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Mortality and Movements of Paddlefish Released as Bycatch in a Commercial Fishery in Kentucky Lake, Tennessee

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Abstract.—We present information on delayed mortality of commercially exploited paddlefish *Polyodon spathula* released as bycatch in Kentucky Lake, Tennessee–Kentucky, an impoundment on the lower Tennessee River. Minimum size limits enacted in 2002 (864 mm eye-to-fork length [EFL]) and 2005 (914 mm EFL) sought to protect paddlefish from overfishing. In 2005, bycatch of sublegal paddlefish represented 75% of the total catch, and releasing undersized fish will not reduce fishing mortality unless those fish survive. Paddlefish caught and released by commercial fishers in 2005 and 2006 were externally tagged with radio transmitters and tracked a minimum of 2 weeks to estimate delayed mortality. Four of the 104 tagged paddlefish died following release, 94 survived, and 6 were censored because their fate could not be determined. Paddlefish that survived moved rapidly from release locations. Net movements of the 94 fish that survived averaged 12.0 km (SE = 5.3) upriver and ranged from 91.5 km downriver to 390.0 km upriver. Fish that died could not be distinguished from fish that lived on the basis of mean water temperature, fish length, net-soak time, or handling time. Given the low delayed mortality of discarded paddlefish, imposing minimum size limits is a reasonable approach to reduce fishing mortality of juveniles and reduce the likelihood of overfishing. Efforts to reduce fishing mortality should focus on avoiding fishing gear and seasons (e.g., early fall and late spring) that cause high initial bycatch mortality.

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Introduction

Commercial fisheries for paddlefish *Polyodon spathula* currently exist in only six states, and Tennessee has until recently led the nation in the number of paddlefish harvested each year (Hoffnagle and Timmons 1989; Timmons and Hughbanks 2000). Many questions about paddlefish biology and ecology have been answered (see review in Jennings and Zigler 2000), but bycatch mortality of paddlefish has only recently been investigated (Bettoli and Scholten 2006).

Bycatch is defined in the Magnuson-Stevenson Fishery and Conservation and Management Act (amended 1996) as "fish which are harvested in a fishery, but which are not sold or kept for personal use, and includes economic and regulatory discards." Bycatch mortality consists of two components: initial mortality (i.e., fish are dead when fishing gear is retrieved) and delayed mortality (i.e., fish die soon after being released alive). Bycatch mortality may be influenced by a variety of factors, including length of time fish are exposed to air, water and air temperatures, fish size, and injuries sustained during capture and handling (Kaimmer and Trumble 1998; Davis 2002; Davis and Olla 2002). In a study designed to simulate bycatch processes on nontarget fish, Davis et al. (2001) found that sablefish Anoplopoma fimbria held in warm seawater exhibited reduced feeding, increased physiological stress, and increased mortality. Pacific halibut *Hippoglossus stenolepis*, walleye pollock *Theragra chalcogramma*, witch flounder *Glyptocephalus cynoglossus*, American plaice *Hippoglossoides platessoides*, and pollock *Pollachius virens* all experienced high mortality when exposed to air for 15 min or more (Richards et al. 1995; Ross and Hokenson 1997). Bycatch mortality also increases with decreasing body mass in some species (e.g., sablefish, Davis and Parker 2004; lingcod *Ophiodon elongatus*, Davis and Olla 2002).

Bettoli and Scholten (2006) described the initial mortality experienced by paddlefish captured in the Kentucky Lake gill-net fishery. In their study, target fish were gravid female paddlefish and bycatch referred to paddlefish that were either illegal to possess due to size restrictions (<864 mm eye-to-fork length [EFL]), males, or nonripe females. When there was a market for paddlefish flesh, bycatch of paddlefish represented 60% of the total number caught. When the flesh market was sated, bycatch rates increased to 92% because only mature females were harvested (i.e., mature females represented 8% of the catch). If the survival of discarded fish is low, high rates of bycatch may become problematic. Bettoli and Scholten (2006) reported that initial mortality of paddlefish caught in gill nets ranged from 7% to 86% at water temperatures between 5°C and 30°C; they also observed that monofilament nets were more lethal than multifilament nets. The additive effects of delayed mortality could limit the effectiveness of management strategies that assume high survival of released fish.

No information exists on delayed mortality of gill-netted and released paddlefish; in contrast, there is much information on delayed mortality for commercially fished marine species. For instance, delayed mortality of spotted seatrout *Cynoscion nebulosus* caught in gill nets varied widely (0–100%), depending on water temperatures and soak times (Murphy et al. 1995). Delayed mortality for trawl-caught fish released as bycatch also ranged widely: 0–25% for sablefish (Olla et al. 1997), 15–63% for Atlantic mackerel *Scomber scombrus* (Lockwood et al. 1983), and 0–94% for lingcod (Parker et al. 2003). For Pacific halibut caught on long lines, delayed mortality ranged from 3% to 100%, depending on the condition of released fish (Trumble et al. 2000).

The Magnuson-Stevens Fishery Conservation and Management Act mandates reductions in marine bycatch when possible; however, there are no such regulations for freshwater fisheries in the United States. The Tennessee Wildlife Resources Agency enacted a minimum size limit for paddlefish of 864 mm (34 in) EFL in 2002, increased it to 914 mm (36 in) EFL in 2005, and is prepared to increase the size limit to 965 mm (38 in) EFL by the 2008–2009 commercial season. The minimum size limit was raised to increase spawning escapements and rebuild stock structure, but the benefit of such a regulation may not be achieved because the number of fish caught and released as bycatch will increase as the minimum size limit increases. Thus, an important factor affecting the efficacy of a higher minimum size limit regulation is whether or not released fish survive.

One successful technique for studying mortality of caught and released fishes is biotelemetry (Bendock and Alexandersdottir 1993; Bettoli and Osborne 1998). Biotelemetry studies that examine mortality differ from traditional studies of fish behavior in that short-term effects of tagging must be minimized. Osborne and Bettoli (1995) addressed this concern by externally attaching sonic tags to striped bass *Morone saxatilis* using chromic gut suture. Each tag was attached to a small float and when the suture material dissolved, each tag floated to the surface where it could be retrieved. Tagging fish externally (instead of internally) reduced handling times and minimized possible effects of tagging on mortality. Additionally, using detachable tags that have a chance of being recovered offered researchers the opportunity to obtain additional data without actually tracking the fish. For instance, recovering a tag many kilometers upstream of where a fish was released provides some information on its movements and survival. Although no information exists on the survival of paddlefish released as bycatch, biotelemetry has been used to study paddlefish movements, home range, and habitat selection (Southhall and Hubert 1984; Paukert and Fisher 2001b; Stancill et al. 2002; Zigler et al. 2003; Firehammer and Scarnecchia 2006).

Although total elimination of bycatch may be impossible, every attempt should be made to minimize bycatch numbers and mortality to insignificant levels (U.S. Commission on Ocean Policy 2005). In an effort to better understand the phenomenon of bycatch in paddlefish fisheries, we sought to model delayed mortality of paddlefish caught and released as bycatch as a function of fish length, water temperatures, net soak durations, and handling times. While estimating survival of discarded paddlefish, we collected information on their postrelease movements and those observations are briefly summarized herein.

Study Area

Kentucky Lake is a eutrophic reservoir formed by Kentucky Dam on the lower Tennessee River that extends upriver 296 km to Pickwick Dam near the Tennessee–Mississippi state line (Figure 1). Kentucky Dam was constructed in 1944 at Tennessee River kilometer (TRkm) 35 in southwestern Kentucky; it is the most downstream of nine dams that make a navigable channel stretching 1,049 km across Kentucky, Tennessee, Mississippi, and Alabama. Pickwick Dam at TRkm 331 regulates water flowing north through Kentucky Lake. The Tennessee Valley Authority manages floodgates and power generation at Kentucky and Pickwick dams, and the Army Corp of Engineers oversees navigation locks at these dams.

At full pool, Kentucky Lake covers 64,870 ha and has a mean depth of 5.4 m. Summer pool and winter pool water levels usually fluctuate about 1.5 m. Kentucky Lake seldom stratifies and water column temperatures vary less than 2°C (Cox and Wade 1987). The reservoir is lacustrine north of TRkm 186 and riverine to the

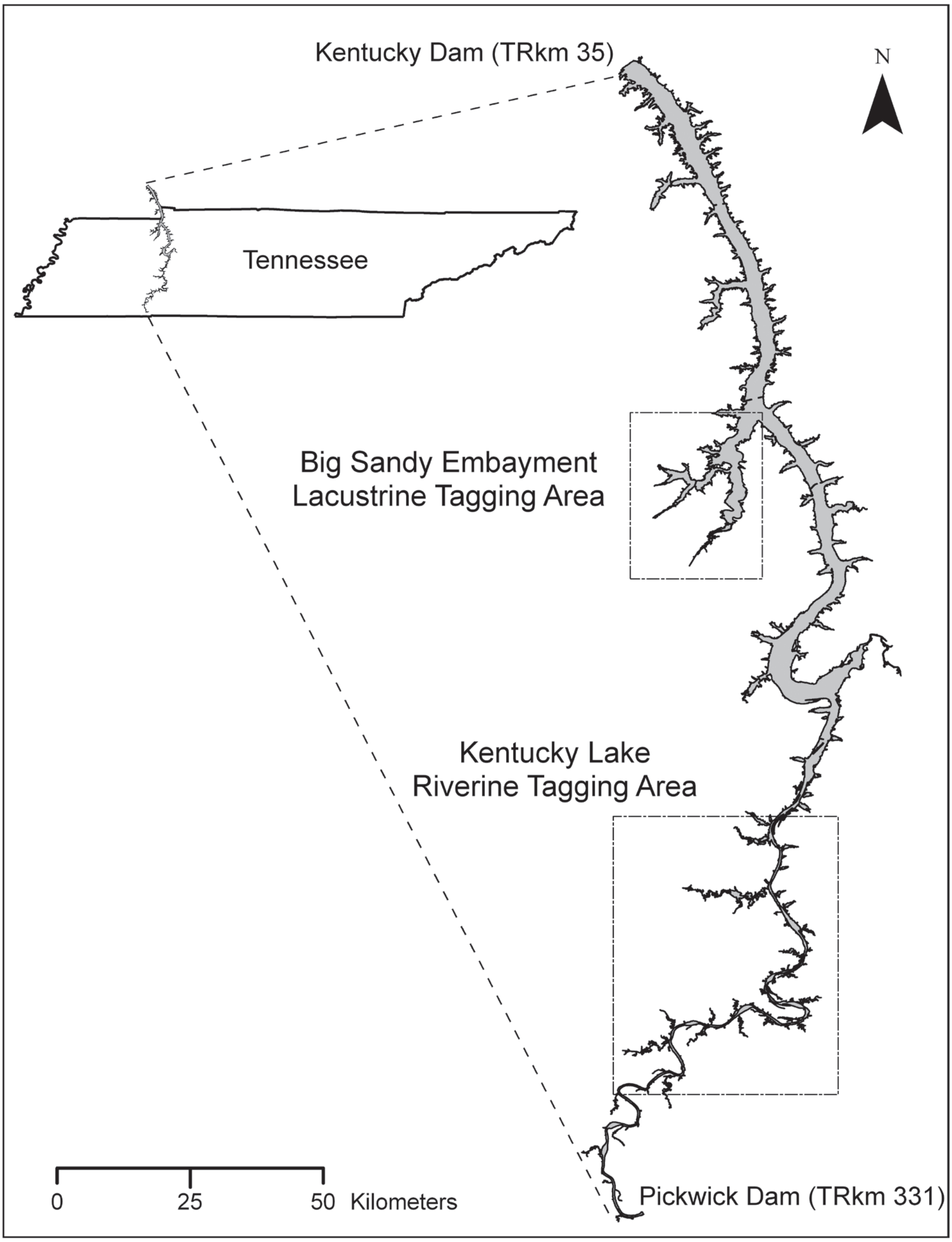

Figure 1. Map of locations where paddlefish were radio-tagged on Kentucky Lake to monitor survival and postrelease movements in 2005–2006. Tennessee River kilometers (TRkm) are measured from the confluence of the Tennessee and Ohio rivers.

south. Average discharge of the Tennessee River at Kentucky Dam is 1,886 m^3/s.

The commercial fishery for paddlefish caviar in Kentucky Lake is one of the largest such fisheries in North America. Annual roe harvest from that one system alone exceeded 9,153 kg in the 2005–2006 season, with an estimated wholesale value of at least $US1.4 million. In our study, paddlefish were netted and tagged in two distinct areas of Kentucky Lake: the riverine (southern) portion and Big Sandy River embayment. Big Sandy embayment is a tributary of the Tennessee River and flows northeast for approximately 93 km to join the river at TRkm 108 (Figure 1). Big Sandy embayment lies within the lacustrine portion of Kentucky Lake and has an average daily flow of only 8.4 m/s. The study was conducted in these two distinct areas because that is where most commercial fishing occurred.

Methods

Netting and Tracking

Paddlefish were caught in gill nets deployed between TRkm 105 and TRkm 298 before, during, and after the 2004–2005 and 2005–2006 commercial paddlefish seasons, which began November 15 each year and ended April 23 in 2005 and April 15 in 2006. Nets used and procedures followed mimicked local commercial gear and fishing techniques. A commercial fisher was present for each sampling event, and he or she independently decided which fish were retained (i.e., harvested) and which were discarded as bycatch. To assess the effect of water temperature on delayed mortality, at least one sampling event occurred within every 5°C increment in surface water temperature between 2.5°C and 17.5°C. Radio transmitters were attached to the first 15–20 paddlefish released as bycatch during each of six sampling events. Eye-to-fork length (mm), handling times (i.e., time that fish spent out of water before release), surface water temperature, and net soak time were recorded for each tagged fish.

Different criteria have been used to conclude that tagged fish died, including no movement for a specified time period (Hightower et al. 2001; Nelson et al. 2005), movement consistent with known dead fish (Stier and Kynard 1986), and repeated locations at a depth consistent with the bottom (Candy et al. 1996; Bettoli and Osborne 1998). One common theme in the previous telemetry studies of mobile, pelagic species was defining death by lack of movement. Paddlefish are a highly mobile fish that have been reported to have movement rates of 348 m/h during the day and 784 m/h at night (Paukert and Fisher 2000); however, downstream movement by a tagged fish in an impounded river does not necessarily mean that the fish was alive. Tennessee River discharges regularly exceeded 2,000 m^3/s during our study and carcasses of dead fish could conceivably drift downriver along the bottom at high flows, at least for a short distance. Thus, tagged fish could not be declared alive simply because they displayed some downstream movement. Definitions used by other authors, although valid for their studies, were not completely applicable to the present study. Therefore, we chose a modified version of Bendock and Alexandersdottir's (1993) description of fate to fit the present study and system-specific characteristics of Kentucky Lake. Specifically, the first located position after fish were released was used as a starting point for determining the fate of fish (i.e., alive or dead) using the following classification scheme:

(1) Survived—fish moved upriver more than 0.5 km, fish moved downriver at an average rate of more than 0.5 km per day, the fish was recaptured in another gill net, or the radio tag was found at least 1.0 km upriver of where the fish was released;
(2) Died—fish remained immobile (i.e., total distanced moved < 50 m), fish moved downriver slowly (less than 0.5 km per day), or radio transmitted in mortality mode;
(3) Censored—fish was never located following release or was only located once (i.e., a missing fish).

Our tags were designed to detach from fish after several weeks in order to provide for a larger sample size (i.e., we could reuse recovered tags) and, more importantly, provide information on movements (and fate) of fish. Because Kentucky Lake is an impounded river, any tags recovered on shore upstream of where a fish was released were evidence that the fish swam upstream at least that distance; if that distance exceeded 1 km, we judged the fish to have survived.

Hightower et al. (2001) attributed missing fish to (1) transmitter failure, (2) unreported harvest, (3) migration of fish through locks of dams, or (4) the fish was present in the study area but the signal was missed. We assumed that no tags failed and that no unreported harvest occurred, although anecdotal evidence suggests that unreported harvest may have occurred. For instance, commercial fishers returned seven tags, but five of those tags were returned by two fishers who worked for us on the project (i.e., they were predisposed to assist us in our research, whereas many fishers were on record as opposing our research). Given that 92 commercial fishers reported harvesting paddlefish from Kentucky Lake during the course of our study, the fact that five of seven tags were returned by two "friendly" fishers suggests that other commercial fishers caught some tagged paddlefish and discarded (or destroyed) tags. Indirect evidence that some dam passage occurred was obtained when a citizen recovered a tag on the banks of an upstream reservoir. Finally, tag signals were very weak when the tag was in deep (≥10 m) water, and such habitats were commonplace in Kentucky Lake; thus, it is likely that some tagged fish (either dead or alive) were present in a particular reach when it was searched but were not located on some dates.

External radio transmitters and floats were constructed and attached following the methods of Osborne and Bettoli (1995). Each radio tag transmitted a unique frequency in the 30.171–30.992 MHz bandwidths (model F1859, Advanced Telemetry Systems, Isanti, Minnesota) and had a guaranteed battery life of 475 d. Transmitters were equipped with a mortality circuit that activated when transmitters remained motionless for 8 h. The float was constructed of 16-mm acrylic tubing sealed at both ends with 11-mm lengths of acrylic rod. All floats were tested for water tightness at a depth of 35 m for 4 h. The radio transmitters were attached to the eyelet of the float using Kevlar fishing line and 23-kg monofilament. Rubberized shrink tubing covered the gap between the ends of the tag and float to create a seamless assembly. Each transmitter and float assembly was 300 mm long, weighed 55 g in air, and had a cross-sectional area of 2 cm2. Positive buoyancy exerted by the float was approximately 6 g. The transmitter and float assembly was attached to the dorsal musculature posterior to the dorsal fin using absorbable chromic gut suture (#3, Vetrus Animal Health, Westbury, New York) and a half-circle triangular reverse cutting needle. Each transmitter was labeled with contact information and the words "$25.00 Reward." Captured fish were released immediately following transmitter attachment.

Our ability to detect radio signals of tagged fish was assessed by suspending two radio tags at various water depths (0, 5, 10, 15, and 20 m) and motoring in and out of signal range. Using a Global Positioning System (GPS) receiver, geographic coordinates were recorded where tags were suspended and where each tag was detected when the boat approached tags from three different directions. ArcGIS 9.0 software (ESRI, Redlands, California) was then used to estimate the distance between the first point of detection while approaching each tag from each angle. It was subsequently determined that maximum range of signal detection averaged 411 m when tags were at the surface, 134 m at a depth of 5 m, and only 31 m at 10 m. The signal could not be detected when tags were suspended at a depth of 20 m.

Thirty-two tracking trips were conducted by running one boat down the center of the river or using two boats simultaneously, running each boat an equal distance from the closest shore and the other boat. Radio-tagged paddlefish were located using an Advanced Telemetry Systems (Insanti, Minnesota) model R2000 receiver and a loop antenna. An attempt was made to locate each paddlefish at least three times during the first week postrelease and then again approximately 2 and 3 weeks after tagging or until the fate of each fish could be determined with reasonable confidence. We devoted more effort to tracking fish in their first week of release than in later weeks to reduce the chance that we would lose fish in the nearly 65,000-ha study area. Once a fish was located, geographical coordinates were determined using a GPS receiver and incorporated into a geographic information systems database. Distance and bearing between each recorded location were estimated with ArcGIS 9.0 software. Movement was computed as (1) the distance between the release location and the last known position (i.e., net movement), and (2) the sum of the distances between successive locations (i.e., total movement) (Muhlfeld and Marotz 2005). Total movement divided by days at large was used to describe average daily movements. Because the suture material was expected to decompose in about three weeks, only data collected during the first 3 weeks were used to describe average daily movements. Location information gathered before and after 3 weeks was used to determine the fate of released fish and to calculate net distance moved.

Statistical Analyses

The response variable "fate" was binomial in nature (1 = alive, 0 = dead). Therefore, we were prepared to use logistic regression (SAS Institute 2001) to model the relationship between the fate of fish and handling time (min), surface water temperature (°C), net soak time (h), and length of each fish (EFL, mm). We also compared mean values for all four variables between the two classes of fish using Wilcoxon two-sample tests. All tests were considered significant at $P \leq 0.05$.

Results

One hundred and four paddlefish (mean EFL = 844; SE = 6.9) were tagged with radio transmitters between January 7, 2005 and April 15, 2006 (Table 1). Of those 104 fish, 4 were classified as dead following release, 94 survived the encounter with commercial gill nets, and 6 were censored (Figure 2). Assuming that all censored fish died (worst-case scenario), the delayed mortality rate was 9.6%. Average handling time was 1.8 min (SE = 0.1) and ranged from 0.65 to 5.0 min (Table 1). Net soak times averaged 14.2 h (SE = 0.4) and ranged from 4.7 to 21.6 h. Temperature ranged from 4.3°C to 16.9°C and averaged 11.3°C (SE = 0.4) during tagging events.

Too few fish died to warrant (or permit) logistic modeling. The four fish that died could not be distinguished from survivors based on their mean lengths ($P = 0.4088$), net soak times ($P = 0.6399$), handling times ($P = 0.8434$), or water temperatures ($P = 0.7379$; Wilcoxon two-sample tests). Similarly, the mean responses for each of those four variables could not be declared different between the two classes of fish when the censored fish were presumed dead ($P \geq 0.1759$ for all tests).

Although 91% of the fate classifications were based on observations collected within the first week after a fish was released, some classifications could not be made for more than a year. For instance, one fish went missing after it was released and was

Table 1. Means, standard errors, and range of the four independent variables used to examine variation in delayed mortality of paddlefish released as bycatch in Kentucky Lake, Kentucky–Tennessee, January 2005 through May 2006. Water temperature was measured at the surface at the time each fish was captured. EFL = eye-to-fork length.

Fate		EFL (mm)			Net soak time (h)			Handling time (min)			Water temperature (°C)		
category	*n*	Mean	SE	Range	Mean	SE	Range	Mean	SE	Range	Mean	SE	Range
Alive	94	841.6	7.3	638–1,040	14.3	0.4	5.7–21.6	1.7	0.1	0.7–5.0	11.4	0.5	4.3–16.9
Dead	4	869.0	8.3	845–883	13.7	2.2	7.3–17.1	1.8	0.7	1.0–3.8	11.8	1.7	9.3–16.9
Censored	6	871.5	37.3	710–990	13.4	2.3	4.7–18.1	2.3	0.5	1.0–3.7	9.6	1.6	4.4–16.4
Total	104	844.4	6.9	638–1,040	14.2	0.4	4.7–21.6	1.8	0.1	0.7–5.0	11.3	0.4	4.3–16.9

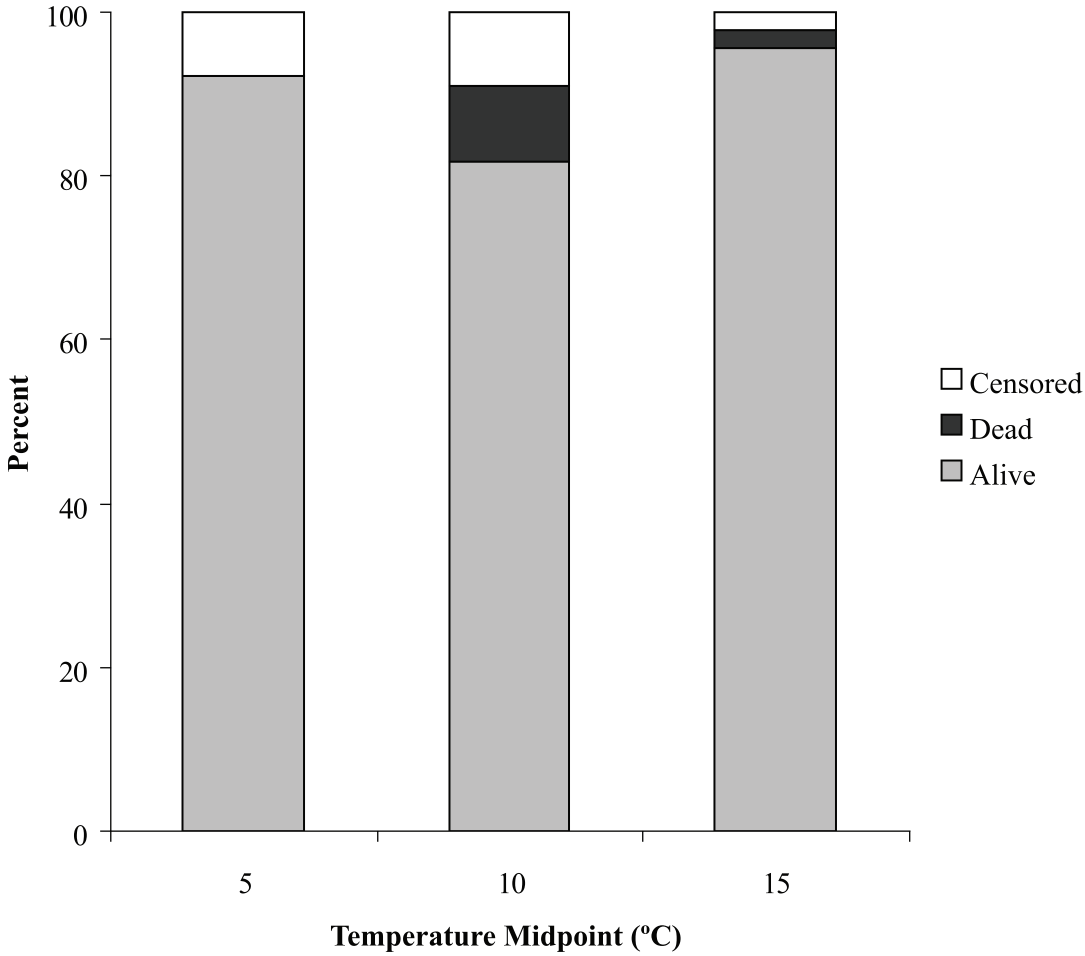

Figure 2. The fate of paddlefish tagged with radio transmitters in 2005–2006 and released as bycatch in Kentucky Lake, Tennessee,over three ranges of water temperatures (2.5–7.5°C; 7.6–12.5°C; 12.6–17.5°C). Censored fish are fish that were never located following release or were only located once.

never located during routine tracking, but its tag was subsequently recovered 253 km upriver approximately a year and half later. More commonly, the tags of fish that went missing soon after their release were later recovered upriver in Kentucky Lake (*n* = 19). One of the fish that was censored was never located after it was released (nor was its tag found), one fish was located only once after tagging, and four were never located by tracking but their tags were subsequently recovered downriver of where they were tagged.

Paddlefish that survived moved rapidly from release locations. On the day following their capture and release, fish moved an average of 2.2 km (SE = 0.35); total distance moved increased to 5.0 km (SE = 0.85) 24–48 h after release. By day 5, net distance moved ranged from 57 km upriver to 18 km downriver from where each fish was tagged (Figure 3). Net movements of the 94 fish that survived averaged 12.0 km (SE = 5.3) upriver and ranged from 91.5 km downriver to 390.0 km upriver. Most (62%) of the fish that survived moved upriver af-

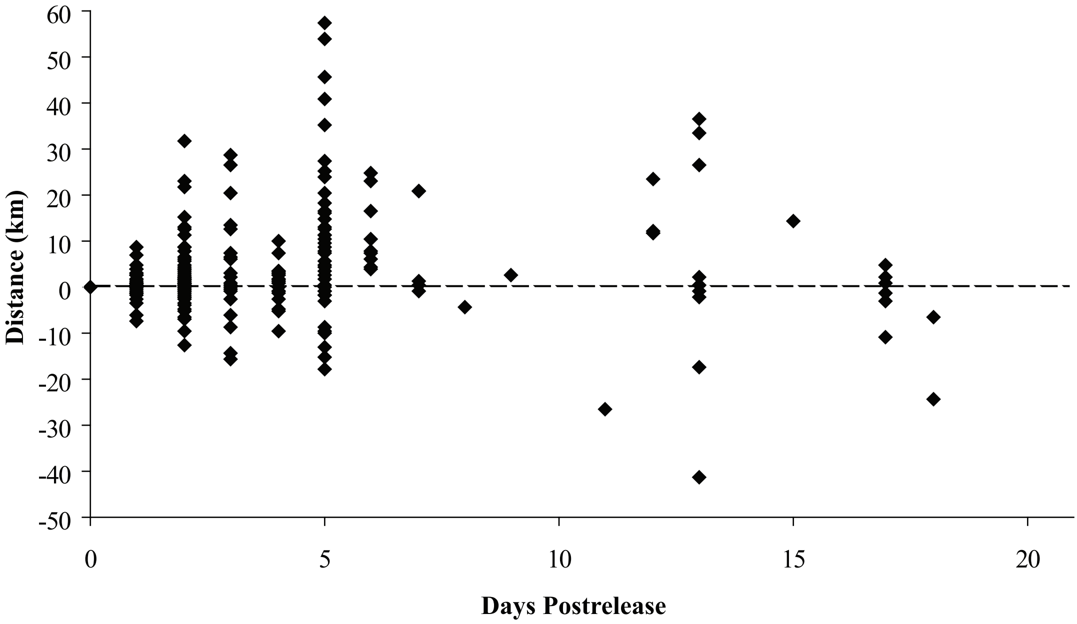

Figure 3. Net distances moved upstream or downstream by radio-tagged paddlefish released as bycatch in Kentucky Lake on the lower Tennessee River in 2005–2006. Dashed line represents tagging location. One fish that moved 390 km upriver in 19 d is not shown.

ter release. Average daily movement within the first 3 weeks of release was 4.6 km (SE = 0.54). The highest average daily movement was 20.5 km per day for a fish that moved upriver through the locks of four dams and swam 390 km within 19 d of its release.

Three of the four fish classified as dead remained within 1 km of where they were released. The fourth fish moved slowly downriver more than 1 km over 2 d and then remained immobile. The mortality switch did not activate for three of the four fish that were presumed to have died based on their lack of movement. The mortality signal of the fourth fish turned on and off over 2 weeks while remaining in the same general location, suggesting that the tag (and perhaps the tags attached to the other three fish classified as dead) experienced some movement every few hours (which would have deactivated the mortality switch) while attached to the carcass of the fish. Four other tags were found transmitting mortality signals, but these tags were all found washed up on shore and free from any movement after they detached from fish that survived their encounter with gill nets.

Of the 104 tags attached to fish during this study, 66% (n = 69) were subsequently recovered. The public returned 32 tags and project personnel recovered 37 tags during routine tracking efforts. With rare exceptions, the suture material remained intact and tags stayed attached to fish for at least 14 d. One tag was shed within 4 d of attachment, and we suspect that fish encountered (but escaped) a gill net; by chance, we located one fish 47 d after release and its tag was still attached.

Discussion

Gill netting and subsequently releasing paddlefish of various lengths over a range of water temperatures, soak times, and handling times did not result in substantive delayed mortality. In contrast, Bettoli and

Scholten (2006) reported high initial mortality of paddlefish netted in warm waters at the beginning and end of the commercial fishing season. Likewise, high rates of delayed mortality have been documented for other commercially exploited species (e.g., Lockwood et al. 1983; Olla et al. 1997; Trumble et al. 2000; Parker et al. 2003). We chose to mimic the commercial paddlefish fishery in Tennessee; thus, we did not examine the effects of more extreme temperatures, excessive handling, or longer-than-normal net soak times on delayed mortality. It is generally accepted that fish have species-specific temperature tolerances, outside of which mortality increases (Brett 1952, 1960; Fry 1971). Paddlefish may have some threshold of tolerance to different environmental stressor in terms of delayed mortality, but finding that threshold was beyond the scope of this study.

Of the four possible reasons noted above for why some fish could not be located during our study (Hightower et al. 2001), we had direct or circumstantial evidence that some fish were harvested but not reported, some fish passed through the upstream dam and out of the study area, and tagged fish inhabiting deep (>10 m) water were virtually undetectable. Although these factors made field tracking difficult, none of them prevented us from assigning a fate to nearly all (94%) of the 104 fish we tagged and released and concluding that delayed mortality was negligible.

High postrelease survival rates have been reported for paddlefish and other chondrosteans. Low mortality of released paddlefish was observed in a recreational snag fishery in the Yellowstone River, Montana (Scarnecchia and Stewart 1997). In several other studies, paddlefish caught in gill nets and implanted with transmitters all survived at least 3 years (Paukert and Fisher 2000, 2001a; Stancill et al. 2002). Zigler et al. (2003) reported no short-term mortality (i.e., within 2 months) of paddlefish due to capture in various fishery gears and surgical procedures used to implant radio transmitters. Caron et al. (2002) reported 100% postrelease survival of Atlantic sturgeon *Acipenser oxyrinchus* caught in multifilament gill nets with soak times of 24 h at water temperatures up to 23°C.

Other researchers have noted that paddlefish are a robust, hardy fish that can tolerate grievous wounds, which may explain why postrelease survival was high in the present study. Rosen and Hales (1980) reported that one-third of the 458 paddlefish they sampled were either scarred or had lost their rostrum due to injury. In the present study, it was common to capture paddlefish with striations on their flanks, indicating that they had previously been entangled in a gill net. It was also common to observe abdominal incisions made by fishers checking for eggs, which is an illegal practice. We tagged one paddlefish that was missing its rostrum, and it subsequently survived long enough to be caught in commercial nets three more times within 48 h.

Low stress response by paddlefish may be one reason why their postrelease survival rate was so high in the present study. Stress, as defined by Chrousos (1998), is a state of threatened homeostasis that is reestablished by a complex suite of adaptive responses. If the stress is long-lasting and the fish cannot regain homeostasis, the fish's health will be compromised. Barton et al. (1998, 2000) observed relatively low stress response in sturgeons *Scaphirhynchus* spp. and paddlefish. In both of those studies, fish recovered to prestress levels of plasma cortisol within 24 h of acute physical disturbances, and no mortalities were observed. In comparison, Barton et al. (1980) reported high stress response in juvenile rainbow trout *Oncorhynchus mykiss*, and mortality occurred soon after the initial stressor. Stress factors do not always predict mortality (Barton and Iwama 1991;

Davis et al. 2001; Davis and Schreck 2005), and different stressors can elicit different stress responses. Thus, relationships between mortality and stressors may differ among species (Olla et al. 1995, 1997, 1998; Morgan and Iwama 1997; Manire et al. 2001). Bettoli and Scholten (2006) reported a direct relationship between paddlefish initial mortality and water temperature and net soak times, and the findings presented herein indicate that the chances of survival are very good if paddlefish captured in gill nets can survive long enough to be released.

Paddlefish released as bycatch from commercial gill nets were highly mobile. Postrelease movements of the paddlefish we tagged and released were comparable to movements of paddlefish elsewhere. Russell (1986) reported mean 24-h movements of paddlefish between 5.0 and 7.1 km. Zigler et al. (1999) reported median movements of 4.7–6.4 km per 24 h. Daily movement of tagged paddlefish in Kentucky Lake in the first 3 weeks postrelease averaged 4.6 km. The general agreement among studies regarding daily movements suggests that neither encountering commercial gill nets nor having a radio tag-and-float attached externally impeded the normal movements of tagged paddlefish released as bycatch.

Management Implications

Given the low delayed mortality rates we observed, forcing fishers to release undersized fish by raising the minimum size limit in 2002 and 2005 appears to have been a viable approach to reduce fishing mortality of juvenile paddlefish and to help reduce the likelihood of overfishing. However, raising the minimum size limit will not by itself protect the paddlefish stock in Kentucky Lake from overfishing because initial mortality was high at the end of the fishing season and the exploitation of legal-sized fish may still be occurring at an unsustainable rate. The Tennessee Wildlife Resources Commission agreed with that assessment and voted on September 20, 2006 to end the commercial season 1 week earlier each year (on April 7th, when water temperatures are cooler), which should reduce overall exploitation and lessen concerns regarding high rates of initial bycatch mortality. Unlike many other fisheries worldwide, the size-distribution of the gill-net catch (and subsequent bycatch) of paddlefish in Kentucky Lake cannot be altered by increasing the size of meshes fished, due to a lack of size-selectivity (Scholten and Bettoli 2007). Efforts to reduce bycatch rates and discard mortality will have to focus on avoiding gear (e.g., monofilament nets) and seasons (early fall and late spring) that cause high initial bycatch mortality.

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