DELAYED MORTALITY AND MOVEMENTS OF PADDLEFISH RELEASED AS BYCATCH

A FINAL REPORT SUBMITTED TO

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EXECUTIVE SUMMARY

(1) Paddlefish *Polyodon spathula* in Kentucky Lake, TN-KY, are commercially exploited for their caviar and flesh. Minimum size limits enacted in 2002 (864 mm eye-fork-length [EFL]) and 2005 (914 mm EFL) sought to protect paddlefish from overfishing. Following the change in the size limit in 2005, the bycatch of sub-legal paddlefish increased from 49% to 75% of the total catch. The minimum size limit is expected to increase to 965 mm EFL in 2008; thus, the bycatch of sublegal fish will probably increase again. Forcing fishers to release small fish will not reduce fishing mortality unless those fish survive; therefore, post-release survival and movements of paddlefish released as bycatch were examined.

(2) Paddlefish (n = 104) caught and released by commercial fishers between 2004 and 2006 were externally tagged with radio transmitters and tracked for several weeks. Each radio tag was equipped with a float and the apparatus was designed to detach from the fish after several weeks and float to the surface, where it could be recovered and reused. The direction and magnitude of movements (or lack thereof) by tagged paddlefish were usually sufficient to distinguish live fish from dead fish. The survival of some fish (n = 19) was inferred by recovering detached tags upriver of where fish were released.

(3) Only 4 of the 104 tagged paddlefish died following release, 94 survived the encounter with commercial gillnets, and six were censored because their fate could not be determined.

(4) Water temperature, fish length, net-soak time, and handling time were not significantly related to delayed mortality in separate logistic regression models that assumed that none, or all, of the censored fish died.

(5) Released paddlefish will experience good survival rates, which is necessary for minimum size limit regulations to be effective.

INTRODUCTION

Paddlefish *Polyodon spathula* have been found in recent years in the rivers of at least 21 states in the Mississippi River and Gulf coast drainages (Williamson 2003). Commercial fisheries for paddlefish currently exist in only six states; of those states, Tennessee has in the past led the nation in the number of paddlefish harvested (Hoffnagle and Timmons 1989; Timmons and Hughbanks 2000). The United States Fish and Wildlife Service (USFWS) was petitioned in 1989 to list paddlefish as an endangered species but the petition was denied. However, the USFWS proposed in 1992 that paddlefish should be protected under the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES). Some questions about paddlefish biology and ecology have been answered in recent years (see review in Jennings and Zigler 2000), but the effects of bycatch mortality on paddlefish populations have yet to be fully investigated.

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 the 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 non-target fish, Davis et al. (2001) found that sablefish *Anoplopoma fimbria* held in elevated sea water temperatures 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 saithe *Pollachius virens* all experienced high mortality when exposed to air for 15 minutes 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) documented high rates of paddlefish bycatch in commercial gillnets. In their study, bycatch referred to paddlefish that were either illegal to possess due to size restrictions (< 864 mm eye-fork length, EFL), males, or non-ripe 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 released fish is low, high rates of bycatch may become problematic. Bettoli and Scholten (2006) also found that initial mortality of paddlefish caught in gillnets ranged from 7 to 86% at water temperatures between 5 and 30ºC. With initial mortality rates approaching 90% in warm water, the additive effects of delayed mortality at any water temperature could limit the effectiveness of management strategies that assume good survival of released fish.

In contrast to the wealth of knowledge on delayed mortality for commercially fished marine species, no information exists on the delayed mortality of gillnetted and released paddlefish. The mortality of spotted seatrout *Cynoscion nebulosus* caught in gillnets and released varied widely (0-100%) depending on water temperatures and soak times (Murphy et al. 1995). Delayed mortality estimates 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 eye-to-fork length (EFL) in 2002, increased it to 914 mm EFL in 2005, and has proposed to increase the size limit to 965 mm 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 the mortality of caught and released fishes is biotelemetry (Bendock and Alexandersdottir 1993; Bettoli and Osborne 1998). This method has also been used to study paddlefish movements, home range, and habitat selection (Southhall and Hubert 1984; Paukert and Fisher 2001; Stancill et al. 2002; Zigler et al. 2003; Firehammer and Scarnecchia 2006). Biotelemetry studies require large sample sizes and are expensive due to the high cost of transmitters. Osborne and Bettoli (1995) addressed this concern by attaching floats to sonic tags that were externally attached to striped bass *Morone saxatilis* using chromic gut suture. When the suture material dissolved, each tag floated to the surface where it could be retrieved and reused until the battery failed. Tagging fish externally (instead of internally) reduced handling times and minimized the possible effects of tagging on mortality. Finally, using detachable tags that have a chance of being recovered offers researchers the opportunity to obtain data without actually tracking the fish. For instance, recovering tags upstream of where fish are released will provide some information on movements and survival.

Although the total elimination of bycatch may be impossible, every attempt should be made to minimize bycatch numbers and bycatch mortality (US Commission on Ocean Policy 2005). In an effort to better understand the ramifications of bycatch in paddlefish fisheries, the objectives of this study were to (1) model delayed mortality of paddlefish caught and released as bycatch as a function of fish length, water temperatures, net soak durations, and handling times; and (2) describe immediate post-release movements of paddlefish caught and released by commercial fishers.

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 the water flowing north through Kentucky Lake. The Tennessee Valley Authority (TVA) controls the navigation locks, power generation, and flood gates of Kentucky and Pickwick 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 2ºC (Cox and Wade 1987). The reservoir is lacustrine north of TRkm 186 and riverine to the south. The average discharge of the Tennessee River at Kentucky Dam is 1,886 $m^3 \cdot s^{-1}$.

Paddlefish were netted and tagged in two distinct areas of Kentucky Lake: the riverine (southern) portion and the Big Sandy River embayment. The 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 $m^3 \cdot s^{-1}$.

METHODS

Netting and Tracking

Paddlefish were caught in gillnets 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. The nets used and the procedures followed mimicked local commercial gear and fishing procedures. A commercial fisher was present for each sampling event and he or she independently decided which fish were harvested and which were released as bycatch. 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 to 20 paddlefish released as bycatch during each of six sampling events. Eye-to-fork length (EFL, 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.

External radio transmitters and floats were constructed and attached following the methods of Osborne and Bettoli (1995). Each radio tag (Model F1859, Advanced

Telemetry Systems, Isanti, MN) transmitted a unique frequency in the 30.171 to 30.992 MHz bandwidths and had a guaranteed battery life of 475 days. Transmitters were equipped with a mortality circuit that activated when the transmitter 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. The 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, and had a cross sectional area of 2 cm^2. The 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, NY) 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 the radio signal 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; the person listening for the signal did not know their position relative to the suspended tags during this exercise. Using a global positioning system (GPS) receiver, geographic coordinates were recorded where the tags were suspended and where each tag was detected when the boat approached the tags from three different directions. ArcGIS 9.0 software was then used to estimate the distance between the first point of detection while approaching each tag from each angle. Maximum range of signal detection was 411 m when the 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 close to opposing shores. Radio-tagged paddlefish were located using an Advanced Telemetry Systems Model R2000 receiver and a loop antenna. An attempt was made to locate each paddlefish at least three times during the first week post-release, then again approximately two and three weeks after tagging, or until the fate of each fish could be determined with reasonable confidence. Once a fish was located, geographical coordinates were determined using a GPS receiver and incorporated into a geographic information system (GIS) database. Distance and bearing between each recorded location were estimated with ArcView GIS 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 decomposed in about three weeks, only data collected during the first three weeks were used to describe average daily movements. Location information gathered before and after three weeks was used to determine the fate of released fish and to calculate net distance moved.

Fate has been variously defined in other telemetry studies. In a study on catch and release of steelhead *Oncorhynchus mykiss*, Nelson et al. (2005) assumed fish had died if tags were repeatedly located in the same position and they defined survival as any fish that sustained upstream movement. Stier and Kynard (1986) concluded that Atlantic salmon *Salmo salar* smolts survived if they moved more than euthanized hatchery fish released at the same time at the same tagging location. Hightower et al. (2001) assumed that striped bass repeatedly located in the same position had died; they did not specifically define survival. Candy et al. (1996) attached depth-sensing tags to Chinook salmon *Oncorhynchus tshawytscha* captured in purse seines; fish that slowly sank to a depth corresponding with the bottom and remained there for at least 2 h were classified as dead. Similarly, Bettoli and Osborne (1998) used transmitters that varied the pulse rate with temperature and they assumed fish had died when tags transmitted pulse intervals consistent with the temperature at the bottom of the reservoir. Lack of movement over several days was also considered an indicator of death in that study.

One common theme in these telemetry studies was defining death by lack of movement. Although lack of movement is a universal descriptor of death in pelagic species, 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^{-1} during the present study and at high flows, the carcasses of dead fish could conceivably drift downriver along the bottom, at least for a short distance. Thus, fish could not be declared alive simply because they displayed downstream movement. The definitions used by other authors, although valid for their studies, were not completely applicable to the present study. Therefore, a modified version of Bendock and Alexandersdottir's (1993) description of fate was chosen because it best fit the present study and the system-specific characteristics of Kentucky Lake. To wit, 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, or the fish was recaptured in another gillnet;
(2) Died –Fish remained immobile (i.e., total distanced moved < 50 m), fish moved downriver slowly (less than 0.5 km per day), or the radio transmitted in the mortality mode;
(3) Censored – fish was never located following release or was only located once (i.e., a missing fish).

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. It was assumed in the present study that no tags failed and that no unreported harvest occurred, although anecdotal evidence suggests that unreported harvest occurred. For instance, seven tags were returned by commercial fishers, but five of those tags were returned by two fishers who worked on the project. Given that 92 commercial fishers reported harvesting paddlefish from Kentucky Lake during the course of this study, the fact that five of seven tags were returned by two fishers who supported our research suggests that other commercial fishers caught some tagged paddlefish and discarded (or destroyed) the 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.

Statistical Analyses

The response variable “fate” was binomial in nature (1=alive, 0=dead). Therefore, logistic regression (SAS Institute 2001) was used to model the relationship between the fate of fish and handling time (min), surface water temperature (ºC), net soak time (h), and length of each fish (EFL, mm). To detect whether multicollinearity existed, Pearson correlation coefficients were calculated for all independent variables. Censored fish were excluded from the initial logistic model. The influence of the four predictor variables on the fate of released fish was also examined by assuming that all censored fish had died. All tests were considered significant at $P \leq 0.05$.

Variation in post-release movements was examined using stepwise multiple linear regression techniques. The five predictor variables subjected to the stepwise procedure were net soak time, calendar day, EFL, handling time, and water temperature. The two response variables in separate analyses were (1) net movement after two days, and (2) total movement after two days. The response variables were limited to observations made on the second day post-release because the sample size was greatest for that day.

RESULTS

Bycatch Mortality

One hundred and four paddlefish (mean EFL = 844; SE = 6.9) were tagged with radio transmitters between 7 January 2005 and 15 April 2006. Of those 104 fish, four were classified as dead following release, 94 survived the encounter with commercial gillnets, and six were censored (Figure 2). 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 to 16.9ºC and averaged 11.3ºC (SE = 0.4) during tagging events.

When censored fish (n = 6) were excluded from the analysis, five of the six correlations among the four independent variables were significant ($|r| \geq 0.25$; $P \leq 0.01$). In separate logistic regression models, delayed bycatch mortality was not significantly related ($P \geq 0.440$) to any of the four predictor variables.

If we assumed that the six censored fish died, five of the six correlations among the four independent variables were correlated ($|r| \geq 0.28$; $P \leq 0.01$). In separate logistic regression models, delayed bycatch mortality was not significantly related ($P \geq 0.21$) to any of the four predictor variables.

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 over a year. For instance, one fish went missing after it was released and was 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 (n = 19). Of the fish that were censored, one 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.

Of the 104 tags attached to fish during this study, 65% (n = 68) were subsequently recovered. The public returned 31 tags and project personnel recovered 37 tags during routine tracking efforts. Using 60 tags to track 104 fish resulted in a gross savings of

$8,800. The public received $775 in rewards for returning tags (31 tags @ $25/tag); thus, the difference between the gross savings and the amount paid out in rewards created a net savings of $8,025.

Post release movements

Total movements of the 94 fish that survived averaged 29.3 km (SE = 4.6) and ranged from 0.9 to 390.0 km. Net movements averaged 12.0 km (5.3) upriver and ranged from 91.5 km downriver to 390.0 km upriver. Most (62%) of the fish that survived moved upriver after release. Average daily movement within the first three weeks of release was 4.6 km (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 days of its release.

Paddlefish that survived moved rapidly from release locations. On the day following release, fish had moved an average of 2.2 km (0.35); total distance moved increased to 5.0 km (0.85) 24-48 h after release (Table 2). By day 5, net distance moved ranged from 57 km upriver to 18 km downriver from where each fish was tagged (Figure 3).

The only variable that explained a significant amount of variation in net movement two days post-release was soak time ($F = 13.32$; d.f. = 1,61; $r^2 = 0.18$; $P < 0.01$). The relationship was negative; that is, shorter movements were associated with longer soak times. No other variables were significant predictors of net movement ($P \geq 0.15$). Total movement during the first two days at large varied directly with handling time ($F = 29.26$; d.f. = 1,61; $r^2 = 0.32$; $P < 0.01$). No other variables explained a significant ($P \geq 0.13$) amount of variation in total movements of paddlefish.

Three of the four fish that died remained within 1 km of where they were released. The fourth fish moved slowly downriver more than 1 km over two days 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 then turned off over two weeks while remaining in the same general location, suggesting that the tag experienced some movement every few hours while attached to the carcass of that fish. Four other tags were found transmitting mortality signals, but these tags were all found washed up on shore, free from any movement.

DISCUSSION

Bycatch Mortality

High rates of delayed mortality have been documented for some commercially-exploited species (e.g., Olla et al. 1997; Lockwood et al. 1983; Parker et al. 2003; Trumble et al. 2000), but gillnetting and 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. We chose to mimic the commercial 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 (Fry 1971; Brett 1944, 1952, 1960). 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. Thus, it is possible that netting paddlefish under more extreme conditions (e.g., higher water temperatures) might result in higher delayed mortality for those fish that were not dead when nets were retrieved.

High post-release 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). Stancill et al. (2002) reported that all (n = 32) of the paddlefish caught in gill nets and implanted with ultrasonic tags survived at least three years. Zigler et al. (2003) reported no short-term mortality (i.e., within 2 months) of paddlefish due to capture in various fishery gears or surgical procedures used to implant radio transmitters. Caron et al. (2002) reported

100% post-release survival of Atlantic sturgeon *Acipenser oxyrinchus* caught in multifilament gillnets with soak times of 24 h at water temperatures up to 23ºC.

Other researchers have noted that paddlefish are a robust, hardy fish that can tolerate grievous wounds, which may explain why post-release 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 they had previously been entangled in a gill net. 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 post-release survival rate was so high in the present study. Stress, as defined by Chrousos (1998), is a state of threatened homeostasis that is re-established 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 and death will occur. Barton et al. (1998, 2000) observed relatively low stress response in sturgeons *Scaphirhynchus* spp. and paddlefish; in both studies, fish recovered to pre-stress 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 gillnets can survive long enough to be released.

The use of detachable radio transmitters proved to be a successful method to study short-term movements and delayed mortality in paddlefish. Return rates (65%) and average tagging times (1.8 min) were comparable to what Osborne and Bettoli (1995) reported when they studied hooking mortality of striped bass using similar tags-and-floats

(59% and 1.8 min, respectively). The high return rate allowed the project to save thousands of dollars and increase the sample size. In addition, the quick external tag attachment cut down on the possibility of tagging mortality. The tag assembly itself probably had minimal impact on each paddlefish based on the fact that some tags were recovered hundreds of km upstream of where fish were tagged. The small size and weight of the tag-and-float assembly (relative to the size of the fish tagged) also reduced concerns that the survival of the tagged fish was compromised.

Post-release movements

Paddlefish released as bycatch from commercial gillnets were highly mobile. Similar to the observations of Zigler et al. (1999), Moen et al. (1992), and Roush et al. (2003), the present study recorded substantial variation in movement among individual paddlefish. It was suggested by Filipek (1990) that paddlefish movements vary with the state of sexual maturity of the fish. The sexual maturity of tagged fish could not be determined in the present study; however, 95% of the fish we tagged were shorter than the smallest mature female (EFL = 926 mm) observed by Scholten and Bettoli (2005) in the same reservoir. Thus, it is likely that the most of the paddlefish tagged in the present study were either mature males or immature fish of either sex.

Post-release movements of tagged paddlefish 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 to 6.4 km per 24 h. Daily movement of tagged paddlefish in Kentucky Lake in the first three weeks post release averaged 4.6 km. The general agreement among studies regarding daily movements suggests that neither encountering commercial gillnets, nor having a radio tag-and-float attached externally, impeded the normal movements of tagged paddlefish released as bycatch.

MANAGEMENT IMPLICATIONS

In order for a minimum size limit to have the desired effect (e.g., reduce fishing mortality of juvenile or undersized fish), released fish must experience good survival, as we observed for paddlefish in this study. 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 20 September 2006 to end the commercial season one week earlier each year (on April 7th), which should reduce overall exploitation and lessen concerns regarding high rates of initial bycatch mortality. Unlike many other fisheries worldwide, the bycatch of paddlefish in Kentucky Lake cannot be influenced 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 should instead focus on other approaches (e.g., restrict the use of monofilament nets; avoid netting in early fall and late spring).

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Table 1. Means, standard errors, and range of the four independent variables used to explain variation in delayed mortality of paddlefish released as bycatch in Kentucky Lake, KY-TN, January 2005 through May 2006.

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 -1040	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 -1040	14.2	0.4	4.7 - 21.6	1.8	0.1	0.7 - 5.0	11.3	0.4	4.3 - 16.9

Table 2. Total distance moved by tagged paddlefish within the first week of release.

Days after release	n	Mean (km)	SE
1	38	2.18	0.35
2	63	5.00	0.82
3	20	9.67	0.86
4	24	5.36	1.07
5	41	16.89	2.18
6	9	16.90	2.64
7	5	18.40	4.90

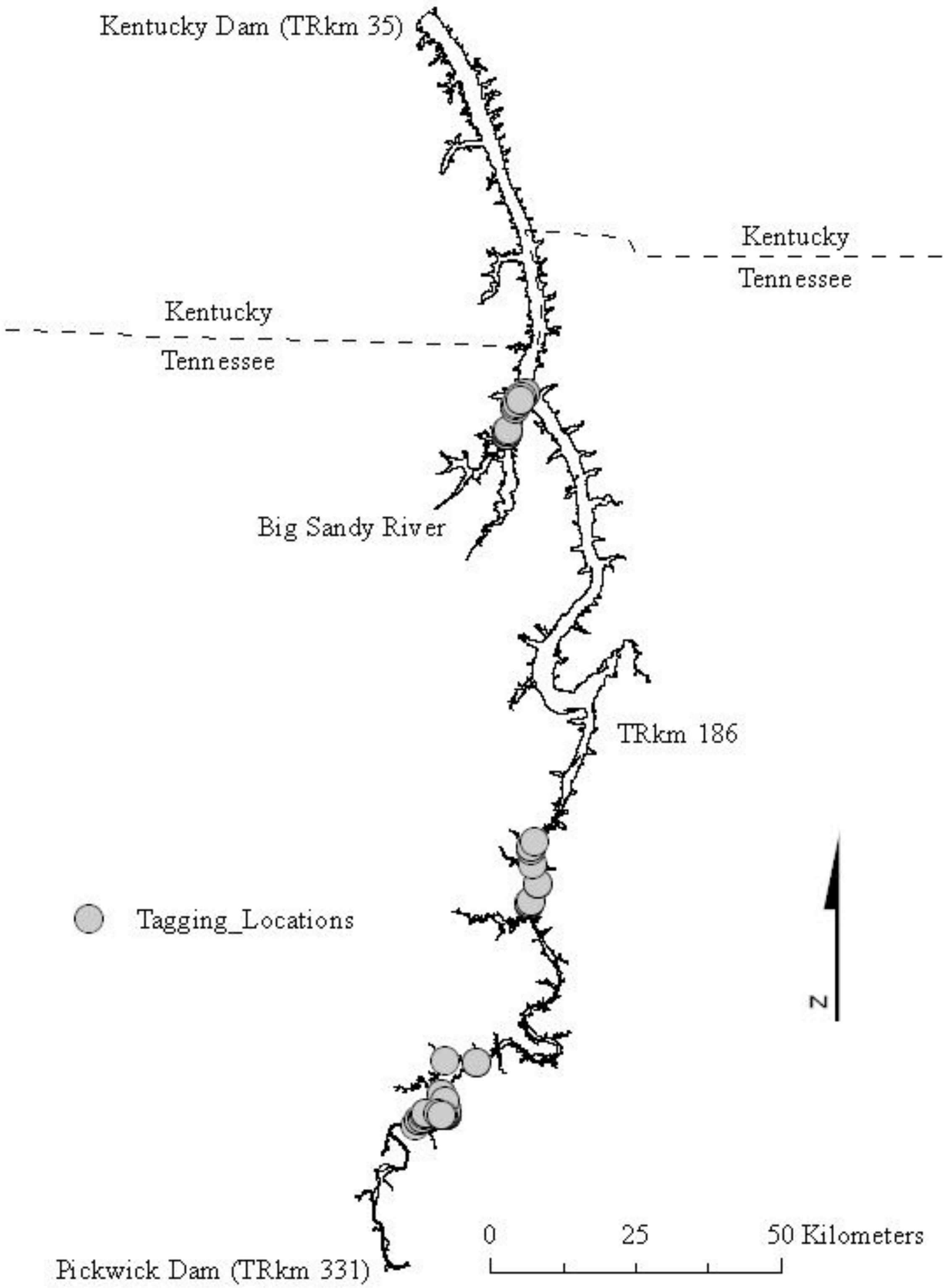

Figure 1. Map of tagging locations on Kentucky Lake. Tennessee River kilometers (TRkm) are measured from the confluences of the Tennessee and Ohio rivers.

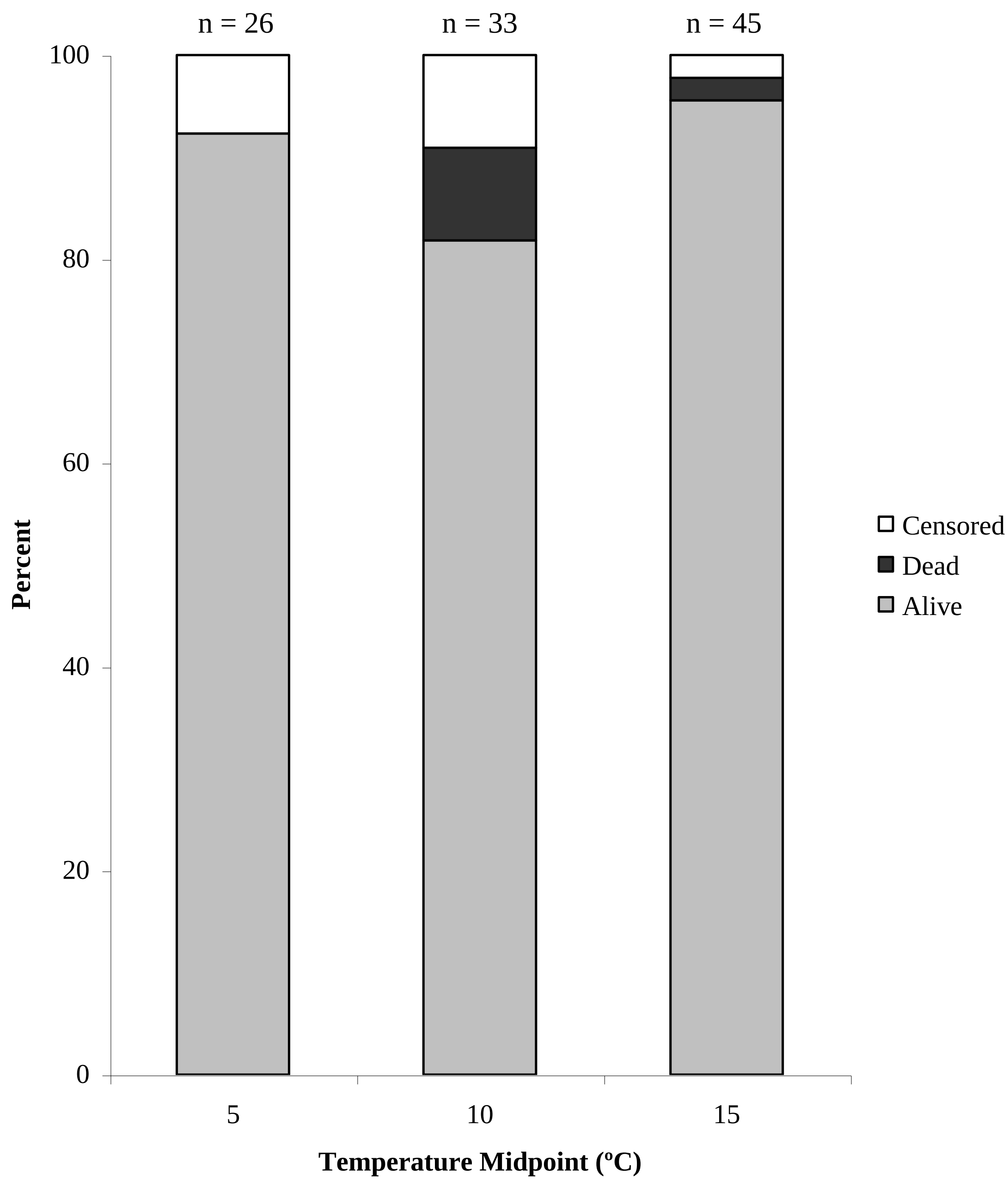

Figure 2. The fate of paddlefish tagged with radio transmitters and released as bycatch in Kentucky Lake over three ranges of water temperatures (2.5 to 7.5 ºC; 7.6 to 12.5 ºC; 12.6 to 17.5 ºC)

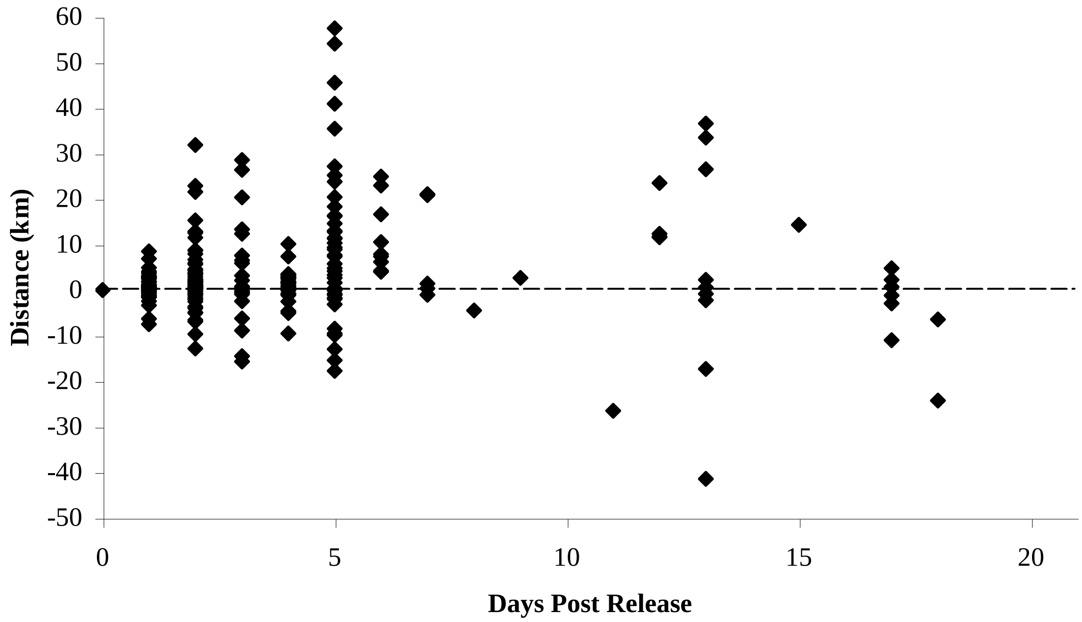

Figure 3. Net distances moved by paddlefish released as bycatch. Dashed line represents tagging location. One fish that moved 390 km upriver in 19 d is not shown.

APPENDIX

Appendix. Summary of radio tagged paddlefish data collected from January 2005 through May 2006 in Kentucky Lake, KY-TN. Days tracked is the interval between tagging and last location. See text for definitions of net distance and total distance. An asterisk denotes fish that were never located after release. Fate codes are: A = alive; D = dead; and C = Censored.

Fish ID	Days tracked	Number of locations	EFL (mm)	Net soak time (h)	Handling time (min)	Water temperature (°C)	Net distance (km)	Total distance (km)	Fate
1171	84	4	787	18.10	1.53	7.0	6.60	14.70	A
1180	11	3	884	18.10	1.79	7.0	25.10	26.70	A
1239	3	3	820	16.42	1.17	9.3	-1.40	23.80	A
1250	47	5	828	18.10	2.17	7.0	6.80	14.10	A
1259	12	2	990	17.08	3.22	9.3	-23.20	23.00	C
1313	46	3	901	17.12	1.48	9.3	10.70	10.70	A
1323	1	2	867	18.10	2.07	7.0	0.68	0.68	C
1333	119	6	870	17.30	0.92	9.3	4.50	21.00	A
1342	118	4	873	17.08	1.30	9.3	3.50	4.70	D
1352	531	2	901	16.42	1.08	9.3	252.70	252.70	A
1362	42	3	830	17.30	1.08	9.3	-4.30	5.40	A
1372	98	4	750	17.40	0.93	4.5	14.80	15.40	A
1382	3	3	870	17.30	1.03	9.3	-2.60	4.40	A
1393	96	2	710	16.85	1.13	4.4	-4.00	4.00	C

Appendix (Continued)

Fish ID	Days tracked	Number of locations	EFL (mm)	Net soak time (h)	Handling time (min)	Water temperature (°C)	Net distance (km)	Total distance (km)	Fate
1403	46	5	868	16.42	2.50	9.3	5.90	19.30	A
1412	46	4	872	17.08	1.33	9.3	12.10	13.30	A
1422	38	4	855	17.30	0.83	9.3	-4.50	18.80	A
1432	46	3	757	17.08	1.72	9.3	5.20	10.20	A
1443	11	4	730	17.30	0.92	9.3	11.60	11.60	A
1453	48	2	684	18.10	1.17	7.0	50.10	50.10	A
1462	32	4	720	17.35	0.90	4.4	2.70	3.90	A
1472	34	5	820	15.47	0.87	10.4	76.10	98.15	A
1473	4	4	660	8.00	3.17	16.4	11.55	14.29	A
1482	52	3	770	16.85	1.79	4.4	-18.00	18.00	A
1492	31	4	775	17.40	1.18	4.5	3.80	6.20	A
1502	203	6	875	15.33	1.07	10.4	-33.18	33.31	D
1512	32	4	815	16.85	0.65	4.5	4.20	17.10	A
1522	12	6	890	14.92	4.20	14.4	35.77	36.17	A
1532	16	4	834	15.47	1.25	10.4	-3.10	28.10	A

Appendix (Continued)

Fish ID	Days tracked	Number of locations	EFL (mm)	Net soak time (h)	Handling time (min)	Water temperature (°C)	Net distance (km)	Total distance (km)	Fate
1573	7	5	804	15.10	1.15	10.4	-4.49	13.31	A
1583	75	4	872	18.37	1.02	4.7	14.30	34.50	A
1593	3	3	846	20.47	1.27	4.8	2.69	2.69	A
1703	3	5	980	15.00	1.35	16.9	-9.60	11.30	A
1723	58	7	920	14.95	1.02	16.9	9.90	33.07	A
1733	34	4	638	16.85	1.25	4.3	-4.00	9.50	A
1742	3	3	735	18.60	0.88	4.6	1.50	2.10	A
1762	4	3	783	9.15	1.30	16.3	18.30	18.30	A
1773	1	3	792	14.25	2.03	14.4	1.90	2.09	A
1783	41	4	781	14.67	0.93	5.0	-9.20	18.80	A
1793	96	4	830	17.40	0.87	4.5	-1.70	8.00	A
1802	2	4	882	14.97	0.93	16.9	23.20	26.40	A
1812	12	6	920	15.17	2.02	14.4	-17.20	20.90	A
1822	4	7	830	14.08	1.80	14.4	9.87	10.33	A
1832	4	5	805	15.08	1.20	16.9	54.09	54.09	A

Appendix (Continued)

Fish ID	Days tracked	Number of locations	EFL (mm)	Net soak time (h)	Handling time (min)	Water temperature (°C)	Net distance (km)	Total distance (km)	Fate
1852	31	4	801	16.85	0.88	4.5	40.00	40.60	A
1862	3	4	865	5.65	3.57	10.4	-0.23	2.70	A
1873	4	4	868	14.50	2.87	14.4	40.90	41.73	A
1892	96	4	645	16.85	0.87	4.5	-0.30	5.30	A
1902	32	4	695	16.85	0.78	4.5	1.80	3.80	A
1913	23	4	910	16.85	1.33	4.5	-3.00	6.00	A
1922	32	4	897	16.85	1.47	4.5	2.00	8.90	A
1932	96	4	807	16.85	1.17	4.5	17.80	18.26	A
1942	33	4	867	8.00	2.97	16.4	-24.70	74.80	A
1952	32	4	920	21.58	0.77	4.8	3.60	22.00	A
1962	96	4	850	19.58	1.53	4.8	3.80	4.30	A
1982	4	4	914	14.33	3.80	14.4	-0.85	0.85	A
1992	12	4	927	14.17	2.28	14.4	2.30	14.67	A
2180	70	4	805	17.00	1.10	4.4	-5.70	19.40	A
2250	12	6	853	14.42	1.75	14.4	0.59	2.98	A

Appendix (Continued)

Fish ID	Days tracked	Number of locations	EFL (mm)	Net soak time (h)	Handling time (min)	Water temperature (°C)	Net distance (km)	Total distance (km)	Fate
2259	52	4	844	9.63	2.22	10.4	-31.30	43.70	A
2313	38	2	905	15.83	0.93	10.3	-7.80	7.80	C
2333	16	4	860	9.30	1.35	16.3	1.10	26.00	A
2362	14	3	874	5.65	4.25	10.4	14.30	31.50	A
2372	37	5	795	14.88	0.73	16.9	21.19	21.19	A
2403	17	6	847	15.47	0.92	10.4	-24.26	25.23	A
2412	16	5	840	15.82	1.22	10.4	5.20	23.20	A
2422	5	4	864	15.47	1.08	10.4	10.57	11.40	A
2432	8	5	922	15.82	1.33	10.4	2.69	40.50	A
2453	17	6	895	15.82	1.83	10.4	-6.40	33.40	A
2462	58	6	900	15.70	1.48	10.3	-35.69	53.50	A
2482	4	5	884	14.00	5.00	14.4	23.78	23.78	A
2492	5	4	875	15.98	1.03	10.4	3.99	3.99	A
2502	12	6	863	15.00	4.20	14.4	26.53	44.72	A
2512	5	4	775	15.40	1.00	10.3	24.91	24.91	A

Appendix (Continued)

Fish ID	Days tracked	Number of locations	EFL (mm)	Net soak time (h)	Handling time (min)	Water temperature (°C)	Net distance (km)	Total distance (km)	Fate
2532	54	3	850	9.15	1.42	16.3	16.70	16.70	A
2583	16	6	1040	15.12	1.08	16.9	-2.30	54.30	A
2723	1	3	899	8.00	2.67	16.4	31.90	35.11	A
2783	12	6	890	14.83	3.43	14.4	33.50	33.50	A
2793	16	5	915	15.07	1.25	16.9	0.85	7.70	A
2812	4	3	870	8.00	2.20	16.4	20.40	20.40	A
2852	0	3	715	14.52	0.90	16.9	-6.30	6.30	A
2913	12	6	845	14.58	2.87	14.4	-0.45	16.40	A
2922	3	4	883	7.33	3.83	10.4	0.15	0.58	D
2932	4	3	894	9.67	1.60	16.3	57.50	57.50	A
2952	10	5	867	15.33	0.85	10.4	-26.50	38.90	A
2962	4	5	792	15.08	3.02	14.4	-12.98	15.78	A
2972	6	5	954	15.40	1.20	10.4	20.88	25.10	A
2982	18	4	875	8.00	1.80	16.4	390.17	390.20	A
3250	4	5	865	8.00	2.13	16.4	-1.90	5.72	A

Appendix (Continued)

Fish ID	Days tracked	Number of locations	EFL (mm)	Net soak time (h)	Handling time (min)	Water temperature (°C)	Net distance (km)	Total distance (km)	Fate
3259	16	5	880	15.17	1.00	16.9	-10.98	17.87	A
3333	4	4	907	8.00	3.52	16.4	4.14	21.86	A
3403	12	5	804	14.67	1.25	14.4	-2.24	35.60	A
3432	37	7	845	14.93	0.97	16.9	-0.16	0.52	D
3443	4	4	864	8.00	1.85	16.4	-17.71	21.91	A
3453	12	6	765	14.75	2.03	14.4	-41.43	48.97	A
3462	98	4	782	9.20	1.33	16.3	-91.50	103.10	A
3532	4	4	887	8.00	2.30	16.4	14.20	14.20	A
3583	1	3	842	8.00	2.72	16.4	1.87	2.13	A
3783	1	4	920	8.00	3.25	16.4	-0.65	2.47	A
3913	4	4	879	8.00	1.98	16.4	-1.70	32.30	A
4403	4	4	826	8.00	2.80	16.4	45.56	45.56	A
4432	1	3	914	8.00	4.42	16.4	-2.00	13.00	A
2733*	0	1	891	4.73	3.70	10.4	N/A	N/A	C
3793	0	1	866	8.00	3.57	16.4	N/A	N/A	C