Notes
What Environmental Conditions Reduce Predation Vulnerability for Juvenile Colorado River Native Fishes?

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Abstract

The incompatibility of native Colorado River fishes and nonnative warm-water sport fishes is well documented, with predation by nonnative species causing rapid declines and even extirpation of native species in most locations. In a few rare instances, native fishes can survive and recruit despite the presence of nonnative warm-water predators, indicating that specific environmental conditions may help reduce predation vulnerability. We experimented with turbidity, artificial blue water colorant (artificial turbidity pond treatment), woody debris, rocks, and aquatic vegetation in a laboratory setting to determine whether any of these types of cover could reduce predation vulnerability and confer survival advantages for juvenile Bonytail *Gila elegans* (mean = 70 mm total length), Roundtail Chub *Gila robusta* (mean = 35 mm total length), Humpback Chub *Gila cypha* (mean = 67 mm total length), and Razorback Sucker *Xyrauchen texanus* (mean = 74 mm total length). We exposed selected species of juvenile native fishes to predation by adult Largemouth Bass *Micropterus salmoides*, Smallmouth Bass *Micropterus dolomieu*, Green Sunfish *Lepomis cyanellus*, Flathead Catfish *Pylodictis olivaris*, and Black Bullhead *Ameiurus melas* in overnight trials. Razorback Suckers served as prey in trials conducted with Largemouth Bass and Black Bullhead. Bonytail served as prey in trials conducted with Largemouth Bass and Flathead Catfish. Roundtail Chub served as prey in trials conducted with Smallmouth Bass and Green Sunfish. We matched sizes of predator and prey so that the maximum body depth of the prey never exceeded 40% of the maximum anatomical gape of the predators. Turbidity of 500 nephelometric turbidity units reduced effectiveness of sight-feeding predators such as Largemouth Bass, Smallmouth Bass, and Green Sunfish by up to 50% but also increased predation vulnerability to non–sight-feeding predators (Flathead Catfish and Black Bullhead) by up to 55%. Turbidity was the only treatment that significantly altered predation mortality of native fish. These results may help explain recent patterns of wild juvenile native fish recruitment to adult life stages at the Colorado River inflow to Lake Mead and at the inflow of the San Juan River into Lake Powell. Both areas possess abundant introduced predatory fishes but are also very turbid.

Keywords: *Gila cypha*; *Gila elegans*; *Gila robusta*; predation; turbidity; *Xyrauchen texanus*

Received: April 9, 2018; Accepted: September 25, 2018; Published Online Early: December 2018; Published: June 2019

Citation: Ward DL, Vaage BM. 2019. What environmental conditions reduce predation vulnerability for juvenile Colorado River native fishes? *Journal of Fish and Wildlife Management* 10(1):196–205; e1944-687X. https://doi.org/10.3996/042018-JFWM-031

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Introduction

The decline of native fishes in the southwestern United States is largely attributed to negative interactions with introduced predatory fishes. Although human alteration of waterways has also played a role, the largest single factor contributing to native fish declines is believed to be introduced aquatic species (Clarkson et al. 2005; Minckley and Marsh 2009). Warm-water predatory fishes dominate most aquatic systems in the desert southwest. Once established, these introduced predatory fishes prey upon native fishes, typically
causing rapid disappearance of native fish populations (Moyle et al. 1986; Mueller 2005). The incompatibility of native fish and warm-water sport fish (Marsh and Pacey 2005) is true in most cases, but not always. In a few rare instances native fishes can survive and recruit to adult life stages despite the presence of nonnative warm-water fishes. Specific environmental conditions may reduce predation vulnerability in these locations and allow native species to survive. One example of this is near the Colorado River and Razorback Suckers Xyrauchen texanus appear to be recruiting in the presence of robust populations of introduced warm-water fishes (Albright et al. 2010; Van Haverbeke et al. 2017; Rogowski et al. 2018). The same pattern of recruitment in juvenile native suckers has also been documented in the San Juan River inflow of Lake Powell (Albright et al. 2017). Another example is the Little Colorado River in Grand Canyon where juvenile Humpback Chub persists despite the influx of introduced predators (Stone et al. 2018). The observation of native fish recruitment led us to question what specific environmental conditions were present in these areas that might reduce predation vulnerability for native fish. In these locations, turbidity is often high. At reservoir inflows submerged brush or other aquatic vegetation are often present. In canyon-bound areas, rocky talus slopes are common. All of these environmental features may provide cover for juvenile fish. We chose these specific types of cover—turbidity, submerged brush, aquatic vegetation, and rocks—for experimentation in the laboratory because they are commonly associated with providing cover for juvenile fish and they are abundant in these natural environments where juvenile native Colorado River fishes appear to recruit (Van Haverbeke et al. 2017). Johnson and Hines (1999) reported that in a laboratory setting, Razorback Suckers effectively avoided predation by Green Sunfish Lepomis cyanellus as turbidity increased, and Ward et al. (2016) demonstrated that an increase in turbidity from clear to 150 nephelometric turbidity units (NTUs) resulted in a more than fourfold increase in juvenile chub survival, when exposed to predation by Rainbow Trout Oncorhynchus mykiss and Brown Trout Salmo trutta. This information on turbidity caused us to include blue pond dye in our experimental treatments to evaluate the effects of other nonsediment forms of turbidity on predation relationships. We conducted replicated overnight predation trials in the laboratory to quantify how each of these different environmental characteristics impact predation vulnerability of Colorado River native fishes to introduced warm-water predators.

Methods

We conducted laboratory trials in a temperature-controlled greenhouse at the U.S. Fish and Wildlife Service (USFWS) Horse Thief Canyon Native Fish Facility in Fruita, Colorado. We obtained juvenile Roundtail Chub Gila robusta and Razorback Sucker from the Arizona Game and Fish Department, Aquatic Research and Conservation Center located in Cornville, Arizona. We sorted all native fish by size and held them in indoor holding tanks at 20°C until predation trials began. We collected Largemouth Bass Micropterus salmoides, Smallmouth Bass Micropterus dolomieu, Green Sunfish, Black Bullhead Amiurus melas, and Flathead Catfish Pylodictis olivaris from the Verde and Colorado rivers in Arizona by using standard electrofishing techniques (Persons et al. 2013). We also held predators in indoor holding tanks at 20°C and fed live Fathead Minnows Pimephales promelas for at least 30 days before trials, with food withheld 48 h before predation trials began.

We conducted predation trials in replicate 150-gallon (568-L) fiberglass tanks that measured 1.2 m long by 0.9 m wide, with a water depth of 30.5 cm. Each tank held a single fiberglass hoop (41.3 × 30.5 × 29.2 cm) in the middle that provided a small area for fish to hide. A magnetic drive pump (2,650 L/h) and air stone in each tank provided water circulation and aeration, and we covered each tank with 6.35-mm netting to prevent fish from escaping (Figure 1). We set greenhouse temperatures so that water temperatures in all tanks were 20 ± 1°C, a temperature range that is within the thermal optimum for all predators and prey species used in this study (Bulkley et al. 1981; Kappenman et al. 2012) and that is representative of water temperatures commonly found within the Colorado River near the inflow to Lake Mead. We added Amquel® Plus ammonia remover (Kordon, Hayward, CA) to each tank at the beginning of each trial to keep ammonia and nitrite levels low during the experiments and to prevent adverse effects on fish behavior that could impact predation results. Treatments consisted of a tank with no additional cover except for the standard fiberglass hoop (control); a tank with natural clay collected from the Paria River, Arizona, mixed with water to create a turbidity of 500 NTUs (500 NTU = a Secchi depth of 70 mm by using this Paria River clay) as measured with a Hach® 201 turbidimeter (Loveland, CO); a tank with blue commercial pond dye (Blue Vail™; Valox Ltd., Fredericton, New Brunswick, Canada) added at twice the label dosage for typical control of aquatic vegetation; a tank containing woody brush (one-half of a 2-m-tall Christmas tree [Douglas fir Pseudotsuga menziesii] whose needles had fallen off); a tank with a stack of river rocks added (average diameter of 120 mm, a full 19-L bucket); and a tank containing aquatic floating aquatic vegetation (Ceratophyllum demersum) collected from a local pond (19-L bucket filled loosely; Figure 2). We chose these specific types of cover, except for the artificial colorant, because they are similar to those encountered in natural environments where native Colorado River fishes reside. We used the blue pond dye to evaluate effects of nonsediment forms of turbidity and doubled the dosage so that if there was an effect on predation relationships, it would be more apparent.
At the beginning of each trial, we placed four introduced predators of the same species into each tank and 12 native fish of the same species of a presorted size (29–99 mm total length) into a cylindrical mesh basket within each tank (Table 1). We allowed all fish to recover from capture and handling and acclimate to the predation tanks for a period of 24 h. Following this acclimation period, we carefully released native juvenile fish into the tank, thereby initiating the predation experiment. We left tanks undisturbed for 24 h under natural light after which we drained the water in each tank and captured all surviving fish. We then counted the fish and measured the total length of each fish to the nearest millimeter. Experiments typically began between 0800 and 1000 hours.

We conducted 126 individual overnight trials using 504 adult sport fish (72 of each species) and 1,512 juvenile native fish (Razorback Suckers, Bonytail, Humpback Chub, and Roundtail Chub) as prey (Table 1). The limited number of endangered Chubs of any one species available for predation trials necessitated the use of multiple Chub species. Bonytail, Humpback Chub, and Roundtail Chub are all morphologically very similar at small sizes (Douglas et al. 1989), exhibit the same predation avoidance behaviors (Ward and Figiel 2013), and inhabit similar environments (Karp and Tyus 1990; Bestgen et al. 2008), especially as juveniles. Bonytail, Humpback Chub, and Roundtail Chub are commonly used as surrogates for each other in laboratory trials because of the limited availability of research specimens (Hansen et al. 2006; Ward 2012; Ward et al. 2016).

Size of predator and prey is known to affect predation vulnerability, with larger predators more effectively feeding on prey and larger prey being less vulnerable to predation (Ward and Morton-Starner 2015). In our laboratory trials, we maintained size ratios of predator and prey below published ranges for maximum size of predators and prey.

![Figure 1](https://example.com/figure1.jpg) **Figure 1.** Photo of replicated experimental tanks in a temperature-controlled greenhouse in Flagstaff, Arizona, used in 2017 to evaluate predation vulnerability of juvenile native fishes to introduced warm-water sportfish in overnight trials. Round baskets containing prey fish are removed following an acclimation period. Netting prevents fish from jumping out of the treatment tanks (photo credit D. Ward, U.S. Geological Survey).

![Figure 2](https://example.com/figure2.jpg) **Figure 2.** Photo of six treatments used in 2017 to evaluate the effects of environmental characteristics on vulnerability of native fish to introduced warm-water predators. Treatments included (A) control tank, (B) turbidity (500 nephelometric turbidity units), (C) blue commercial pond colorant, (D) woody debris, (E) rocks, and (F) floating aquatic vegetation (photo credit D. Ward, U.S. Geological Survey).
ingested prey by species (Slaughter and Jacobson 2008; Gaeta et al. 2018). We did not standardize the sizes of predators and prey across trials, so comparisons of predator effectiveness as a means of assessing risk of each predator species are not effectively evaluated with these data. We used analysis of variance (ANOVA) to evaluate differences in mean number of native fish surviving predation by a given predator species under each replicated set of six environmental conditions. Data generated during this study are available from the U.S. Geological Survey’s ScienceBase-Catalog (Ward 2018; see Supplemental Material, Data S1).

### Results

Turbidity above 500 NTUs significantly reduced predation vulnerability of Bonytail (ANOVA: $F_{5,12} = 6.78; P = 0.0026$) and Razorback Sucker to Largemouth Bass (ANOVA: $F_{5,12} = 6.78; P = 0.0044$), Roundtail Chub to Smallmouth Bass (ANOVA: $F_{5,12} = 10.00; P = 0.006$), and Roundtail Chub to Green Sunfish (ANOVA: $F_{5,12} = 3.61; P = 0.0287$; Figure 3). This represents a 58, 42, and 15% increase in survival, respectively, compared to predation vulnerability in clear water. In contrast, high turbidity significantly increased vulnerability of Bonytail and Humpback Chub to predation by Flathead Catfish (ANOVA: $F_{5,12} = 3.14; P = 0.048$) and Black Bullhead

### Table 1.

Total length (mm) and range of predators and prey and the number of replicates conducted in laboratory experiments conducted in 2017 to evaluate how environmental conditions effect predation vulnerability of Colorado River native fishes to introduced predators.

| Treatment     | Predator               | Prey                   | No. of replicates | Predator total length (mm), mean (range) | Prey total length (mm), mean (range) |
|---------------|------------------------|------------------------|-------------------|------------------------------------------|--------------------------------------|
| Clear Largemouth Bass | Micropterus salmoides   | Bonytail Gila elegans  | 3                 | 180 (162–192) 73 (55–85)                |                                      |
| Turbid Largemouth Bass | Micropterus salmoides   | Bonytail Gila elegans  | 3                 | 183 (157–196) 74 (59–85)                |                                      |
| Colorant Largemouth Bass | Micropterus salmoides | Bonytail Gila elegans  | 3                 | 176 (165–192) 74 (62–87)                |                                      |
| Rocks Largemouth Bass | Micropterus salmoides  | Bonytail Gila elegans  | 3                 | 174 (167–183) 73 (61–87)                |                                      |
| Weeds Largemouth Bass | Micropterus salmoides   | Bonytail Gila elegans  | 3                 | 182 (170–195) 71 (55–83)                |                                      |
| Trees Largemouth Bass | Micropterus salmoides  | Bonytail Gila elegans  | 3                 | 181 (169–196) 70 (57–83)                |                                      |
| Clear Largemouth Bass | Xyrauchen texanus      | Razorback Sucker       | 3                 | 329 (245–354) 81 (71–99)                |                                      |
| Turbid Largemouth Bass | Xyrauchen texanus      | Razorback Sucker       | 3                 | 336 (245–377) 81 (69–95)                |                                      |
| Colorant Largemouth Bass | Xyrauchen texanus        | Razorback Sucker       | 3                 | 327 (245–375) 81 (71–90)                |                                      |
| Rocks Largemouth Bass | Xyrauchen texanus      | Razorback Sucker       | 3                 | 310 (230–345) 80 (70–90)                |                                      |
| Weeds Largemouth Bass | Xyrauchen texanus      | Razorback Sucker       | 3                 | 318 (242–370) 83 (69–98)                |                                      |
| Trees Largemouth Bass | Xyrauchen texanus      | Razorback Sucker       | 3                 | 347 (315–370) 81 (72–99)                |                                      |
| Clear Smallmouth Bass | Micropterus dolomieu    | Roundtail Chub Gila Robusta | 3             | 144 (121–166) 36 (32–41)                |                                      |
| Turbid Smallmouth Bass | Micropterus dolomieu    | Roundtail Chub Gila Robusta | 3             | 142 (125–167) 38 (30–39)                |                                      |
| Colorant Smallmouth Bass | Micropterus dolomieu | Roundtail Chub Gila Robusta | 3             | 137 (110–155) 37 (32–42)                |                                      |
| Rocks Smallmouth Bass | Micropterus dolomieu    | Roundtail Chub Gila Robusta | 3             | 136 (125–150) 36 (31–42)                |                                      |
| Weeds Smallmouth Bass | Micropterus dolomieu    | Roundtail Chub Gila Robusta | 3             | 141 (125–153) 36 (32–43)                |                                      |
| Trees Smallmouth Bass | Micropterus dolomieu    | Roundtail Chub Gila Robusta | 3             | 136 (117–153) 37 (32–42)                |                                      |
| Clear Green Sunfish | Lepomis cyanellus       | Roundtail Chub Gila Robusta | 3             | 150 (132–184) 32 (29–39)                |                                      |
| Turbid Green Sunfish | Lepomis cyanellus       | Roundtail Chub Gila Robusta | 3             | 143 (126–162) 33 (29–38)                |                                      |
| Colorant Green Sunfish | Lepomis cyanellus       | Roundtail Chub Gila Robusta | 3             | 143 (128–184) 32 (29–39)                |                                      |
| Rocks Green Sunfish | Lepomis cyanellus       | Roundtail Chub Gila Robusta | 3             | 147 (128–170) 32 (29–37)                |                                      |
| Weeds Green Sunfish | Lepomis cyanellus       | Roundtail Chub Gila Robusta | 3             | 140 (126–182) 32 (28–36)                |                                      |
| Trees Green Sunfish | Lepomis cyanellus       | Roundtail Chub Gila Robusta | 3             | 140 (121–165) 32 (29–37)                |                                      |
| Clear Flathead Catfish | Pylodictis olivaris     | Bonytail Gila elegans  | 3                 | 303 (244–352) 75 (68–81)                |                                      |
| Turbid Flathead Catfish | Pylodictis olivaris     | Bonytail Gila elegans  | 3                 | 309 (263–385) 75 (68–81)                |                                      |
| Colorant Flathead Catfish | Pylodictis olivaris    | Bonytail Gila elegans  | 3                 | 316 (264–352) 75 (69–81)                |                                      |
| Rocks Flathead Catfish | Pylodictis olivaris     | Bonytail Gila elegans  | 3                 | 311 (264–350) 75 (68–82)                |                                      |
| Weeds Flathead Catfish | Pylodictis olivaris     | Bonytail Gila elegans  | 3                 | 300 (244–345) 76 (70–81)                |                                      |
| Trees Flathead Catfish | Pylodictis olivaris     | Bonytail Gila elegans  | 3                 | 313 (263–350) 75 (69–81)                |                                      |
| Clear Black Bullhead | Ameiurus melas          | Humpback Chub Gila cypha | 3             | 191 (177–213) 67 (60–71)                |                                      |
| Turbid Black Bullhead | Ameiurus melas          | Humpback Chub Gila cypha | 3             | 193 (174–223) 67 (60–71)                |                                      |
| Colorant Black Bullhead | Ameiurus melas          | Humpback Chub Gila cypha | 3             | 198 (180–225) 67 (60–71)                |                                      |
| Rocks Black Bullhead | Ameiurus melas          | Humpback Chub Gila cypha | 3             | 189 (174–223) 66 (60–71)                |                                      |
| Weeds Black Bullhead | Ameiurus melas          | Humpback Chub Gila cypha | 3             | 195 (175–220) 66 (60–70)                |                                      |
| Trees Black Bullhead | Ameiurus melas          | Humpback Chub Gila cypha | 3             | 198 (177–227) 66 (60–70)                |                                      |
| Clear Black Bullhead | Gila cypha              | Roundtail Chub         | 3                 | 251 (234–274) 30 (22–36)                |                                      |
| Turbid Black Bullhead | Gila cypha              | Roundtail Chub         | 3                 | 254 (241–276) 30 (24–35)                |                                      |
| Colorant Black Bullhead | Gila cypha              | Roundtail Chub         | 3                 | 253 (231–278) 29 (20–35)                |                                      |
| Rocks Black Bullhead | Gila cypha              | Roundtail Chub         | 3                 | 251 (234–276) 30 (25–35)                |                                      |
| Weeds Black Bullhead | Gila cypha              | Roundtail Chub         | 3                 | 253 (220–280) 29 (23–34)                |                                      |
| Trees Black Bullhead | Gila cypha              | Roundtail Chub         | 3                 | 252 (222–273) 29 (20–35)                |                                      |
ANOVA: \( F_{5,12} = 4.612; P = 0.014 \). For Razorback Sucker predation by Black Bullhead, we did not note a significant increase at high turbidity (ANOVA: \( F_{5,12} = 0.552; P = 0.732 \); Figure 4), although a similar pattern of increased vulnerability to predation in turbid water was apparent. This represents a 55, 44, and 8% decrease in survival, respectively, compared to predation vulnerability in clear water. No other treatment significantly increased or decreased predation vulnerability compared to clear water conditions. Prey size (total length) as a percentage of predator total length ranged from 12 to 40%.

**Discussion**

High turbidity was the only environmental factor we tested that consistently altered survival of juvenile native fish to multiple predator species. Turbidity levels of 500 NTUs increased survival of Bonytail, Razorback Sucker, and Roundtail Chub when preyed upon by sight-feeding predators such as Largemouth Bass, Smallmouth Bass, and Green Sunfish, but high turbidity increased predation vulnerability of Bonytail, Humpback Chub, and Razorback Sucker when the predator was a Black Bullhead or Flathead Catfish, which do not rely on sight to feed. Turbidity is known to negatively influence the visual feeding ability of adult piscivorous fishes in both freshwater (Utne-Palm 2002; Ran˚aker et al. 2012) and saltwater environments (Johansen and Jones 2013). Dyes are commonly used in pond management to control aquatic vegetation, but did not confer survival advantages for native fish in our study, indicating that not all forms of turbidity are equal. Jönsson et al. (2013) found that turbidity caused by humic water also does not convey the same level of visual degradation for predators as turbidity from other sources. It therefore appears unlikely that commercially sold pond dye could be used as a management tool to reduce predation vulnerability of native fishes.
Fish are physiologically adapted to their environment and anthropogenic changes to those environments have consequences for species survival. Closure of Glen Canyon Dam in 1963 resulted in significant changes to the physical environment of the Colorado River in Grand Canyon (Sabo et al. 2012), including reduced turbidity (Voichick and Topping 2014). On average, the turbidity of the Colorado River in Grand Canyon at Phantom Ranch (river kilometer 140) is now less than 24 formazin nephelometric units (Voichick and Topping 2014). By contrast, the predam Colorado River at the same location had an average turbidity greater than 907 formazin nephelometric units and almost always exceeded 250 formazin nephelometric units (Voichick and Topping 2014). These changes in water clarity, along with the addition of introduced sight-feeding predators, have had dramatic impacts on the fish populations inhabiting the Colorado River (Mueller and Marsh 2002; Marsh and Pacey 2005).

When a novel fish predator is introduced into an aquatic system, extirpation of the native fish typically occurs if the range of the new predator and prey overlap completely and if native prey do not possess physiological, morphological, or behavioral attributes that in combination with specific environmental features allow some individuals to avoid predation (Matter and Mannan 2005). At the inflows of Lake Powell and Lake Mead, the specific habitat feature of high turbidity may be allowing juvenile Razorback Suckers and Humpback Chub to recruit in those respective locations despite a robust population of introduced warm-water predators (Albrecht et al. 2010, 2017; Van Haverbeke et al. 2017). The combination of elevated turbidity at these river inflows (Figure 5), which decreases predation vulnerability to sight feeding predators, and the current lack of Flathead Catfish in those reservoirs, may be responsible for recent patterns of juvenile Razorback Sucker recruitment at these locations, although other catfish species such as Channel Catfish *Ictalurus punctatus*, Black Bullhead *Ameiurus melas*, and Black Bullhead *Ameiurus* have been recorded in the Colorado River at various locations.

![Graphs showing predation rates](image-url)

**Figure 4.** Number of juvenile native fish—Bonytail *Gila elegans*, Humpack Chub *Gila cypha*, and Razorback Sucker *Xyrauchen texanus*—that survived predation by non–sight-feeding predators to include Black Bullhead *Ameiurus melas* (A and B) and Flathead Catfish *Pylodictis olivaris* (C) during 24-h laboratory predation trials conducted in 2017 under six different environmental conditions (clear = control). Each point is the mean of three replicate trials. Error bars represent 95% confidence intervals. Asterisks denote statistically significant differences.
Catfish *Ameiurus melas*, and Yellow Bullhead Catfish *Ameiurus natalis* are present.

In general, animals have evolved to respond in specific ways to threats (Griffin et al. 2000), and the ability of prey to show appropriate and effective antipredator responses may be more important than detecting the threat itself (Rehage et al. 2009). For example, Razorback Suckers and June Suckers *Chasmistes liorus* avoid detection by sitting motionless on the bottom and reducing movement (Ward and Figiel 2013; Kraft 2009). Reduced activity in response to a threat may be beneficial for avoiding detection by sight-feeding predators, especially in turbid water, but this same behavior may not confer an advantage to avoid Catfish, which possess specialized adaptations for finding and capturing prey in low-visibility environments. This may be why Razorback Suckers in our trials showed high vulnerability to Black Bullhead Catfish in all treatments, with no significant reduction in predation vulnerability in in turbid water (Figure 4). There are no Catfish species native to the Colorado River (Minckley and Marsh 2009); hence, Colorado River native fishes did not evolve mechanisms to avoid this type of predator. Channel Catfish and Flathead Catfish prevented the establishment of Razorback Suckers stocked into the Gila River, Arizona (Marsh and Brooks 1989). There are likely some combinations of native prey and nonnative predator that may not be compatible. Although more than 200,000 Razorback Suckers have been reared in captivity and repatriated to Lake Mohave, the repatriate population has dwindled to a few thousand fish and the wild population is now functionally extinct (Schooley and Marsh 2007; Marsh et al. 2015). Information about the unique adaptations and behaviors that native fish possess to avoid predation may help in evaluating the survival potential of native fish in the face of novel predators and novel environmental conditions.

Conservation of imperiled native fishes requires an understanding of the ecological and evolutionary processes that have shaped predator–prey interactions and how those interactions are mediated by specific environmental factors. When predation is a limiting factor, management actions designed to prevent extinction of native fishes often need to include elements of maintaining or enhancing features of habitat that reduce predation vulnerability (Matter and Mannan 2005). Our results indicate turbidity may be one such environmental condition that can reduce vulnerability of native fishes to specific sight-feeding predators. Evidence of recruitment of endangered native fishes at inflows of Lake Powell and Lake Mead appear to support our laboratory findings, but predation rates in natural systems under varied environmental conditions still need to be quantified to fully assess potential impacts of introduced predators on native species. Predation of juvenile Humpback Chub by Rainbow Trout in Grand Canyon increased under turbid conditions (Yard et al. 2011; Yackulic et al. 2018), indicating that in natural systems factors other than turbidity can also control predation dynamics. Recovery and long-term survival of endangered Colorado River fishes may depend on management of specific sections to maintain features of the predam river, such as elevated turbidity to reduce predation vulnerability of native fish to introduced sight-feeding predators, while also continuing to exclude particularly harmful nonsight-feeding predators such as Flathead Catfish.

### Supplemental Material

Please note: The *Journal of Fish and Wildlife Management* is not responsible for the content or functionality of any supplemental material. Queries should be directed to the corresponding author for the article.

**Reference S1.** Bulkley RV, Berry CR, Pimentel R, Black T. 1981. Tolerance and preferences of Colorado River endangered fishes to selected habitat parameters. Logan: U.S. Fish and Wildlife Service, Utah Cooperative Fisheries Research Unit, Utah State University, Completion Report, Contract 14-16-0018-1061 A-2.

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Found at DOI: [https://doi.org/10.3996/042018-JFWM-031.S2](https://doi.org/10.3996/042018-JFWM-031.S2) (889 KB PDF); also available at [http://www.fwspubs.org/doi/suppl/10.3996/092012-JFWM-084/suppl_file/10.3996_092012-jfwm-084.s1.pdf?code=ufwssite](http://www.fwspubs.org/doi/suppl/10.3996/092012-JFWM-084/suppl_file/10.3996_092012-jfwm-084.s1.pdf?code=ufwssite).

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Found at DOI: https://doi.org/10.3996/042018-JFWM-031.55 (2.2 MB PDF); also available at https://pubs.usgs.gov/tm/tm2a12/tm2a12.pdf.

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Found at DOI: https://doi.org/10.3996/042018-JFWM-031.56 (1.93 MB PDF); also available at http://pubs.usgs.gov/sir/2014/5097/pdf/sir2014-5097.pdf.

Data S1. Raw data used to compare predation vulnerability of Colorado River native fish to introduced warm-water predators in overnight laboratory predation trials conducted in 2017. Predator species are Large-mouth Bass Micropterus salmoides, Smallmouth Bass Micropterus dolomieu, Green Sunfish Lepomis cyanellus, Flathead Catfish Pylodictis olivaris, and Black Bullhead Amiurus melas. Prey species are juvenile Bonytail Gila elegans, Roundtail Chub Gila robusta, Humpback Chub Gila cypha, and Razorback Sucker Xyrauchen texanus.

Found at DOI: https://doi.org/10.3996/042018-JFWM-031.57 (56 KB XLSX); also available at https://doi.org/10.5066/P94ANHV3.

Acknowledgments

We thank R. Morton-Starner, C. Nelson, and T. Knecht for assistance with collecting fish and performing these studies. We thank the Arizona Game and Fish Department, Bubbling Ponds Fish Hatchery in Cornville, Arizona, and the USFWS, Horsethief Canyon Native Fish Facility in Fruita, Colorado, for providing research specimens. The U.S. Forest Service, Rocky Mountain Research Station in Flagstaff, Arizona, provided facilities to hold fish. S. Vankorono, K. Dibble, and the Journal of Fish and Wildlife Management Associate Editor, and reviewers provided valuable comments on earlier drafts of this manuscript. This work was conducted under Federal Endangered Species permit TE821356-0.

Any use of trade, firm, or product names is for descriptive purposes only and does not imply endorsement by the U.S. Government.

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