Tennessee commercial fishing season.

In this paper, bycatch in the Kentucky Lake paddlefish fishery refers to captured paddlefish that were either illegal to possess because they were shorter than the minimum eye-fork length (EFL) limit of 864 mm (i.e., regulatory discards), or non-egg fish (i.e., economic discards; males and immature females). Our objectives were to (1) describe bycatch by estimating the relative abundance of sublegal paddlefish, legal paddlefish (i.e., ≥864 mm EFL), and mature females in the paddlefish commercial fishery in Kentucky Lake; and (2) model the influence of water temperature, fish length, soak time, mesh size, and netting material on rates of initial mortality for paddlefish caught in gillnets.

2. Study area

Kentucky Lake is a mainstream impoundment of the Tennessee River located in western Tennessee and Kentucky. Impounded in 1944 by the construction of Kentucky Dam at Tennessee River km (TRkm) 35, this 296-km long reservoir is a eutrophic impoundment that covers 64,870 ha at full pool and has a mean depth of 5.4 m. Water discharged from Pickwick Dam, the upstream boundary of the reservoir at TRkm 331, flows north through Kentucky Lake. Beginning in 2002, the commercial season for paddlefish ran from November 15 to April 23 and fishers were required to use nets with at least 152-mm bar measure netting. The fishery was regulated with an 864-mm eye-EFL minimum length limit; there were no other paddlefish regulations in effect during our study.

3. Methods

Paddlefish were collected in the riverine and lacustrine regions of Kentucky Lake between TRkm 105 and TRkm 298 before, during, and after the 2003–2004 and 2004–2005 fishing seasons. A cooperative interaction with several experienced commercial fishers gave us access to "Traditional Ecological Knowledge" (Price and Rulifson, 2004); that is, the collective experiences and knowledge of the people who rely on the resource for their livelihood. This interaction and the experiences we gained allowed us to collect paddlefish over a wide range of habitat types, flow regimes, and seasons. Horizontal experimental monofilament gill nets (0.40–0.57 mm diameter twine; 3.6 m × 128 m, tied down to 2.4 m; and 9.1 m × 91 m, tied down to 7.6 m) with six panels of 89, 102, 127, 152, 178, and 203 mm bar-measure meshes were fished overnight. Horizontal multifilament gill nets

(0.52 mm diameter twine; 9.1 × 91 m, tied down to 7.6 m) with either 102, 127, or 152 mm bar-measure mesh were fished before and during the 2004–2005 fishing season. During the 2002–2003 and 2003–2004 commercial fishing seasons, we accompanied commercial fishers using single mesh (152 mm bar-measure) multifilament nets (0.52 mm diameter twine) and observed their catch to collect data on bycatch rates and additional data on initial mortality.

Paddlefish were removed from the nets and immediately coded as dead (i.e., no opercular flap movements; unresponsive to touch; code = 0) or alive (code = 1). Surface water temperature (°C) and soak time (recorded to the nearest minute and subsequently coded in hours) were recorded when each net was retrieved. If we accompanied commercial fishers, soak time was based on their best estimate of when they set each net. Capturing mesh size (mm, bar measure), twine type (monofilament = 0; multifilament = 1), and EFL (mm) were recorded for each paddlefish. The binomial mortality data were subjected to multiple logistic regression analysis (SAS Institute, 2001) to test whether fish length, mesh size, twine type, soak time, or water temperature were significant ($P \leq 0.05$) predictors of initial mortality. The relative abundances of sublegal fish shorter than 864 mm EFL, legal males and immature females, and mature (egg-laden) females were subsequently calculated for the commercial catch during the 2002–2003 and 2003–2004 fishing seasons.

4. Results

We examined 1445 paddlefish captured in monofilament gillnets ($n = 618$ fish) and multifilament gillnets ($n = 827$ fish) to estimate rates of bycatch and initial mortality. Paddlefish measured between 356 and 1161 mm EFL. Water temperatures ranged from 4.5 to 28.6 °C (mean = 16.6; S.E. = 0.15). Soak times ranged from 4.0 to 46.2 h (mean = 17.0; S.E. = 0.14). During the 2002–2003 and 2003–2004 fishing seasons, 60% of the paddlefish captured by commercial fishers were sublegal (≤864 mm EFL) and mature females represented only 8% of the catch (i.e., the bycatch rate for fishers targeting mature, egg-laden females was 92%).

Initial bycatch mortality was high at certain times of the year. Most (71%) paddlefish were dead when the nets were retrieved in water temperatures exceeding 17 °C (Fig. 1). Conversely, the observed initial mortality rate was low (<7%) at water temperatures less than 11 °C. In all, we observed 582 dead paddlefish and 863 live paddlefish. Mesh size was not a significant ($P = 0.145$) predictor of mortality in the logistic regression model. Fish length was inversely related to mortality, but the relationship was weak and not statistically significant ($P = 0.098$); all other predictor variables specified in the logistic regression model were significant. Initial mortality increased significantly with soak time ($P = 0.004$) and water temperature ($P < 0.001$) and fish were more likely to be dead in a monofilament net than a multifilament net ($P < 0.001$). Based on the χ^2 test statistic, water temperature was the most influential variable ($\chi^2 = 145.0$), followed by net material ($\chi^2 = 23.1$), and soak time ($\chi^2 = 8.2$). The logistic model that included only temperature, net material, and soak time predicted the probability of death (P_i) as:

$$P_i = \frac{e^{-4.7790+(0.2410\times \text{temperature})-(0.8545\times \text{twine})+(0.0396\times \text{time})}}{1 + e^{-4.7790+(0.2410\times \text{temperature})-(0.8545\times \text{twine})+(0.0396\times \text{time})}}$$

The Hosmer and Lemeshow goodness-of-fit test indicated that the logistic model provided a good fit to the data ($P = 0.301$).

When soak time was held constant at 12 h, predicted mortality rates exceeded 26–45% when water temperatures exceeded 17 °C (Fig. 2). Those warm temperatures are often

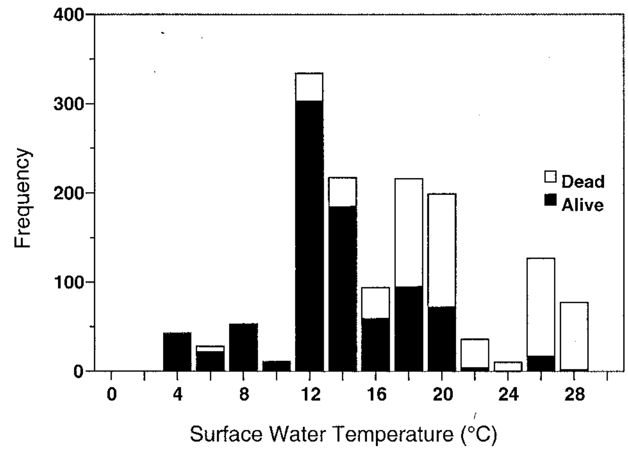

Fig. 1. Status of paddlefish at different water temperatures when removed from gillnets deployed in Kentucky Lake, Tennessee-Kentucky, 2002–2004. Data were pooled over all mesh sizes, twine types, fish lengths, and soak times.

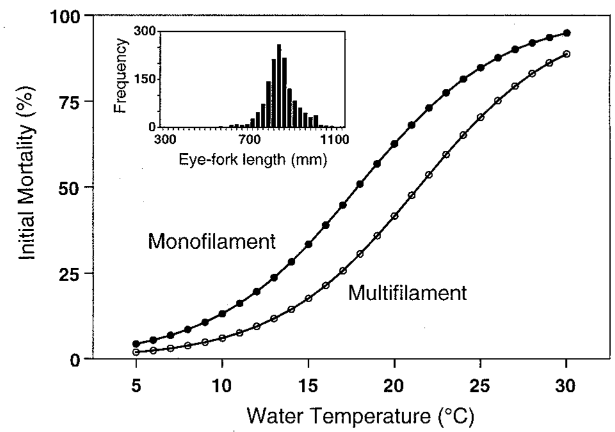

Fig. 2. Predicted initial mortality of paddlefish removed from gillnets in Kentucky Lake, Tennessee-Kentucky, before, during, and after the 2002–2003 and 2003–2004 commercial harvest seasons. Soak time was held constant at 12 h. Inset depicts the length–frequency histogram for the 1445 paddlefish that were observed in this study.

observed in April at the end of the commercial season. Water temperatures at the beginning of the commercial season (mid November) are usually less than 15 °C and predicted mortality rates are lower (18–33%) at 15 °C. Low (<10%) initial mortality rates for both twine types with a 12-h soak would not be expected until the water temperature fell below 8.7 °C. According to the model, netting should be restricted to waters cooler than 14.2 °C if the objective was to keep initial mortality below 15% in a typical commercial gill net (i.e., multifilament net set for 12 h).

5. Discussion

The positive relationship we observed between gillnet soak time and initial mortality of paddlefish has been described for other species (e.g., coho salmon, *Oncorhynchus kisutch;* Buchanan et al., 2002) and that effect was not unexpected. Fish removed from nets with long soak times have a higher likelihood of being constrained longer by the netting, and experiencing more tissue damage and physiological stress due to capture, than fish removed from nets with short soak times. Likewise, it is generally assumed that mortality in gillnets increases with water temperature for many, if not most, species (e.g., Pacific halibut, Davis and Olla, 2001; spotted seatrout, *Cynoscion nebulosus*, Murphy et al., 1995). Although the inverse relationship between paddlefish length and initial mortality was not significant, smaller fish of other species have also been shown to suffer higher mortality than larger fish (e.g., lingcod *Ophiodon elongatus;* Davis and Olla, 2002). In contrast to these expected findings, we are unaware of any published information relating to differential mortality caused by monofilament and multifilament nets. Some fish hatchery managers always use multifilament nets to collect their wild broodfish because they feel they are less harmful to the fish than monofilament nets (M. Smith, Eagle Bend State Fish Hatchery, Clinton, Tennessee; personal communication), but hard data are lacking as to why monofilament nets may be more injurious.

The high bycatch rates we observed were typical of many ocean fisheries (e.g., Zeller and Pauly, 2005) in that the number of paddlefish discarded was an order of magnitude higher than the number of paddlefish retained by fishers seeking egg-laden females. Lack of size selectivity by hobbled (tied-down) gillnets used by commercial fishers in Kentucky Lake contributed to high bycatch rates (Bettoli and Scholten, 2005). Managers are sometimes forced to prohibit certain gears in cases when bycatch rates cannot be reduced and bycatch mortality cannot be minimized. For instance, Sullivan (2003) demonstrated that walleye bycatch in Alberta, Canada, could be reduced if commercial fishers switched from gill nets to trap nets to harvest lake whitefish.

Initial mortality rates were low at cold water temperatures and limiting fishing to winter months may be a viable strategy to reduce bycatch mortality of males and immature female paddlefish. Benefits that might accrue from limiting fishing to the winter months would rely on a low rate of delayed mortality, which is the subject of an ongoing investigation. Cooler water temperatures increase the likelihood of survival of fish released in sport and commercial fisheries (e.g., striped bass *Morone saxatilis,* Bettoli and Osborne, 1998). The Tennessee Wildlife Resources Commission adopted this management strategy in the 1990s when they imposed higher minimum size limits in winter months for striped bass in a Tennessee reservoir sport fishery. Similarly, Ross and Hokenson (1997) suggested that bycatch mortality of finfish caught in the Gulf of Maine fishery for northern shrimp, *Pandalus borealis*, could be reduced if shrimp trawling was confined to colder months. Although it may be difficult to reduce bycatch rates, managers of Tennessee's commercial paddlefish fisheries proposed to reduce bycatch mortality by ending the season 23 days sooner (March 31 instead of April 23); thus, avoiding warm water temperatures. A ban on the use of monofilament netting material was also proposed to reduce bycatch mortality of paddlefish, particularly at the beginning and end of the commercial season. These proposals met with stiff opposition from commercial fishing interests. Consequently, in September 2005 the Tennessee Wildlife Resources Commission voted to close the season only 8 days sooner (April 15) and no ban on monofilament netting was enacted. A proposed plan to increase the minimum EFL limit from 864 to 965 mm was enacted to increase spawning escapements. However, the benefits of this size limit increase may not be realized because bycatch will increase as the EFL limit increases and the season still encompasses dates when water temperatures are frequently warm. A no-fishing refuge in an embayment in the lower reaches of Kentucky Lake, where mature fish were scarce but large juveniles were common, was established at that same public meeting as a means to reduce the encounters between paddlefish discarded as bycatch and commercial fishing gear.

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