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MANAGEMENT BRIEF

Introduced Flathead Catfish Consumptive Demand on Native Fishes of the Upper Gila River, New Mexico

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Abstract
Predation by nonnative fish is often cited as a leading cause of declining native fish populations, but quantifying these negative interactions is difficult. Bioenergetics modeling provides a tool to estimate consumptive demand of nonnative species and to identify those that pose the greatest threats to native biota. We used bioenergetics modeling to estimate the consumptive demand of Flathead Catfish *Pylodictis olivaris* on native fishes in the upper Gila River, New Mexico, across an elevational gradient. Model results were coupled with measured densities and size structure of Flathead Catfish populations, as well as water temperatures, to predict its predatory threat. Potential consumption was highest at lower elevation sites because of higher water temperatures, but actual consumption was highest at mid-elevation sites because of the prevalence of larger individuals there. Potential annual consumptive demand of Flathead Catfish on native fish across our nine sampling sites ranged from 0.0 to 3.1 g/m², which exceeded native fish productivity at one site. Our results identify areas within the upper Gila River where introduced Flathead Catfish consumption is likely to negatively impact native fish populations.

Bioenergetics modeling can be used to estimate the consumptive demand of nonnative fish, thus allowing for quantitative ranking of predatory threats that nonnative species pose to native biota (Johnson et al. 2008). Models estimating food consumption are based on water temperature, diet, energy density of prey, and growth rate of individual fish (Kitchell et al. 1977). When combined with field monitoring, estimates of consumption can help create an effective management framework for nonnative fish control. For instance, in the Yampa River, Colorado, bioenergetics modeling showed that total piscivory estimates for nonnative Smallmouth Bass *Micropterus dolomieu* were similar to those for nonnative Northern Pike *Esox lucius* when native small-bodied fishes were rare; but if native small-bodied fishes were in higher abundances, Smallmouth Bass predation could be more than 10 times greater than that by Northern Pike, thus creating a greater hindrance to the recovery of native fishes (Johnson et al. 2008). This knowledge of species-specific predatory threats to native fishes in the Yampa River will help managers focus their nonnative fish control efforts (Johnson et al. 2008). Thus, bioenergetics modeling can be used as a tool to evaluate whether consumptive demand of predators is sufficient to warrant time-consuming and expensive management actions, such as mechanical removal programs (e.g., Propst et al. 2014).

Negative interactions between native and nonnative fishes are considered drivers of native decline (Douglas et al. 1994; Bryan et al. 2002; Pelicice and Agostinho 2009). Although these negative interactions are cited as a leading cause of recent species extinctions, there is little evidence supporting this general idea, and research is needed to identify specific pathways by which alien species negatively affect native biota (Gurevitch and Padilla 2004). The knowledge gap of these specific pathways is largely related to difficulties in quantifying species interactions, as controlled laboratory and field experiments might not reflect field conditions due to the fine spatial scale of the experiments (Carpenter 1996; Lima 1998).

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nonnative fishes have been suggested as the primary threat to the survival and recovery of native fishes in the Gila River (Clarkson et al. 2005; Stefferud et al. 2011).

Flathead Catfish *Pylodictus olivaris* has been a target species of removal efforts in the upper Gila River due to its highly piscivorous behavior (Jackson 1999; Pine et al. 2005; Propst et al. 2014). The potential predatory impact of Flathead Catfish on native species in this system is unknown, despite there being a general negative association in biomass and production of Flathead Catfish and native species (Whitney et al. 2014). Although its rarity makes it difficult to estimate population size, a few individual Flathead Catfish may have disproportionately large effects on native fishes because of the predators’ ability to reach large sizes, travel large distances, and exhibit highly piscivorous feeding habits (Travnichek 2004; Vokoun and Rabeni 2005; Kwak et al. 2006; Pilger et al. 2010). Flathead Catfish in the upper Gila River vary in densities and size structures and are exposed to different water temperature regimes across an elevational gradient. With differences in densities, size structure, and temperature regimes, their consumptive demand probably varies spatially throughout the basin. As a first step in understanding their predation threat to this system, our main objective was to use bioenergetics modeling to estimate consumptive demand of Flathead Catfish populations throughout the upper Gila River basin. Model results were integrated with monitoring across nine sample sites that provided data on Flathead Catfish population densities and size structure as well as the productivity of potential native fish prey, to allow us to evaluate the predatory threat to native fishes along an elevation and stream-size gradient.

**STUDY AREA**

The upper Gila River basin is located in southwest New Mexico and originates in the Mogollon and Black Mountain Range of the Gila National Forest. Climatic conditions vary among sites, the mean summer (June to August) air temperatures ranging between 20.6° and 24.8°C and the mean winter (November to February) air temperatures ranging between 4.0° and 6.8°C, depending on elevation (National Oceanic and Atmospheric Administration [NOAA]) stations USC00293530 and USC00297340). From 2008 to 2014, stream discharge typically peaked during spring (March–April; mean = 5.5 m³/s; SD = 6.4), primarily due to snowmelt, followed by summer baseflows (May–June; mean = 1.6 m³/s; SD = 1.4). Discharge then increased in the late summer (July–August) due to monsoonal rains (mean = 3.3 m³/s; SD = 3.8; United States Geological Survey [USGS] gauging station 09430500).

**METHODS**

*Fish sampling and productivity estimates.*—Fish communities were sampled in spring, summer, and fall along the upper Gila River from 2008 to 2014 or from 2012 to 2014 (see Figure 1) to assess spatial and temporal variation in size structure and biomass of Flathead Catfish as well as their potential prey. Sampling was performed at nine sites, using a combination of seining (4.6 m × 1.2 m with 3.2-mm mesh) and electrofishing (Smith-Root backpack shocker). Sites encompassed a series of pool–riffle complexes that varied in length from 174 m to 310 m. Known capture efficiencies for each species in the upper Gila River (see Whitney et al. 2014) allowed us to estimate total fish biomass (g/m²) across sites. Biomass at each site was summed for all native fishes after calculating biomass of individual species with length–weight regression equations. Estimates of native fish biomass and production/biomass (P/B) ratios at each site, derived from Whitney et al. (2014), allowed us to calculate annual biomass production (g/m²), which we then related to estimates of consumption to assess the potential mortality that Flathead Catfish could impose on native fish populations throughout the upper Gila River.

**Bioenergetics modeling.—**Fish bioenergetics software (Hanson et al. 1997) simulations estimated the consumptive demand of Flathead Catfish by using the five required parameter inputs: (1) mass balance equation, algorithms, and parameter estimates for Flathead Catfish energetics and physiology; (2) growth history of different age-classes of fish; (3) energy density of prey; (4) proportional diets by prey type; and (5) annual water temperature (Hewett and Johnson 1987). Physiological parameters were revised within fish bioenergetics calculations by using estimates from Table 1 in Roell and Orth (1993). Kitchell et al. (1977) provided consumption, respiration, and waste losses (egestion and excretion) equations. Maximum temperature for consumption by Flathead Catfish was set at 35°C (Roell and Orth 1993) with maximum consumption at 31.5°C (Gammon 1973; Roell and Orth 1993). The diet of each fish was assumed to be that described from two rivers in North Carolina by Pine et al. (2005; 75% fish prey, 24% crayfish, and 1% aquatic insects), all of which are present in the Gila River. After total consumption estimates were calculated, consumption was multiplied by 0.75, so that reported consumption refers only to that of fish and the consumption of crayfish and aquatic insects is ignored. This correction was possible because all prey categories have similar energy densities (see below). Given that juvenile Flathead Catfish (<100 mm) are primarily insectivores (Ettrn and Starnes 1993; Jackson 1999), they were excluded from bioenergetics modeling. Feeding was assumed to occur only when water temperatures were above 10°C because Flathead Catfish feeding and movement have not been documented at lower temperatures (Daugherty and Sutton 2005; Bourret et al. 2008). Also, prey activity is minimal to none below 10°C (Fast and Momot 1973; Brown and Fitzpatrick 1978).

Introduced Flathead Catfish riverine populations throughout North America (Pisano et al. 1983; Guier et al. 1984; Quinn 1989; Young and Marsh 1990; Nash 1999; and Kwak...
et al. 2006) provided growth estimates (mm/year) and were used to obtain growth (g/year) from log_{10} transformed length-weight regression for Flathead Catfish (Bister et al. 2000). Cummins and Wuycheck (1971) provided energy densities for aquatic insects (4.3 kJ/g), Hanson et al. (1997) for fish prey (4.2 kJ/g), and Roell and Orth (1993) for crayfish (3.8 kJ/g). Site-specific Flathead Catfish annual consumption (g/m²) was calculated using Flathead Catfish biomass, a function of average body size and population size, corrected for capture efficiencies at each site as described above. Averaged daily water temperatures were recorded at one high (1,689 m above sea level) and one low (1,360 m above sea level) elevation site from 2008 to 2014 (HOBO Water Temperature Pro v2).

**RESULTS**

Size distribution of Flathead Catfish varied longitudinally, large individuals (>500 mm TL) frequently being absent at lower sites and the mean size of all individuals ranging from 71 to 587 mm TL (Figure 2). Temperature was higher at downstream, low-elevation sites (mean = 15.5°C; SD = 5.4) than at upstream, high-elevation sites (mean = 12.9°C; SD = 5.5) and peaked at both sites in July and August. Downstream sites also had 40 more days with temperatures >10°C than did upstream sites. Bioenergetics modeling indicated daily individual consumption (g/d) increased with an increase in temperature and age-class, but the rate of increase with temperature was much

**FIGURE 1.** Nine sites (A–I) longitudinally positioned along the upper Gila River, located in southwestern New Mexico; three higher elevation, upstream sites (squares), and six lower elevation, downstream sites (triangles). Gray circles represent the native fish production at each site and the black area of each circle represents the proportion of native fish production consumed by Flathead Catfish. Fish communities were sampled from 2008 to 2014 at A, C, E, F, and G sites and from 2012 to 2014 at B, D, H, and I sites. Temperature was recorded at sites C and F between 2008 and 2014.
greater for older fish (Figure 3). A single large Flathead Catfish can consume over 4,500 g of prey in a year with peak consumption reaching almost 30 g/d (Figure 3). Seven native fish species were available for consumption in the upper Gila River (Table 1), but Sonora Sucker, Desert Sucker, and Longfin Dace dominated the assemblage. Annual Flathead Catfish consumption of native fish varied across sites in the upper Gila River from 0.0 to 3.1 g/m² but was less variable than among-site variation in native fish productivity, which ranged from 0.13 to 23.3 g/m² annually (Figure 4). Potential annual consumptive demand of Flathead Catfish exceeded native fish productivity at downstream site D (Figure 1). The greatest consumptive demands on native fish production occurred at sites in the middle of the basin due to relatively high consumption and low native fish production at these sites. The site with the greatest native fish production (site F) had low consumptive demand, but two sites (B and I) with relatively high native fish production had potentially high consumptive demand (Figure 4).

TABLE 1. Site-specific relative biomass (%) of seven native fish species across nine sites located in the upper Gila River Basin, New Mexico.

<table>
<thead>
<tr>
<th>Species</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
<th>G</th>
<th>H</th>
<th>I</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sonora Sucker <em>Catostomus insignis</em></td>
<td>60.2</td>
<td>79.6</td>
<td>85.3</td>
<td>0.0</td>
<td>28.1</td>
<td>67.0</td>
<td>45.5</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Desert Sucker <em>Pantosteus clarkii</em></td>
<td>20.0</td>
<td>13.5</td>
<td>14.2</td>
<td>71.1</td>
<td>42.0</td>
<td>20.8</td>
<td>28.9</td>
<td>12.7</td>
<td>4.5</td>
</tr>
<tr>
<td>Longfin Dace <em>Agosia chrysogaster</em></td>
<td>15.3</td>
<td>5.0</td>
<td>0.1</td>
<td>28.0</td>
<td>29.7</td>
<td>8.7</td>
<td>18.7</td>
<td>86.0</td>
<td>95.5</td>
</tr>
<tr>
<td>Spinedace <em>Meda fulgida</em></td>
<td>0.3</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.1</td>
<td>2.2</td>
<td>5.1</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Speckled Dace <em>Rhinichthys osculus</em></td>
<td>1.8</td>
<td>0.7</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Loach Minnow <em>Tiaroga cobitis</em></td>
<td>0.1</td>
<td>1.3</td>
<td>0.2</td>
<td>0.9</td>
<td>0.1</td>
<td>1.2</td>
<td>1.8</td>
<td>1.3</td>
<td>0.0</td>
</tr>
<tr>
<td>Headwater Chub <em>Gila nigra</em></td>
<td>2.2</td>
<td>0.0</td>
<td>0.1</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
</tbody>
</table>

FIGURE 2. Flathead Catfish length distributions and mean lengths at nine sites positioned longitudinally on the upper Gila River, New Mexico. Letters in each panel denote sites ordered longitudinally (site A is the site furthest upstream). Gray bars represent individuals smaller than 100 mm. Fish communities were sampled from 2008 to 2014 at A, C, E, F, and G sites and from 2012 to 2014 at B, D, H, and I sites.
DISCUSSION

Flathead Catfish consumption was spatially variable across the upper Gila River, a result partially explained by variation in population age structure and size. Although we do not know the environmental factors (e.g., habitat availability or disturbance regimes) responsible for the dominance of younger Flathead Catfish at lower elevation sites (Figure 2), this age-class gradient had a large influence on potential predatory threat to native fishes. The absence of younger individuals at upstream sites might be due to young ictalurids having extremely low survivorship at water temperatures below 21°C (Patton and Hubert 1996). A similar pattern of size distribution occurs for Channel Catfish Ictalurus punctatus in the San Juan River, New Mexico and Utah, younger fish being more dominant in downstream, warmer waters and larger fish predominating in upstream, cooler waters (Franssen et al., in press). The scarcity of small individuals at upstream sites might also be related to water temperatures rarely exceeding 20°C at these sites, which is below the spawning temperature (22–29°C) of the Flathead Catfish (McInerny and Held 1995). If high-elevation sites are possibly at the lower thermal limits at which fast-growing juveniles can persist, only large adults might be present. Not only are upstream sites dominated by larger, more prey-demanding individuals, but also some have larger populations (Figure 2). The combination of larger individuals and population sizes could be acting as a dual threat to the persistence of native fishes at different sites throughout the upper Gila River.

Spatial variation in consumptive demand is also related to temperature, as temperature regimes influence consumption rates by regulating metabolic processes and limiting the temporal scope for Flathead Catfish feeding. Assuming there is no local adaptation to temperatures, a lack of feeding by Flathead Catfish and minimal prey activity should occur at temperatures <10°C (Fast and Momot 1973; Brown and Fitzpatrick 1978; Bourret et al. 2008). In the upper Gila River, our lower elevation sites had over a month (40 d) longer with water temperatures greater than this 10°C threshold than did the upper sites. Not only does this provide a growth advantage for Flathead Catfish at lower sites, it also promotes a potentially greater consumptive demand on native fish prey.

Although rates of consumption should vary predictably with size and temperature along this longitudinal gradient, the actual impact of nonnative fish predation on native fish will also depend on diets of Flathead Catfish and the presence of other nonnative piscivores. Flathead Catfish typically have ontogenetic shifts in diet, where younger individuals (<100 mm) primarily consume invertebrate prey before becoming highly piscivorous (Etnier and Starnes 1993; Jackson 1999). Thus, lower elevation sites could have higher rates of consumption but native fish are affected through competition for invertebrate prey rather than fish predation (Pilger et al. 2010). Lower elevation sites also have high densities of nonnative crayfish (Whitney et al. 2014), possibly providing an alternative food source for Flathead Catfish.

Native fish productivity varies temporally and spatially in the upper Gila River, with some areas of relatively high and constant native fish productivity (Whitney et al. 2014). These native “hotspots” occurred in areas where Flathead Catfish biomass was relatively low, suggesting that both native fishes and Flathead Catfish populations may cooccur within the upper Gila River basin, albeit in different reaches. However, understanding the behavior of Flathead Catfish is important in determining whether there are episodic movements into areas...
of high densities of native fish because large Flathead Catfish have been seen periodically in these reaches (Propst et al. 2014). Recognizing the drivers of variation in native fish productivity is important in identifying whether declines in native productivity are due to biological reasons (nonnative fish) or to environmental conditions, especially because both spatial and temporal variation in native fish biomass within the upper Gila River is driven by interactions among water discharge, nonnative fishes, and habitat characteristics (Steffurud et al. 2011). Finally, native fish productivity was probably greater at our sample sites before 2011, given that large wildfires and drought decreased fish production in 2011, 2012, and 2013 (Whitney et al., in press); accordingly, our estimates of both Flathead Catfish and native fish biomass at sites that only included samples during 2012–2014 (sites B, D, H and I) might be much less than at sites that also incorporated samples from nonfire, nondrought periods.

The patchy distribution of Flathead Catfish in the upper Gila River can lead to difficulties managing their populations. If the population of Flathead Catfish remains low and concentrated in reaches with low native fish abundance, it might be possible to manage this species as a sport fish while still protecting native fish. However, before making management decisions, accurate and detailed information on the ecology of introduced fish species is required to avoid serious and irreversible damage to native fish populations. This information includes more precise estimates of abundance of both introduced and native fish populations and a better understanding of the food web. For example, if adequate habitat were available, even a single large Flathead Catfish can consume a large amount of biomass in a year (Figure 3). Flathead Catfish consumption thus could be highly detrimental to native fish populations if several large individuals target areas of high native productivity. Moreover, if these fish target habitats and feed on imperiled species, this might exacerbate their impact on native fish diversity.

Assessment of predatory impacts of nonnative species in complex river networks can be difficult due to variable temperature regimes, longitudinal differences in densities and size structure of predator populations, and variation in abundance of prey. Bioenergetics modeling is a tool that provides a basis for predicting the impact of nonnative predators on native fishes. However, future work is needed to further quantify food web interactions as well as assess movement for spawning and feeding of this introduced predator. Our results suggest Flathead Catfish have the potential to reduce the native fish population in certain river reaches while having minimal influences in others.

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