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Vulnerability of age-0 pallid sturgeon *Scaphirhynchus albus* to fish predation

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Summary

Stocking is a commonly employed conservation strategy for endangered species such as the pallid sturgeon, *Scaphirhynchus albus*. However, decisions about when, where and at what size pallid sturgeon should be stocked are hindered because vulnerability of pallid sturgeon to fish predation is not known. The objective of this study was to evaluate the vulnerability of age-0 pallid sturgeon to predation by two Missouri River predators under different flow regimes, and in combination with alternative prey. To document vulnerability, age-0 pallid sturgeon (<100 mm) were offered to channel catfish *Ictalurus punctatus* and smallmouth bass *Micropterus dolomieu* in laboratory experiments. Selection of pallid sturgeon by both predators was measured by offering pallid sturgeon and an alternative prey, fathead minnows *Pimephales promelas,* in varying prey densities. Smallmouth bass consumed more age-0 pallid sturgeon (0.95 h^{-1}) than did channel catfish (0.13 h^{-1}), and predation rates did not differ between water velocities supporting sustained (0 m s^{-1}) or prolonged swimming speeds (0.15 m s^{-1}). Neither predator positively selected pallid sturgeon when alternative prey was available. Both predator species consumed more fathead minnows than pallid sturgeon across all prey density combinations. Results indicate that the vulnerability of age-0 pallid sturgeon to predation by channel catfish and smallmouth bass is low, especially in the presence of an alternative fish prey.

Introduction

Sturgeon populations worldwide are experiencing declines in abundance and distribution, with most species listed as endangered, threatened, or vulnerable (Rosenthal et al., 2006). Overfishing, habitat loss, and fragmentation due to dam construction combined with slow population growth rates have led to global reduction of sturgeon stocks (Bemis and Findeis, 1994). Historically, augmenting wild populations via stocking has been one of the methods used to facilitate species recovery (Birstein et al., 1997). The ability to predict survival of stocked individuals is necessary to implement a successful stocking plan, and predation can constitute a large portion of post-stocking mortality (Henderson and Letcher, 2003; Buckmeier et al., 2005). Thus, predation on small fishes may limit the effectiveness of stocking in species recovery plans.

The pallid sturgeon *Scaphirhyncus albus* is a federally endangered species native to the Missouri River and Mississippi River systems (Dryer and Sandvol, 1993). Physical and thermal habitat alterations as well as introduced species have been identified as possible threats to species recovery (Bergman et al., 2008). Moreover, the absence of juvenile fish in the Missouri River suggests that spawning, recruitment, or both are limited (Bergman et al., 2008). Without successful recruitment, pallid sturgeon are in danger of extinction in some parts of the Missouri River by 2016 (Kapuscinski, 2002). Restoration of pallid sturgeon is predicated on annually capturing wild broodstock in Montana, North Dakota, and South Dakota to attain needed gametes for propagation of juveniles at federal and state hatcheries. Remnant, free-flowing reaches of the Missouri River, called 'Recovery Priority Management Areas' (RPMAs), provide the best remaining habitats for stocking hatchery-reared fish and possible recovery of pallid sturgeon (Dryer and Sandvol, 1993). Currently, managers stock hatchery-reared juvenile pallid sturgeon (age = 10–15 months) in remnant riverine sections of the Missouri River (RPMAs 1 – 4) after tagging with passive integrated transponder (PIT) tags and color-coded elastomer marks. This practice necessitates rearing sturgeon to approximately 225 mm fork length (FL) to safely insert PIT tags in the dorsal muscle of each fish. High fish density in the hatchery may increase risk of disease such as iridovirus, thus hatchery space is limited during years of successful broodstock collection and hatch. Stocking early life stages of pallid sturgeon (larvae and age-0 fish) has been proposed to increase the number of fish stocked as well as to alleviate some of the overcrowding issues in hatcheries. This proposal has wide appeal and initial revisions of the pallid sturgeon stocking plan incorporated this recommendation (Upper Basin Pallid Sturgeon Workgroup Stocking Plan Committee [UBPSWG-Stocking Committee], 2004).

Despite the appeal and pragmatic need to stock larval and age-0 pallid sturgeon, the effects of predation on survival of stocked pallid sturgeon have not been examined; however, recent experimental work on white sturgeon suggests that juvenile sturgeon may be vulnerable to predators (Gadomski and Parsley, 2005a,b,c). In the presence of prickly sculpin *Cottus asper,* white sturgeon *Acipenser transmontanus* were consumed in substantially higher numbers than goldfish *Carassius auratus* offered as an alternative prey item (Gadomski and Parsley, 2005a). Juvenile white sturgeon (up to 134 mm TL) were vulnerable to predation by channel catfish *Ictalurus punctatus* and northern pikeminnow *Ptychocheilus oregonensis* (Gadomski and Parsley, 2005b).

Environmental conditions may also influence behavior of juvenile sturgeon, thus affecting their susceptibility to predation. Water velocity, for example, influences swimming behavior and orientation of juvenile pallid sturgeon. Juvenile pallid sturgeon spend less time free swimming in the water column and more time oriented near the bottom as the water velocity increases (Adams et al., 2003). This may increase their exposure to benthic predators at higher water velocities.

Diet studies of Missouri River fishes have not documented predation on larval or juvenile sturgeon (Braaten and Fuller, 2001), although this is not surprising given the lack of natural reproduction and the stocking of larger, juvenile fish (>225 mm). Moreover, partial or complete digestion of food items, such as fish larvae, often precludes positive identification in the diet and necessitates complementary laboratory studies to assess predation risk (Kim and DeVries, 2001).

The lack of information on factors that influence the vulnerability of age-0 pallid sturgeon to predation (e.g. body size, environmental conditions) could hamper restoration efforts if considerable numbers of age-0 fish are lost to predation. Thus, the objective of this study was to evaluate the effects of water velocity and the presence of an alternative prey on the vulnerability of age-0 pallid sturgeon to fish predation. We designed experiments to assess vulnerability of pallid sturgeon to two common Missouri River predators: channel catfish (*Ictalurus punctatus*) and smallmouth bass (*Micropterus dolomieu*).

Materials and methods

Fish source

Channel catfish, obtained from a local aquaculture dealer, are a benthic omnivore occurring in sympatry with pallid sturgeon; historically they likely encountered young pallid sturgeon as potential prey. Smallmouth bass represent a generalist predator and were obtained from local ponds in Brookings County, SD. Smallmouth bass were historically absent from much of the Missouri River, although they co-occur with pallid sturgeon in the Mississippi River. Smallmouth bass have been widely introduced in recent years as a sport fish, and are now abundant in the middle and upper Missouri River. Channel catfish (n = 25, 365–420 mm TL) and smallmouth bass (n = 24, 236–355 mm TL) were housed separately in a 1.5 m^3 circular tank connected to a recirculating water supply; aerated water was filtered through a biofiltration system and maintained at 25–29°C for channel catfish or 20°C for smallmouth bass. Dissolved oxygen, ammonia, and temperature were monitored throughout the acclimation process to ensure that they remained at acceptable levels (DO $>$ 5 ppm, Ammonia $<$ 0.5 ppm). All fish were acclimated for a 14-day period prior to experiments. During acclimation, predators were fed ad libitum rations of fathead minnows and pallid sturgeon to ensure prior experience with both prey types.

Age-0 pallid sturgeon were obtained from the U.S. Fish and Wildlife Service Gavins Point National Fish Hatchery in Yankton, South Dakota in early and late August 2006. Two sizes of pallid sturgeon ranging from 30 to 45 mm (n = 100) and 60 to 100 mm (n = 80) were used in experiments, as sturgeon grew during the experiments and only a single cohort was available. Channel catfish were offered 30–45 mm pallid sturgeon, whereas smallmouth bass were offered 60–100 mm pallid sturgeon. Fathead minnows *Pimephales promelas* (45–60 mm) were obtained from a local bait dealer and used as alternative prey in selectivity experiments.

Influence of water velocity

We used information on swimming performance of juvenile pallid sturgeon (Adams et al., 1999, 2003) to characterize sustained and prolonged swimming speeds (Webb, 1975; Beamish, 1978). Swimming speeds <0.10 m s^{-1} represent sustained speeds where pallid sturgeon rely on aerobic metabolism used in routine activities such as foraging or movement (Adams et al., 1999). Prolonged swimming speeds are of shorter duration (30 s to 200 min), often requiring both aerobic and anerobic metabolism (Adams et al., 1999). In juvenile pallid sturgeon, the amount of time spent free-swimming is significantly higher at sustained speeds than at prolonged swimming speed (Adams et al., 1999, 2003). Thus, we compared predation by channel catfish and smallmouth bass on age-0 pallid sturgeon at two water velocities: 0 m s^{-1} (sustained swimming) and 0.15 m s^{-1} (prolonged swimming; Webb, 1975; Beamish, 1978; Adams et al., 1999). Because the fish used in our experiments were smaller (30–100 mm) than those for which swimming performance data were available (130–205 mm; Adams et al., 1999), we assumed that a water velocity of 0.15 m s^{-1} would result in lower endurance values (minutes) and therefore even shorter durations of free-swimming (Adams et al., 2003). In related studies with gulf sturgeon *Acipenser oxyrinchus desotoi*, Chan et al. (1997) showed that age-0 fish (90 mm) avoided water velocities >0.13 m s^{-1}.

We conducted predation trials in two 3.8 m^3 experimental raceways measuring 9.2 m length × 0.7 m wide × 0.6 m deep. An 8.2 m divider was placed longitudinally in the center of each raceway so that water flow could be maintained in a clockwise direction. In one raceway, the water flow was provided by two water pumps, one on each end of the tank, which maintained constant water velocity around the central divider. Water pumps were housed behind a screened compartment to prevent fish entrainment. In the other raceway, no flow was provided. Six cement cinder blocks were evenly distributed in each experimental raceway to provide cover for predators. Photoperiod (ambient lighting) and water temperature were held constant for each set of experiments with channel catfish (25°C) or smallmouth bass (20°C).

A single smallmouth bass or channel catfish was transferred to an isolated holding chamber on one end of the experimental raceway and allowed to acclimate for 24 h. Eight randomly selected pallid sturgeon were then transferred from a holding tank to the raceway and allowed to acclimate for at least 1 h. To begin a trial, the predator was transferred from the holding chamber to the test arena. Prey consumption was monitored hourly and experiments lasted for 14 h or until 50% of the available prey was consumed. Predation trials using channel catfish were replicated five times per treatment (no flow vs moderate flow) for a total of 10 trials using 7 randomly selected predators; trials using smallmouth bass were replicated six times per treatment for a total of 12 trials using 9 randomly selected predators. All predators were used at least once. Predation rates were calculated as the number of pallid sturgeon consumed per h and compared using a two-way analysis of variance (ANOVA) with water velocity and predator species as the main effects.

Alternative prey

To examine the effects of alternative prey on the predation vulnerability of age-0 pallid sturgeon, we compared predation by channel catfish and smallmouth bass offered both fathead minnows and age-0 pallid sturgeon in large, circular arenas (1.2 m diameter, 0.85 m^3). Prey were transferred to the arenas and allowed to acclimate for 18–24 h. Randomly selected predators (a single smallmouth bass or channel catfish) were then added to each tank and predation trials run for 24 h or until approximately 25% of the total number of prey were consumed. Prey treatments were designed to conserve the total number of prey and offered to predators in one of three ratios of 3 : 9, 6 : 6 or 9 : 3 (fathead minnows : pallid sturgeon). Prey treatments were randomly assigned to each predator and replicated five times for both channel catfish and smallmouth bass predators. We determined the mean number (±95% confidence intervals) of pallid sturgeon and fathead minnows consumed in each treatment. Prey selectivity was estimated by comparing means and confidence intervals for both prey types among the three treatment densities. If confidence intervals overlapped, we concluded that prey selection was similar for both prey types. If the mean and confidence intervals did not overlap we considered selection to be stronger for the prey item most frequently consumed. We were unable to estimate other selection indices (e.g. Chesson, 1983) because fathead minnows were depleted in some of our trials.

Results

Water velocity experiments

Consumption rates differed between predators ($F_{1,21}$ = 5.49, P = 0.03), but were similar at water velocities of 0 and 0.15 m s^{-1} ($F_{1,21}$ = 1.09, P = 0.31), and there was no interaction between predator type and velocity ($F_{1,21}$ = 1.07, P = 0.31). Overall consumption rate was higher for smallmouth bass (0.95 SE = 0.31 fish h^{-1}) than for channel catfish (0.13 SE = 0.04 fish h^{-1}; Table 1).

Alternative prey experiments

Smallmouth bass demonstrated neutral selection for pallid sturgeon in all prey density treatments. Smallmouth bass consistently consumed more fathead minnows than pallid sturgeon across all treatment densities, but the confidence intervals overlapped and we concluded that smallmouth bass did not demonstrate positive selection for pallid sturgeon when alternative prey were available (Fig. 1). Channel catfish demonstrated negative selection for pallid sturgeon when alternative prey were available. No pallid sturgeon were consumed by channel catfish in any of the trials, whereas fathead minnows were consistently consumed (mean for all density treatments = 2.71, SE = 0.44; Fig. 2).

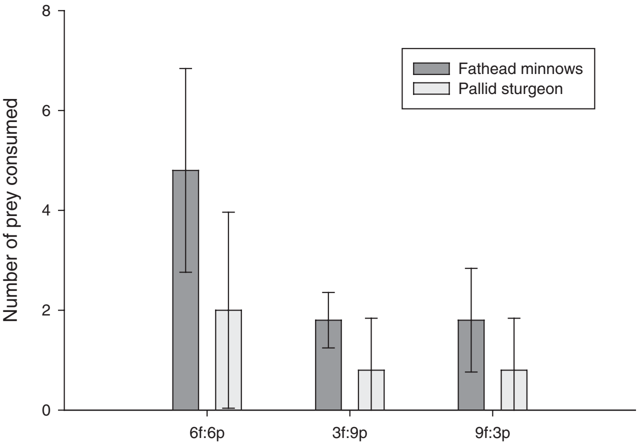

Fig. 1. Mean total number of fathead minnows and pallid sturgeon consumed by smallmouth bass by treatment ratios (fathead minnow : pallid sturgeon) with 95% confidence intervals. N = 5 replicates per treatment, for 15 total trials

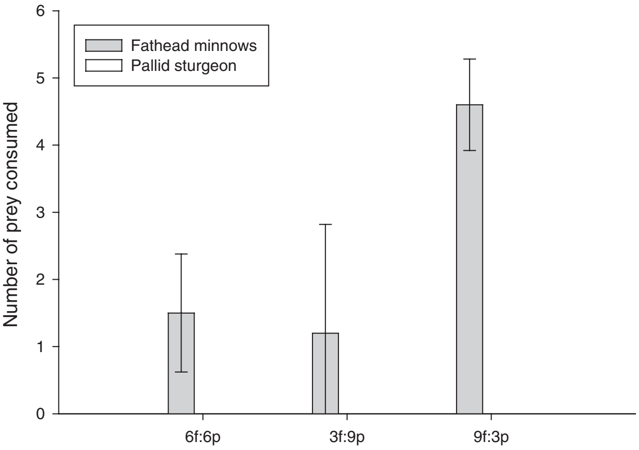

Fig. 2. Mean total number of fathead minnows and pallid sturgeon consumed by channel catfish by treatment ratios (fathead minnow : pallid sturgeon) with 95% confidence intervals. N = 5 replicates per treatment for 15 total trials

Discussion

Water velocity can influence foraging success among piscivorous fishes owing to increased foraging activity (i.e. low flow), increased encounters with prey (i.e. high flow) and ⁄ or changes in prey behavior at different water velocities (0.20–0.40 m s^{-1} Blanchet et al., 2008; 5–40 m^3 s^{-1}; Murchie and Smokorowski, 2004). At water velocities greater than sustained swimming speeds (approximately 0.10 m s^{-1}), juvenile pallid sturgeon spend proportionally more time maintaining position near the bottom (Adams et al., 2003). In predation trials at 0.15 m s^{-1}, pallid sturgeon were often observed maintaining position either near the bottom of the tanks or swimming along the bottom with the current. In the absence of water flow, pallid sturgeon appeared to use more of the water column and swam in a variety of directions along the bottom of the tank. Although not quantified in this study, these behaviors are consistent with those reported by Adams et al. (2003). Nonetheless, we found no differences in predation rates by smallmouth bass or channel catfish at water velocities supporting sustained or prolonged swimming speeds in juvenile pallid

Table 1
Mean consumption rate by two predators on age-0 pallid sturgeon under different flow rates. Pallid sturgeon size and sample size differed among predators. Standard error in parentheses

Predator species	Water velocity (m s^{-1})	Sample size	Mean pallid sturgeon FL (mm)	Prey consumption rate (No. h^{-1})
Channel catfish	0	5	36 (0.89)	0.13 (0.05)
	0.15	5	36 (0.89)	0.14 (0.06)
Smallmouth bass	0	6	83 (2.38)	0.60 (0.35)
	0.15	6	83 (2.38)	1.30 (0.51)

sturgeon. It is possible that juvenile pallid sturgeon would become more vulnerable to predation at higher water velocities because swimming endurance decreases rapidly with water velocity. At swimming speeds of 0.15, 0.20, or 0.30 $m\ s^{-1}$, endurance for juvenile pallid sturgeon (130–160 mm) averaged 20, 10 and 2 min, respectively (Adams et al., 1999). For the smaller pallid sturgeon (30–45 mm) used in the catfish predation trials, endurance would likely be much less at a water velocity of 0.15 $m\ s^{-1}$, yet predation by channel catfish was similar to that measured at 0 $m\ s^{-1}$.

The negative selection by channel catfish for pallid sturgeon was unexpected because Gadomski and Parsley (2005a) showed that juvenile white sturgeon up to 130 mm TL were vulnerable to predation by this predator. Pallid sturgeon in our experiment were within the size range (30–45 mm) in which Gadomski and Parsley (2005a) found white sturgeon to be highly vulnerable to channel catfish. Moreover, we documented consumption of pallid sturgeon by channel catfish during the water velocity experiments with no alternative prey (similar conditions as Gadomski and Parsley, 2005a). We suspect that negative selection of pallid sturgeon by channel catfish was due to the presence of fathead minnow as an alternative prey. When channel catfish were offered a choice of pallid sturgeon or fathead minnows, they consistently avoided pallid sturgeon. Thus, the presence of an alternative prey should reduce the vulnerability of pallid sturgeon to predation by channel catfish.

Smallmouth bass demonstrated neutral selection for pallid sturgeon when alternative prey were available. Pallid sturgeon (relative length 27–42% body length) offered to smallmouth bass were larger (60–100 mm) than those offered to channel catfish, but were still well below the maximum relative length (56% body length) for prey selected by smallmouth bass in other studies (Fritts and Pearsons, 2006). Our results are typical for a generalist predator such as smallmouth bass, which display a flexible and varied diet and are able to take advantage of seasonal changes in prey availability (Zimmerman, 1999). Our results suggest that smallmouth bass will not positively select juvenile pallid sturgeon, but rather may opportunistically prey on pallid sturgeon when encountered.

Predation risk for age-0 pallid sturgeon by channel catfish and smallmouth bass is low, especially when alternative prey is available. Further research is needed to fully understand predation vulnerability of pallid sturgeon. Predation vulnerability of pallid sturgeon should be evaluated with other predators, particularly obligate piscivores such as walleye and flathead catfish. Moreover, there is still much we do not understand about factors that may influence predation on young sturgeon. While water velocity does not appear to influence pallid sturgeon predation vulnerability, other factors such as turbidity may play an important role. Larval pallid sturgeon have been documented to undergo a significant downstream migration (12–13 days, Kynard et al., 2002), which could allow larvae hatched in turbid remnant riverine sections of the river to enter reservoirs with lower turbidity levels. If turbidity plays an important role in reducing predation risk of small sturgeon, altered turbidity regimes in the upper Missouri River may affect the recruitment of young pallid sturgeon. Sturgeon size and predator species may also play an important role in predation on age-0 sturgeon. Predation on early life stage sturgeon is not well documented, but it is likely that sturgeon become less vulnerable to predation as they grow and are better able to avoid predators. We believe that future research should investigate the potential impacts of these factors as well as expand the suite of predator types that may prey on age-0 sturgeon.

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