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Threats to Paddlefish Habitat: Implications for Conservation

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Abstract.—Paddlefish *Polyodon spathula* are large, riverine fishes that occupy extensive home ranges and often migrate long distances in spring to spawn. As a result of these life history characteristics, paddlefish require many habitats to sustain their population over time. Largely as a result of anthropogenic activities, many of the habitats historically used by paddlefish have been altered or destroyed and remaining paddlefish habitats are being threatened by dam construction, channelization and dredging, and altered land use within watersheds. Understanding how habitat alteration may affect paddlefish populations, and identifying threats to current paddlefish habitat, is needed for the management of this species. We review the threats to paddlefish habitats and assess how anthropogenic habitat alterations, such as changes to natural hydrology through the construction of dams and channelization of large rivers or altered land-use patterns leading to increased sedimentation, have affected paddlefish populations. Recent river restoration and conservation measures that help protect and restore paddlefish habitats include fish passage structures and controlled water releases from dams to simulate a more natural hydrograph. New threats such as global climate change may alter paddlefish habitats in the future. Continued efforts to minimize the impact of anthropogenic changes to paddlefish habitats, and measures to restore natural riverine conditions, may help conserve vital habitats for paddlefish populations.

Introduction

Humans have dramatically modified river systems to facilitate navigation, control flooding, and allow for altered land use in riparian habitats. Anthropogenic modifications such as dam construction and channelization have led to changes in the natural hydrology, nutrient loading, and habitat heterogeneity of many large rivers throughout the United States (Wilcove et al. 1998; Ricciardi and Rasmussen 1999; Warren et al. 2000). These changes have often led to population declines of native fish species. As a result, habitat degradation is among the leading causes of population declines for many fishes, including paddlefish *Polyodon spathula*, in the United States (Graham 1997; Jelks et al. 2008).

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Paddlefish were historically found in large rivers throughout the central United States (Stockard 1907), including most of the Mississippi River and adjacent tributaries (Burr 1980; Carlson and Bonislawsky 1981; Gengerke 1986), and they now occupy many large rivers and reservoirs in the same region. Their historical range included 26 states and extended from North Dakota and Montana in the north to the Gulf Coast drainages in Louisiana and Alabama and from the Great Plains states in the west to New York and Pennsylvania in the east (Carlson and Bonislawsky 1981; Gengerke 1986; Jennings and Zigler 2009, this volume). The current paddlefish range has been diminished since the early 20th century largely because of changes to their habitats, and they have been extirpated from four states within their historical range (Gengerke 1986; Graham 1997; Bettoli et al. 2009, this volume). Although populations have remained relatively stable nationwide in the past 20 years, habitat alteration is considered a major threat where declines are still occurring (Bettoli et al. 2009).

Paddlefish are migratory and require a large home range that encompasses many different habitats, and as a result, a variety of habitats may be necessary to conserve or restore paddlefish populations. Juvenile paddlefish are generally found in backwater habitats and oxbow lakes (Hoxmeier and DeVries 1997). In contrast, adult paddlefish overwinter and feed for most of the year in areas with low current velocity, including side channels and backwaters, and adults are rarely found in oxbow lakes (Stockard 1907; Hoxmeier and DeVries 1997). Additionally, in late winter and early spring, adult paddlefish are often found in the main channel as they migrate long distances to reach spawning areas that typically have high current velocity and gravel substrate (Purkett 1961; Paukert and Fisher 2001b; Firehammer and Scarnecchia 2006).

Many of the habitats that paddlefish use throughout their life history have been lost as a result of human alterations to the riverine environment, and this has led to declines in paddlefish populations (Gengerke 1986; Jennings and Zigler 2000; Galat et al. 2005). By constructing dams, channelizing and dredging rivers, and changing land use in riparian habitats, humans have altered the natural flow regime and water chemistry, increased sediment transport, and destroyed habitat needed for paddlefish reproduction. Understanding how habitat alteration may affect paddlefish populations, and identifying threats to current paddlefish habitat, is needed for the management of this species. Additionally, many of the threats facing paddlefish populations also threaten other native riverine fishes so understanding how paddlefish habitat is threatened and restoring degraded habitats will not only benefit paddlefish populations, but may help sustain and preserve populations of many other native fishes.

This chapter will discuss threats to paddlefish habitats as identified by Sparrowe (1986) because these threats are still present today. In addition, we will review the current literature on habitat-related threats to paddlefish to assess how habitat alterations have affected paddlefish populations. Finally, we will identify threats that paddlefish habitats may face in the future and discuss efforts that may help conserve habitats vital to paddlefish populations.

Threats

Dams

Many of the changes to paddlefish habitat have resulted from the construction of dams throughout the rivers. Dams alter water flow, water temperature, and sediment transport and impede fish migrations, and in many cases, these changes have reduced paddlefish reproductive success (Table 1; Ligon et al. 1995; Larinier 2001). Historically,

Table 1. Habitat related threats to paddlefish populations and their possible causes and impacts.

Threat	Risks	Potential impact	Citations
Dams	Physical barrier to spawning migration	Reduced spawning and recruitment success	Northcote 1998; Stancill et al. 2002
Dams; channelization and dredging	Reduction in spawning and recruitment success	Reduced spawning and recruitment success	Allen and Flecker 1993; Paukert and Fisher 2001b; Firehammer and Scarnecchia 2006
	Reduction in spawning and nursery habitats	Reduced spawning and recruitment success	Graham 1997
	Reduction in backwaters and slow-moving habitats	Reduced feeding success; reduced growth	Morris et al. 1968; Russell 1986; Shankman and Drake 1990
Dams; channelization and dredging; riparian land-use changes	Increased sedimentation rates	Increased egg mortality; reduced feeding success; reduction in nursery habitats	Purkett 1961; Muncy et al. 1979; Berkman and Rabeni 1987; Graham 1977
Increased pollutant and contaminant levels	Increased exposure to pollutanats and contaminants	Increased egg and larvae mortality; reduced growth	Allan 2004; Jennings and Zigler 2009

adult paddlefish migrated long distances up river during the spring to spawn. However, dams and other instream barriers (e.g., locks and diversions) now prevent paddlefish from reaching preferred spawning habitats or cause paddlefish to forego reproduction altogether (Russell 1986; Northcote 1998; Stancill et al. 2002). In addition, the creation of reservoirs through dam construction has prevented access to or inundated spawning habitats and reduced backwater and secondary channel habitats that historically served as important feeding and nursery areas (Sparrowe 1986; Graham 1997; Zigler et al. 1999; Jennings and Zigler 2000). Although paddlefish often congregate in the tailwaters created by dams (Jennings and Zigler 2000), these areas may not offer adequate nursery habitat for paddlefish larvae and fry and, therefore, may result in lower reproductive success (Graham 1997).

Dams can also indirectly reduce paddlefish spawning success by decreasing natural flow variation and altering water temperature (Paukert and Fisher 2001b). Paddlefish rely on a narrow range of water temperature, water flow, and photoperiod to cue spawning migrations (Russell 1986; Paukert and Fisher 2001b; Firehammer and Scarnecchia 2006). If any of these conditions are not met, paddlefish may not spawn and females may reabsorb their eggs (Russell 1986). Water releases from dams are often highly regulated; therefore, paddlefish immediately downstream of dams may not experience the needed water flow and temperature fluctuations that historically triggered spawning (Hesse and Mestl 1993). Paddlefish typically time their spawning migrations on an increasing hydrograph (Purkett 1961; Paukert and Fisher 2001b; Miller and Scarnecchia 2008) and altering the hydrograph likely will alter spawning migrations and spawning cues, leading to a reduction in spawning success. By preventing spawning migrations and reducing or eliminating paddlefish spawning habitat, dams have extirpated paddlefish from a number of rivers throughout their historical range (e.g., Gengerke 1986; Graham 1997; Runstrom et al. 2001).

However, paddlefish can thrive in reservoir environments created by dams if the riverine habitats upstream of the reservoirs are accessible and provide suitable spawning habitat (Sparrowe 1986). Access to riverine spawning habitats is considered one of the most important factors in the establishment of reservoir paddlefish populations (Sparrowe 1986). In addition, reservoirs can provide zooplankton-rich areas that have low water velocity suitable for adult paddlefish. As a result, paddlefish typically grow faster in reservoir environments compared to rivers (Paukert and Fisher 2001a). Therefore, construction of reservoirs does not preclude sustainable paddlefish populations if suitable upriver habitats are available.

Channelization and Dredging

River channelization, dredging, and waterway development can also negatively affect paddlefish reproduction and habitat use (Table 1). River channelization can reduce paddlefish habitat by increasing flow and sedimentation loads, which reduce spawning and nursery areas (Allan and Flecker 1993; Graham 1997). Furthermore, most regulated rivers have been modified by both dams and channelization (Nilsson et al. 2005), and as a result, the detrimental effects on spawning and nursery habitats have been amplified (Unkenholz 1986; Graham 1997). Paddlefish traditionally spawn over silt-free gravel in the spring (Purkett 1961). However, increased sedimentation rates have reduced the prevalence of silt-free substrates and may cause paddlefish to spawn in less favorable conditions or forego spawning completely (Unkenholz 1986). Sedimentation could also reduce the hatching success of fertilized eggs. In areas of high sedimentation, eggs may not be able to adhere to hard substrates, leading to lower egg survival (Purkett 1961). Increased sedimentation rates have been shown to decrease the survival of fish embryos for other riverine species (Muncy et al. 1979). While no studies have directly examined the effects of sedimentation on paddlefish eggs or embryos, increased sedimentation may have similar effects on paddlefish offspring.

Channelization has also contributed to a reduction in the distribution and abundance of backwater habitats and secondary channels in rivers where paddlefish are found (Morris et al. 1968; Shankman and Drake 1990; Galat et al. 1998; Ward et al. 1999). Adult and juvenile paddlefish often utilize backwater habitats and oxbow lakes that have low current velocity in many large rivers. For example, Hoxmeier and DeVries (1997) found that adult paddlefish in the Alabama River shifted their habitat use from main river channel habitats in the winter and spring to backwater habitats in the summer and fall, whereas juvenile paddlefish used backwater habitats and oxbows all year. It is likely that adults use main channels in late winter and early spring to migrate to desired spawning habitats while juveniles remain in the oxbow lakes and backwater habitats to feed (Hoxmeier and DeVries 1997). These low-velocity habitats provide higher densities of zooplankton compared to main channel habitats, and it is likely that juvenile paddlefish stay in these areas to exploit the higher food resources (Hoxmeier and DeVries 1997). These results indicate that backwater habitats are important for all paddlefish age-classes, and oxbow lakes may provide nursery habitats for juvenile paddlefish. However, river channelization reduces channel migration, and as a result, new oxbow lakes are no longer being created and existing oxbow lakes are filling in with sediment carried by faster water in channelized reaches (Hoxmeier and DeVries 1997). Because of the reduction of backwater habitats, paddlefish in regulated rivers may use secondary channels (Zigler et al. 1999; Barry et al. 2007) and often congregate behind sandbars, dikes, and eddies below bridge structures and dams (Moen et al. 1992; Hoxmeier and DeVries 1997; Barry et al. 2007), which may not provide the same habitat quality as natural backwaters.

Instream dredging to remove substrate for use in construction materials or to create navigation channels substantially affects fish habitat and may also contribute to paddlefish declines. Instream dredging may increase sedimentation, streambed degradation, and head cutting (Kondolf 1997; Meador and Layer 1998), which destroys fish habitat and alters riverine fish assemblages (Meador and Layer 1998; Padmalal et al. 2008; Paukert et al. 2008). In addition, cutter heads used by dredges may entrain fishes, including paddlefish. Hoover et al. (2009, this volume) used swimming performance models to indicate that paddlefish have a high risk of entrainment if they swim within 1.25 m of the cutter heads, and the authors suggest that smaller diameter pipes may reduce this risk.

Barge traffic that channel dredging facilitates also could negatively affect paddlefish. Telemetry studies have indicated that paddlefish avoid areas within 2 km of barges (Barry et al. 2007). In addition, larval fish may be displaced for up to 90 min after barges move through an area (Holland 1986). Finally, stranding of young river fishes may be caused by the wave action of passing barges. Adams et al. (1999) reported that 38% of paddlefish in a controlled test were stranded during a simulated barge passage.

Land Use

Anthropogenic activities in riparian zones and watersheds may also affect paddlefish habitat (Table 1). Many of the riverine systems with paddlefish have been altered by urbanization and changing land-use practices. In many cases, natural vegetation has been replaced with agriculture or urbanized land (Allan 2004), which can alter runoff volume and rate, increase sediment loads by amplifying bank erosion, and alter water chemistry (Wang et al. 1997, 2001). Aquatic invertebrate and fish communities have also been changed by these land-use practices (Paul and Meyer 2001; Roy et al. 2003; Allan 2004), and these practices may affect paddlefish habitat use and recruitment. Fish eggs and larvae are especially susceptible to increased sedimentation caused by land-use changes, which may smother eggs or prevent them from adhering to clean substrate resulting in high embryo mortality (Muncy et al. 1979; Berkman and Rabeni 1987).

Highly altered watersheds often have large influxes of nonpoint source pollutants from pesticides, herbicides, and other contaminants (Allan 2004) that affect the habitat and water quality of rivers (Muncy et al. 1979; Turner and Rabalais 1991; Pereira and Hostettler 1993). High levels of pollutants can cause egg mortality in large river fish species (Monod 1985; Kime 1995; Rolland 2000), including paddlefish (Jennings and Zigler 2009). Contaminants such as polychlorinated biphenols (PCB), chlordane, and methylmercury have been found in paddlefish flesh or roe (Gundersen and Pearson 1992; Gundersen et al. 1998, 2000; Dasgupta et al. 2004), and may diminish reproductive success (Jennings and Zigler 2009). Although relatively few studies have examined how increased levels of pollutants and higher sedimentation levels directly impact paddlefish, other riverine fish species have experienced population declines that were attributed, in part, to pollution and sedimentation (Gatz and Harig 1994).

Summary and Conservation Efforts

Habitats suitable for paddlefish reproduction, recruitment, growth, feeding, and survival, particularly in large rivers, are being destroyed. Because paddlefish make extensive spawning migrations during spring, long reaches of riverine habitats are needed for sustainable paddlefish populations. However, conserving all habitats necessary for paddlefish populations may be a difficult task. To successfully manage paddlefish habitats, steps may need to be taken to mitigate anthropogenic changes impacting the aquatic ecosystem.

The abundance of dams and diversions throughout the paddlefish range is particularly threatening to paddlefish sustainability. Dams are among the leading causes of habitat destruction and fragmentation and may lead to declines in paddlefish populations because they can hamper spawning migrations, alter sediment transport, decrease paddlefish recruitment, and degrade paddlefish habitat. Subsequently, paddlefish have been extirpated from some rivers as a result of dams (Unkenholz 1986; Lyons 1993; Graham 1997; Runstrom et al. 2001). Although only three states indicated that paddlefish population are currently declining, one of the primary reasons for these declines has remained habitat degradation, which has not changed in the past 30 years (Bettoli et al. 2009).

Adult paddlefish can thrive in reservoirs created by dams, but reservoir stocks need to have access to riverine spawning habitat for adult recruitment to be successful (Russell 1986; Paukert and Fisher 2001b). Efforts to increase spawning habitat upstream of dams could benefit paddlefish populations in reservoirs. In addition, manipulating the discharge from dams may benefit paddlefish spawning in downstream reaches (Elser 1986; Hesse and Mestl 1993; Miller and Scarnecchia 2008). Recent efforts to create shallow water habitat and manipulate flows on the Missouri River to aid in the recovery of pallid sturgeon *Scaphirhynchus albus* (U.S. Fish and Wildlife Service 2003) may also benefit paddlefish populations. Management efforts that seek to link the benefits to paddlefish with benefits for other high-profile species (e.g., endangered species) may be a mechanism to create or restore habitats that would benefit paddlefish and other native riverine species.

Future research may need to examine the effects of altered water quality and increased sedimentation on paddlefish populations. While many studies have shown that increased sedimentation can have negative impacts on paddlefish spawning, none have examined how these changes could impact adult feeding and habitat use or how they would impact larvae and juveniles. Rosen and Hales (1981) indicated that diets of paddlefish in the turbid Missouri River contained up to 50% sand and detritus, suggesting that increased sedimentation may affect paddlefish feeding and diet. Additionally, pollution of large rivers may lead to a reduction in paddlefish growth and condition. Resource managers seeking to protect paddlefish populations may need to consider how pollution caused by habitat alterations (e.g., increased agriculture or urbanization in the watershed) may impact paddlefish reproductive success and other life history characteristics.

Degradation of spawning and nursery habitats is a primary concern for paddlefish conservation. As the number of unregulated rivers with a natural hydrograph dwindles, spawning and migration cues will likely be lost. Additionally, sedimentation in rivers impacted by dams, channelization, and land-use changes will continue to rise and may lead to fewer spawning and nursery habitats for paddlefish. Without efforts to monitor these riverine habitats and restore degraded areas, populations of paddlefish and other native large-river species could continue to decline.

While some progress has been made to improve paddlefish habitats since the threats were originally identified by Sparrowe (1986), some paddlefish populations continue to experience declines in their population size because of habitat degradation (Graham 1997; Bettoli et al. 2009). Many of the threats originally presented by Sparrowe (1986) have not changed. As a result, paddlefish habitat conditions have not greatly improved since 1986 and many paddlefish populations have continued to decline. However, some progress has been made in recent years towards conserving paddlefish habitats. For example, a fish passage structure at the Intake Diversion Dam in the lower Yellowstone River, Montana has been proposed to benefit pallid sturgeon, but paddlefish would likely also benefit (U.S. Department of the Interior 2008). Paddlefish passage through dams has been documented during periods of high flow in the upper Mississippi River, suggesting that dams may not completely block paddlefish migrations (Zigler et al. 2003, 2004). Similarly, during natural and simulated high water events, paddlefish may successfully move upstream through lock structures associated with some dams (Meete et al. 2009, this volume). Efforts to raise water levels and simulate natural flooding events during winter and early spring may cue paddlefish spawning migrations and also allow paddlefish to move through some obstructions such as small lock and dam structures (Meete et al. 2009). As humans continue to engineer riverine ecosystems and develop urban landscapes near riverine environments, paddlefish and other aquatic biota will likely continue to be adversely affected. In order to prevent further declines in paddlefish populations, efforts such as fish passage structures, managed water releases from dams, and increased awareness of how riverine and watershed habitat alterations affect paddlefish populations should be considered to help reduce the impact that future anthropogenic activities may have on paddlefish habitats.

New threats, like global climate change, may exacerbate many of the existing threats to paddlefish and their habitats in coming years. The predicted impacts of global climate change on riverine ecosystems in temperate North America include reduced flows and precipitation, increased frequency of droughts, and more extreme floods (Vorosmarty et al. 2000; Poff et al. 2001; Alcamo et al. 2003). These changes will likely have negative impacts on fish community composition, species diversity, and reproductive success (Poff et al. 2001; Lake 2003). The possibility of these environmental responses to global climate change may need to be considered when biologists and administrators develop long-term strategies to protect paddlefish and their habitats.

Many of the threats to paddlefish habitat are the same threats currently facing other large-river species. River restoration and conservation will benefit many native large-river fishes. Scientists and fisheries managers may need to monitor populations of other native fishes in large rivers and develop an understanding of how these fishes are operating in these human-modified environments. Efforts to protect habitat for all fish species will likely benefit paddlefish populations.

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