Harvest Management Regulation Options for Oklahoma's Grand Lake Stock of Paddlefish

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Abstract: Across its historical range, fisheries for the North American paddlefish (*Polyodon spathula*) have proven sensitive to overexploitation because its roe is a source of expensive caviar. In 2008, the Paddlefish Research Center (PRC) was developed near Miami, Oklahoma, by the Oklahoma Department of Wildlife Conservation (ODWC) to collect biological data and support other monitoring activities on the Grand Lake O' the Cherokees (Grand Lake) paddlefish stock, the state's largest fishery, as part of a voluntary roe donation program. Several key observations led ODWC to conclude that an evaluation was needed of the adequacy of harvest management regulations for the Grand Lake stock and for Oklahoma paddlefish in general. The Grand Lake stock has declined in abundance from an estimated 200,000 to 68,000 adult fish over a five-year period 2008–2012), is maintained by natural, highly variable, and inconsistent recruitment, and is currently dominated by one cohort. The strong interest by anglers in the fishery, liberal harvest regulations compared to other states, and the increasing media attention paid to the fishery have all played roles in stock decline, necessitating harvest management to maintain sufficient fish in the spawning population to result in future strong year-classes. Under the statewide one-fish daily bag limit, most anglers (82%–84%) harvested two or fewer fish annually, with 60%–62% of anglers harvesting only a single fish. The generalized options for reducing harvest considered included 1) reducing the number of paddlefish anglers, 2) instituting a stock-specific, biologically based annual harvest cap, and 3) reducing individual angler harvest. Five methods of reducing individual angler harvest were considered, but two preferred approaches emerged from existing data and fishing patterns: implementation of a harvest cap (total allowable catch) and an individual annual harvest limit of two fish. Implementation would result in substantial changes in the Oklahoma paddlefish recreational fishery. Results for the Grand Lake stock will serve as a framework for statewide harvest management regulation.

Key words: paddlefish, caviar, harvest management, fishery regulation, Oklahoma

Journal of the Southeastern Association of Fish and Wildlife Agencies 1:89–97

The North American paddlefish (*Polyodon spathula*) inhabits the Missouri and Mississippi River basins of the central United States from Montana to the Gulf of Mexico and east to New York (Gengerke 1986, Bettoli et al. 2009). Current populations of this highly migratory species are much reduced in many localities (Russell 1986) and have become fragmented as a result of alterations in their large-river habitats from dam construction, channelization, and other human actions (Sparrowe 1986, Gerken and Paukert 2009). As dams have blocked migratory corridors and as off-channel habitats on many river reaches have disappeared or become disconnected, paddlefish reproductive success has declined (Russell 1986) and the species has increasingly used reservoirs for rearing.

Overfishing has also led to declines of many paddlefish populations. Although paddlefish meat is highly regarded in many quarters, they are sought by commercial fishers mainly for their roe, which has long been highly prized as caviar (Hussakof 1911, Carlson and Bonislawsky 1981, Jennings and Zigler 2009). The commercial demand for paddlefish roe has been increasing greatly in recent years due to collapse of beluga (*Huso huso*) and other Caspian Sea sturgeons (Scholten 2009). Since beluga sturgeon was upgraded from endangered (1996) to critically endangered (2010) by the International Union for Conservation of Nature (Gesner et al. 2010) and U.S. trade was prohibited in 2005 (USFWS 2005), paddlefish caviar has been increasingly accepted as a high-quality replacement in many domestic and foreign markets. In addition, paddlefish caviar is also occasionally repackaged and illegally labeled as beluga caviar (Williamson 2003). The full impacts of this escalating fishing pressure have yet to be quantified (Hintz and Garvey 2012). Reservoir ranching (Onders et al. 2001, Dasgupta et al. 2006), captive rearing (Mims et al. 1999, Mims 2001), and genetic modification (Shelton and Mims 2012) of paddlefish for roe production overseas are increasing. Although aquaculture may potentially assist in reducing the exploitation of wild stocks, the current supply is not yet sufficiently abundant or cost-effective compared to wild harvest to satisfy the international demand for caviar, as evidenced by the active commercial fisheries in states where they are permitted (Scholten 2009).

In the United States, many states attempt to counter population declines and illegal harvest via increasingly restrictive commercial and recreational fishing regulations. Regulatory measures used vary by state and include bag limits, protected slots, minimum length limits, harvest caps or quotas, and mandatory catch-and-release (Hansen and Paukert 2009, Scholten 2009). Unfortunately, little published evidence is available on the conservation impacts of various paddlefish harvest management strategies. The paddlefish fisheries often exist under inadequate regulatory attention and a paucity of information on stock status, ecology, and fishing pressure (Raymakers 2002, Blundell and Mascia 2005). Although coordinated management of the migratory paddlefish often calls for inter-jurisdictional management, at a fundamental level, effective management requires proactive, conservative harvest management on a local population scale (Pikitch et al. 2005, Scarnecchia et al. 2008, 2013).

Oklahoma Paddlefish

The history and current status of paddlefish in Oklahoma is thoroughly reviewed in Oklahoma's Paddlefish Management Plan (Scarnecchia et al. 2013). Paddlefish are widely distributed in the eastern half of the state, including the Arkansas, Grand, Neosho, Verdigris, Canadian, and Red rivers. They also inhabit a series of reservoirs on those rivers, including Grand Lake O' the Cherokees (hereafter, Grand Lake), Hudson, Fort Gibson, Eufaula, Oologah, Keystone, Kaw, and Texoma (Miller and Robison, 2004, Scarnecchia et al. 2013). Since 1992, no commercial harvest has been allowed and only recreational fisheries for the species have been permitted in the state. As of 2013, statewide paddlefish regulations in Oklahoma for the year-round fisheries include the requirement of a mandatory annual paddlefish permit (free), a daily bag (creel) limit of one, no culling, barbless hooks, and mandatory catch-and-release on Monday and Friday (ODWC 2013a, 2013b, Oklahoma Register 2013). The most common harvest method is hook-and-line snagging, although bowfishing, trot-lines, and throwlines are also used. Retention of roe and production of caviar for personal use are permitted within strict limitations and transport of roe or caviar out of the state is prohibited. Special area regulations include a snagging curfew on the Grand River below Hudson Lake and a complete closure of snagging on the Spring River to the Kansas state line (Figure 1). Daily bag limits in Oklahoma have incrementally tightened from five fish in 1979 to three (1982) to one (2003). Prior to the 2003 implementation of a year-round daily limit of one, the daily limit from 1995 to 2002 was three fish during 15 March – 15 May, and one fish per day the rest of the year. For a full review of historic paddlefish regulation changes in Oklahoma, see Gordon (2009) and Scarnecchia et al. (2013).

Until 2008, Oklahoma's paddlefish had been only periodically studied (Houser and Bross 1959, Combs 1982, Paukert 1998, Paukert and Fisher 2000, 2001). However, in 2008, the Oklahoma Department of Wildlife Conservation (ODWC) created the Paddlefish Research and Processing Center (renamed the Paddlefish Research Center [PRC] in 2012) on Grand Lake. At the PRC, anglers receive free cleaning of their fish for a donation of the roe from their fish, if present. The roe is processed into caviar, with the proceeds of sales going toward ODWC fish and wildlife resource conservation, management, and enforcement activities. As a result of the PRC, high-quality data have been obtained to help manage the paddlefish in Grand Lake and elsewhere in the state, and the paddlefish research and stock assessment activity has increased greatly (Scarnecchia et al. 2011). Oklahoma paddlefish management activities currently consist of traditional fisheries collections of adults (winter gillnetting, mark/recapture with jaw banding), research focused on population ecology (acoustic telemetry, genetic analyses), and harvest- and recruitment-based stock assessment (creel surveys, springtime larvae netting, and benthic trawling). These data are supplemented by information acquired from the PRC. At the PRC, dentary bones from angler-harvested fish

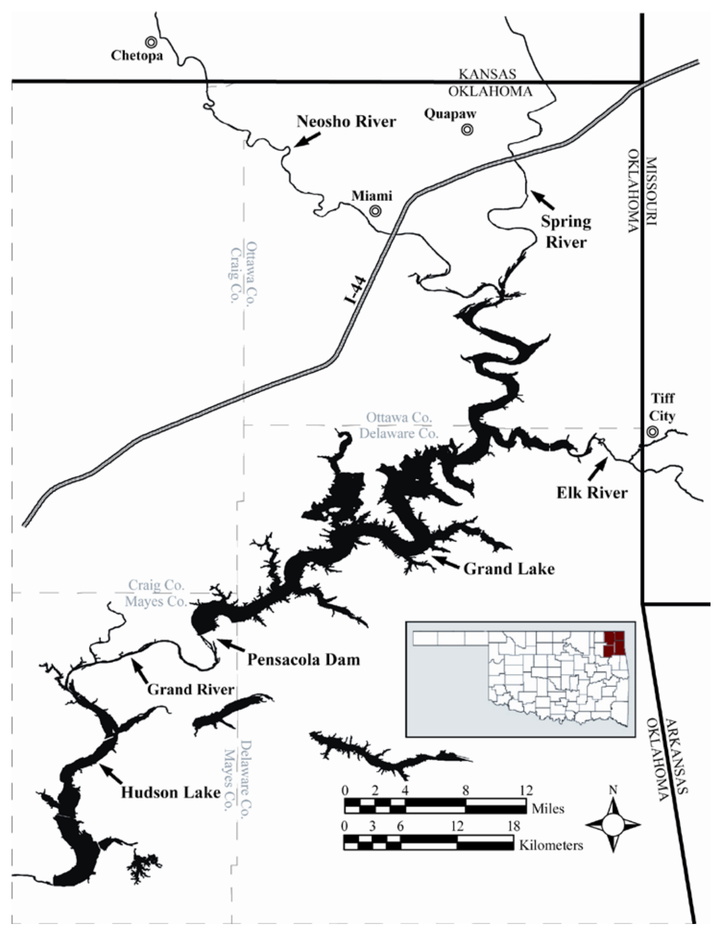

Figure 1. Map of northeastern Oklahoma, depicting Grand Lake O' the Cherokees and its watershed. Map courtesy of D. Griffith, Oklahoma Department of Wildlife Conservation.

provide age structure for the Grand Lake population and internal examination provides metrics for physiological and reproductive status. The PRC provides angler residency, angler statistics, and angler contacts which are valuable for harvest assessment. Simultaneously with the opening of the PRC in 2008, ODWC required a free, mandatory permit of all anglers who attempt to harvest paddlefish.

Grand Lake Paddlefish Status and Trends

Grand Lake Paddlefish. The Grand Lake paddlefish harvest management unit in northeastern Oklahoma extends from Pensacola Dam up to the Neosho River as it enters the state from Kansas. Pensacola Dam was constructed by Grand River Dam Authority from 1938 to 1940 creating Grand Lake (Figure 1). This hydroelectric dam impounded the waters of the Elk, Neosho, and Spring rivers and these waters form the Grand River below Pensacola Dam until its confluence with the Arkansas River. Grand Lake is the northernmost reservoir in a series of three, and adult migrant paddlefish have access to the three inflowing rivers for spawning. Populations in the downstream reservoirs, Lake Hudson and Ft. Gibson Lake, impounded later in 1964 and 1949, respectively, are blocked from upstream migrations by Pensacola Dam. All three Grand River reservoirs support active spring snag fisheries on naturally produced (wild) fish, with Grand Lake receiving a majority of the fishing pressure. The Grand Lake population is harvested in the reservoir year-round and during spring at popular fishing sites along the Neosho River. Grand Lake paddlefish also move up into Kansas and are harvested at a few upriver sites (Scarnecchia et al. 2013).

Stock status and trends. Population estimates (Peterson-Chapman single-survey; Ricker 1975) obtained by ODWC from Grand Lake paddlefish marked during winter gillnetting in the reservoir and recaptured at the PRC demonstrated (1) a declining trend in abundance of adult paddlefish (≥800 mm) in Grand Lake, with a 67% decline from 2008 to 2012 (Table 1), (2) an increasing band-return rate (recapture rate) during the 2008–2012 period (Figure 2), and (3) an increasing trend in exploitation (<7%) over this same period. In addition, detailed studies of ages of fish since 2008 indicated that Grand Lake paddlefish typically only live about 20 years, and that prime spawning of females occurs from about age 12 to age 16 (Scarnecchia et al. 2011). Paddlefish from Grand Lake exhibited sexual size dimorphism, with males being shorter than females of a given age (Scarnecchia et al. 2011).

Age data from 19,076 fish aged 2004–2012 further indicated that the Grand Lake adult population was dominated by one cohort spawned in 1999 (Figure 3). With few exceptions, other cohorts have not exceeded 5% of the annual PRC harvest since 2008.

Table 1. Parameters (numbers of paddlefish) from single-census adjusted Peterson/Chapman population estimates (*N*) and 95% confidence intervals (CI) for adult paddlefish in Grand Lake. Estimates are developed from winter gillnetting collections where fish were marked (*M*) with jaw bands and subsequent spring harvest of banded fish (*R*) within the total angler harvest (*C*) at the Paddlefish Research Center.

Winter	*M*	*C*	*R*	*N*	95% CI
2008	566	7332	19	207,891	135,876–332,625
2009	517	3911	13	144,744	86,971–256,508
2010	1079	4579	31	154,575	109,920–224,836
2011	1099	3931	48	88,269	72,087–131,067
2012	498	4512	32	68,242	48,850–98,771

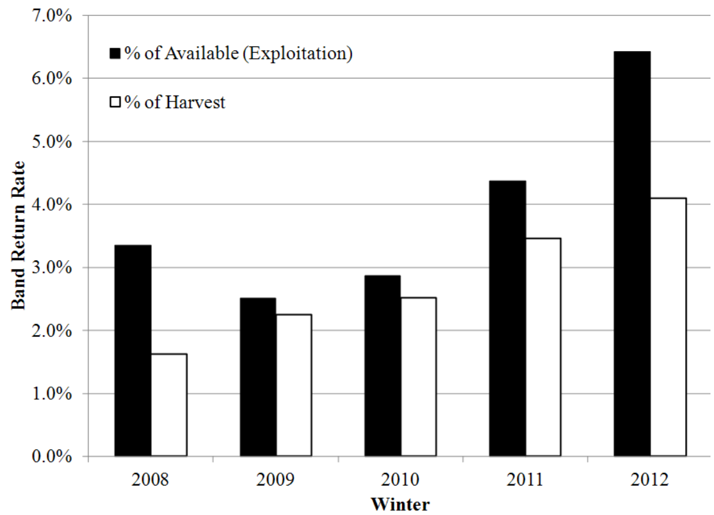

Figure 2. Band-return rates from paddlefish jaw-banded by Oklahoma Department of Wildlife Conservation in winter gillnets and later harvested by anglers and checked at the Paddlefish Research Center.

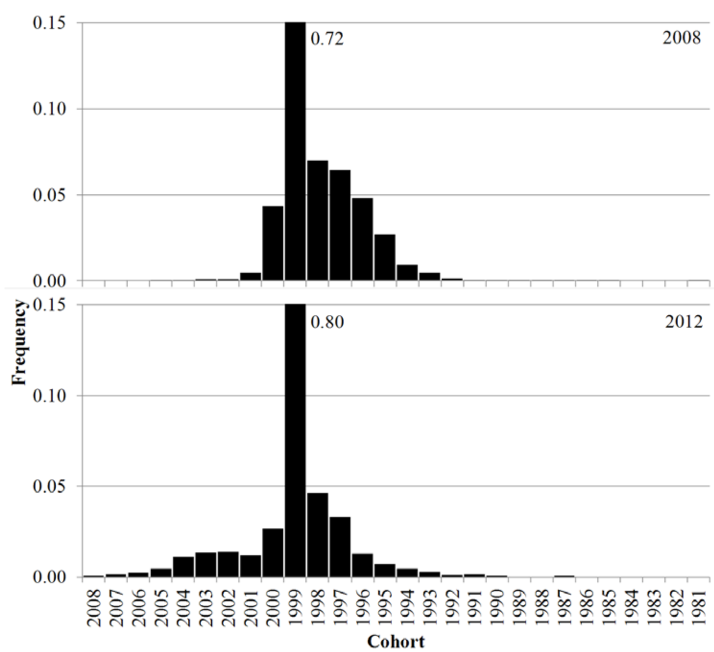

Figure 3. Relative frequency of paddlefish cohorts from 2008 and 2012 aging efforts demonstrating the dominance of the 1999 cohort (frequency inset). Results 2009–2011 were similar.

The exact cause of this strong cohort is not known, but was associated with high river discharges and reservoir levels (Scarnecchia et al. 2013). Regardless of the cause, the strong 1999 cohort has supported a robust fishery since 2008. However, the combination of natural mortality and harvest has outpaced recruitment since 2008, resulting in a declining population. The rate of decline cannot be explained solely by angler exploitation, but also by natural mortality, although non-harvest (hooking) mortality remains unquantified. What evidence is available suggests that the Grand Lake population probably also fluctuated in abundance greatly in the past. Combs (1982) reported angler exploitation in the Neosho River at 15%–18% and a modest adult population abundance of 25,118 (95% CI; 19,375–32,485), a level at which the current Grand Lake stock may be approaching. Population age structure and life history aspects are more thoroughly examined in Scarnecchia et al. (2011).

Fishery and angler status and trends. Socioeconomic and angler survey data obtained by ODWC from permit requests (required of potential paddlefish anglers) and from a post-season angler survey during the years 2008–2011 (Crews 2009, 2010, 2011) indicated that between 29,000 and 46,000 paddlefish permits were issued each spring over the period 2008–2011 (Table 2). Active anglers fished the Grand Lake area an average of 3.8–5.7 days annually during 2008–2011. During 2010–2011, when harvest was prohibited on Mondays and Fridays statewide, only 30% of anglers surveyed continued to fish on these catch-and-release days (Crews 2011).

In terms of harvest by individual anglers, respondents fishing Grand Lake reported keeping an average of 1.5 fish per year in 2010 and 2011 (Crews 2011). Higher averages from 2008 (2.4) and 2009 (2.3) were skewed by a few extremely industrious anglers reporting harvest of up to 80 and 110 fish, respectively (Crews 2009). Another indication of harvest per angler, obtained from permit data from fish donated to the PRC, indicated an average harvest of 1.67–1.74 fish per angler (within the March–April timeframe of PRC operation, ODWC unpublished data). Trends in individual harvest rates were consistent across years and when individual harvest totals (within year) were examined, most anglers (82%–84%) were found to have harvested two or fewer fish, with 60%–62% of anglers harvesting only a single fish. These low-harvest anglers (one or two fish) accounted for 60%–63% of the annual harvest recorded at the PRC. Only a small segment of paddlefish anglers harvested three or more fish in a year (six-year average 17%, range 16%–18%). Though this segment was small, the impact of these anglers was high, comprising 37%–40% of the total harvest. Each year, 6 to 13 anglers harvested 10 or more paddlefish. More than 16,000 permits were used to harvest a total of 28,622 paddlefish during 2008–2013 (ODWC unpublished data).

The Grand Lake fishery was dominated by nonresident anglers, though they largely hailed from the neighboring states of Arkansas, Kansas, and Missouri (Crews 2009, 2010, 2011). Numbers of paddlefish anglers in Oklahoma estimated from survey responses showed an increasing trend from 2008–2011 (Table 2). Statewide, resident anglers outnumbered nonresidents approximately 2 to 1, but the reverse was true on Grand Lake; during 2008–2011, 84%–93% of active, nonresident anglers used the Grand Lake area, compared to only 24%–47% of active resident anglers (Crews 2009, 2010, 2011, Table 2). Based on reporting rates estimated from the angler survey, total estimated harvest from Grand Lake ranged from 6,828 fish in 2011 to a peak of 15,088 fish in 2009 (Crews 2011, Table 2). Aside from the spike in harvest in 2009, estimated total harvest was relatively stable. Based on the average harvest reporting rate from 2008–2011 (57%) the total estimated harvest from Grand Lake during 2008–2013 was 51,379 fish (ODWC unpublished data).

Coincident with a decreasing stock size and strengthening interest by anglers, media attention on paddlefish and caviar in Oklahoma also increased during the period 2008–2012. The number of regional newspaper articles on "Paddlefish" in 2010 tripled that of any year 2000–2008 (NewsOk.com 2013). A distinct in-

Table 2. Paddlefish permits issued, estimated anglers, and harvest totals in Oklahoma from 2008–2013. Data represent permits available in springtime (S, deadline varied across years), during the entire calendar year (C), or partial calendar year (P, 1 January – 30 July). As no angler survey was performed in 2012 or 2013, the average harvest reporting rate for 2008–2011 (*0.57) was used to estimate Grand Lake harvest. Data are assembled from Crews (2009, 2010, 2011) and ODWC unpublished data.

Year	Paddlefish permits issued (% OK resident)	Permit period	Estimated active resident anglers (% using Grand Lake)	Estimated active nonresident anglers (% using Grand Lake)	PRC harvest (Grand Lake)	Harvest reporting rate	Estimated Grand Lake harvest
2008	29,387 (0.74)	S	8387 (0.24)	4711 (0.84)	4222	0.58	7279
2009	33,488 (0.72)	S	9462 (0.47)	5700 (0.90)	7408	0.49	15,088
2010	39,412 (0.73)	S	10,839 (0.43)	5374 (0.89)	3948	0.54	7379
2011	46,060 (0.78)	S	10,735 (0.38)	5657 (0.93)	4609	0.68	6828
2012	81,497 (0.81)	C	–	–	3931	*0.57	6893
2013	93,459 (0.81)	P	–	–	4512	*0.57	7912

creasing trend in media articles with keywords "Oklahoma AND Caviar" occurred during 2008–2012, after the initiation of free fish cleaning and public visibility provided at the PRC (NewsOk.com 2013). Increased media attention via ODWC advertisement plus the success of the PRC have also made the fishery more attractive and accessible to inexperienced anglers. A majority of anglers (59%) using the PRC in 2011 began fishing for paddlefish after the PRC opened in 2008 (Crews 2011). Though no angler survey data specifically address this phenomenon, increased media attention garnered by the PRC and paddlefish activities in Oklahoma may have played a role in enlisting new paddlefish anglers.

The Need for More Harvest Management

Several key observations led ODWC to conclude that an evaluation was needed of the adequacy of harvest management regulations for the Grand Lake stock and for Oklahoma paddlefish in general. The decline in abundance from an estimated 200,000 to 68,000 adult fish from 2008 to 2012 (Table 1), the inconsistent recruitment over the same period leading to domination of the recruits by one cohort (Scarnecchia et al. 2011, Figure 3), the strong interest by anglers in the fishery (Crews 2009, 2010, 2011), the liberal harvest regulations compared to other states, and the increasing media attention paid to the fishery all contributed to this conclusion.

The long-term health of the population and the fishery are strongly dependent on production of one or more strong year classes in the near future to rebuild the harvestable stock. Until then, harvest must be apportioned out carefully with an appropriate harvest management strategy. An alternative approach, stock enhancement through stocking, while always an option, is not encouraged by the Oklahoma Paddlefish Management Plan in places such as Grand Lake, where the aim is to conserve the historically wild, naturally recruiting population (Scarnecchia et al. 2013). Flow enhancement for the benefit of paddlefish recruitment is also impractical within the large, unimpeded stretch of the Neosho River.

Instead of the current one-fish-per-day bag limit that does not effectively nor precisely define total harvest, the situation may require the development of a more structured harvest management approach, such as an annual harvest cap, an annual individual bag limit (i.e., a specified number of fish per year per angler), or both, as has occurred in other paddlefish fisheries (Scarnecchia et al. 2008, Hansen and Paukert 2009). In the last section of this paper, we consider a range of possible regulatory measures for sustainable harvest. Results for the Grand Lake stock will serve as a framework for statewide harvest management regulation under the recently adopted Paddlefish Management Plan (Scarnecchia et al. 2013).

Harvest Management Options

To sustainably conserve the stock and manage this traditional fishery on Grand Lake and the Neosho River, ODWC has considered several harvest management options. The options are not mutually exclusive and combinations of them may be employed, with the understanding that ODWC, consistent with its mission, aims to allow continued resource use by current and future Oklahoma residents, and will seek to encourage angler opportunity wherever possible. The generalized options for reducing harvest considered include reducing the number of paddlefish anglers, instituting a stock-specific, biologically-based annual harvest cap, and reducing the number of fish harvested per angler.

Reducing the Number of Paddlefish Anglers. The first option, reducing the number of anglers, is not consistent with the intent of the Paddlefish Management Plan for providing benefits of paddlefish to the many as opposed to the few. Unlike commercial paddlefish fishers in other states, Oklahoma paddlefish anglers are individuals and they have little direct economic dependence on the fishery (aside from fishing guides and local businesses that benefit from the presence of anglers). Individual sale of paddlefish parts, including meat or roe, is prohibited in Oklahoma. Rather, the value of the fishery for paddlefish anglers is one of tradition, recreation, and a modest subsistence benefit. Angler survey responses indicated that the "fun, excitement, and sport of paddlefishing" and the "chance of catching a very big fish" are the two most strongly valued motivations for fishing in Oklahoma (for >71% of respondents; Crews 2009, 2010, 2011). In contrast, the ability to "keep a paddlefish at the end of the day" was reported as being of lesser importance (30% of respondents) to anglers (Crews 2011). More anglers provide more indirect economic benefits to communities and, when possible, ODWC seeks to support local economies receiving financial benefits from nonresident and resident paddlefish anglers. It was determined, then, that a successful harvest management plan would be aimed at overall harvest reduction rather than reduction in the number of anglers and spreading available harvest among as many anglers as possible, consistent with the Paddlefish Management Plan (Scarnecchia et al. 2013).

A Stock-Specific, Biologically-Based Annual Harvest Cap. A cap on annual harvest—or "total allowable catch" (TAC, Copes 1986)—has been used effectively in some paddlefish fisheries, including in Montana and North Dakota (Scarnecchia et al. 2008), where it is not considered a target but a conservation limit on harvest. Some years the cap is not met because river flows preclude fish movements and naturally limit angler harvest. This harvest cap approach does not seek to make individual anglers less efficient daily or weekly, but seeks to limit total aggregate harvest, and may reduce an individual's annual catch. Enactment and implementation of a TAC requires real-time monitoring of harvest and fishery closure when the threshold of TAC is reached or exceeded. These concepts are more simply and appropriately applied to a single harvest management unit (or population), rather than on a statewide scale where each population receives differential pressure and mixing of those populations is precluded by dams. Even with limits on individual harvest, however, there is nevertheless a tendency for the prospect of fishing closure to result in a "race for fish" and progressively shorter seasons as individual anglers seek their incremental share of the TAC (Copes 1986, Scarnecchia et al. 2008). For effective implementation in Oklahoma, TACs should be site-specific and developed as data on stock status and angling pressure of lesser-studied populations becomes more available. A TAC for each population should be set and adjusted annually based on annual stock assessment and fishing pressure. As of 2013, the TAC approach is still in under consideration for the Grand Lake stock and other Oklahoma populations, but it is not yet possible to set a reliable TAC or harvest cap. Although it is viewed as a primary harvest management tool (Scarnecchia et al. 2013), as of 2013, indirect methods of reducing total annual harvest through effects on individual angler success rate and harvest are receiving primary consideration.

Reducing the Number of Fish Harvested Per Angler. Variations of this approach seek to make individual anglers less efficient in terms of their total harvest daily, weekly, annually, or in any of these combinations. Five possible methods of reducing the number of fish harvested per angler are considered: individual annual harvest limit, additional time and area closures, additional mandatory catch and release days, fish length restrictions, and mandatory retention.

Individual annual harvest limits are designed to specify the maximum number of fish that an individual angler can harvest each year, which are usually based on individual harvest success and angler satisfaction. Because most Grand Lake paddlefish anglers harvested two or fewer fish annually, individual annual harvest limit of two fish would not impact about 84% of those anglers. However, it would prevent a 16% minority of anglers from harvesting from three to as many as 18 fish annually. Studies in Montana indicated that most anglers would much prefer harvesting two fish to one fish annually, but would gain much less from harvesting three fish as opposed to two fish (Scarnecchia et al. 1996). A positive aspect of the annual limit would be the establishment of a precedent for using this egalitarian approach; the individual annual bag limit can be adjusted up or down as stock size allows. However, a potentially negative consequence might be that some anglers under an annual harvest limit may expend whatever fishing effort is needed to fill their limit (i.e., to "limit out" and maximize their harvest success), at whatever limit is set (Hobbs 1948).

Time and area closures are used by many states for a variety of ecological or social reasons. For example, both North Dakota and Montana use time closures (i.e., May and 15 May – 30 June fishing seasons, respectively) to consolidate harvest and the necessary monitoring over a manageable interval. North Dakota uses area closures to protect key feeding and staging areas for paddlefish (Scarnecchia et al. 2008). In Oklahoma, time (i.e., seasonal or day and night) and area closures for paddlefish angling typically have been avoided as contrary to the goals of ODWC and the Paddlefish Management Plan; however, exceptions have been made for specific enforcement and conservation needs. For example, nighttime closure of the snag fishery of the Grand River below Hudson Lake was enacted in 2010 after ODWC Game Wardens identified it as an area where harvest violations were especially prevalent and enforcement especially difficult. The Spring River was closed to snagging in 2010 as an enforcement aid (it consolidated paddlefish harvest primarily into the Neosho River and upper Grand Lake and to reduce angler use (estimated numbers of total anglers had increased by 24% from 2008 to 2010). Further time or area closures will need to be carefully evaluated for their appropriateness and effect. For example, implementation of a night time closure on the Neosho River would impact bank anglers at only a few locations (mainly Riverview Park in Miami, Oklahoma) with long social traditions of nocturnal snagging (Gordon 2009). Such a closure would only be justifiable if enforcement problems were shown to be severe. Some benefit would be obtained by eliminating harvest (although not necessarily catch and release) from the reservoir other than during the spring migratory period (March through May), thereby preventing harvest of some immature fish and avoid having to account for largely unmonitored harvest. The benefits of such closures to fishery monitoring and enforcement would have to be weighed against the social and economic costs of a more restricted fishery.

Additional mandatory catch and release angling is consistent with the intent of the Paddlefish Management Plan and may be considered in the future as conservation needs dictate either by adding more days per week or by mandating it within reservoirs during the non-migratory period for the stocks. In particular, more catch-and release days during the peak spring migration has the potential to reduce harvest. For example, by adding two catch-and-release days per week (Monday and Friday) via an emergency ruling in 2010, ODWC aimed to reduce harvest while retaining opportunities to fish. While the exact effects of this change on harvest are not quantified in a controlled evaluation, the new regulation prevented resident and especially non-resident anglers from filling a four-fish limit in a four-day fishing trip, potentially reducing individual harvest by 25%–50%. Although adding additional days of catch-and-release may be necessary in the future, may further alienate or disenfranchise anglers (Scarnecchia et al. 1996), 70% of whom reported avoiding fishing on catch and-release days, regardless of resident or non-resident status (Crews 2011). Similarly, most anglers on the Yellowstone River, Montana, desired to be able to harvest a fish, even if they chose not to (Scarnecchia et al. 1996).

Fish length restrictions are typically implemented to prevent harvest of a segment of the population (often spawning females) for the benefit of enhanced reproductive success and recruitment. Length limits (and protected slots) are utilized by only a few states with varying metrics and little evaluation on effectiveness (Hansen and Paukert 2009). In theory, because female paddlefish grow faster and attain larger sizes than males (Scarnecchia et al. 1989), a maximum length limit would disproportionately protect female spawners and leave more males unprotected (Scarnecchia et al. 2011), a desirable outcome. For example, a maximum length limit of 1000 mm applied to harvest reported to the PRC during 2008–2013 would have left 91% of males subject to harvest, while protecting 76% of females. Hook scar information recorded at the PRC for harvested fish provided evidence that anglers often high-grade for larger fish, and that male fish were more likely than females to have hook scars (ODWC unpublished data).

However, implementation of an effective length limit regulation for paddlefish presents some challenges for all but protection of broad groupings of fish (e.g., smaller, immature fish versus the largest adults). Adult paddlefish vary more in girth than length, resulting in a wide range of fish weights having a narrow range of lengths (Scarnecchia et al. 2007, 2011). Relatively minor errors in length measurements could reduce the potential benefits of a length restriction. In addition, completely prohibiting the harvest of the largest fish in the population would be contrary to the harvest motivations of many paddlefish anglers in Oklahoma. Implementation of a harvest slot for harvest management would more closely align with angler motivations in Oklahoma, as they would retain the ability to catch large fish, but would be required to release fish bigger than the slot maximum length (Scarnecchia et al. 1989). Slot harvest regulations are more complex than maximum length; therefore, few states utilize this approach (Hansen and Paukert 2009). Managing harvest with a slot in Oklahoma (either protected slot or harvest slot) would need to align with angler needs and current systems based on trophy fishing.

Mandatory retention of snagged fish during harvest days remains an option if a harvest with an unbalanced sex ratio becomes a problem. Mandatory retention has been used with great effectiveness in Montana and North Dakota where females are much larger than males (Scarnecchia et al. 2007, 2008). The desirable outcomes are a harvest much more representative of age and sex composition of the actual recruited population, as high-grading of older, larger females is avoided. Another major benefit of mandatory retention for fisheries based mainly or completely on migratory adults (such as the Grand lake stock) is that catch of younger recruited males can be used to forecast year class strength ahead of the harvest of the later maturing (and later recruiting) females (Scarnecchia et al. 2008). However, there is less difference between age-specific weights of males and female fish in Oklahoma (Scarnecchia et al. 2013), so that sex ratios in the harvest have remained balanced (approximately 56% male during 2008–2013, range 49%–61%) and the need for mandatory retention is somewhat less beneficial than for more northerly stocks. Mandatory retention also would require anglers catching a fish to stop harvesting fish once their daily or seasonal limit had been met even if they had not caught the size or sex of fish they had sought.

Regardless of the approaches which may eventually be taken, results of this study and previous work (Scarnecchia et al. 2011) indicate that the Grand Lake paddlefish stock suffers from highly variable recruitment and should be actively managed within the resulting population size variations through a combination of harvest regulations serving to limit total and individual angler harvest. Logistically, the implementation of a harvest cap (total allowable catch) and an individual annual harvest limit of two fish (favored for improved harvest management), would require some substantial changes in the paddlefish recreational fishery application and reporting process. The development of an online application system and harvest reporting through an online database or check station should be strongly encouraged or made mandatory. Such a system would not only aid in managing the Grand Lake paddlefish population, but would also provide information on lesser-known populations in the state and their annual harvest could also be monitored in real-time.

More effort needs to be directed toward educating the angling public of the need for careful management of paddlefish as a species prone to overexploitation and as an ancient survivor requiring more attentive and conservative management than other, short-lived, more common game species. Unfortunately, many angler surveys indicated a lack of concern or awareness for paddlefish overharvest: 40% of residents and nonresidents had no strong feelings about paddlefish overharvest and nearly 30% of nonresidents feel that the harvest rates in Oklahoma are within sustainable levels (Crews 2011). As outlined in the Paddlefish Management Plan (Scarnecchia et al. 2013), cornerstones of effective harvest management will include a reliable system of harvest regulation, angler compliance, enforcement, monitoring, angler information, and education.

Acknowledgments

Many people have provided valuable hours and efforts to the Oklahoma paddlefish program. A dedicated group of ODWC employees, interns, volunteers, and recreational anglers have provided important data needed for this paper and for proactive conservation of paddlefish.

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