MOVEMENT AND CONSUMPTIVE DEMAND OF THE INTRODUCED FLATHEAD CATFISH *Pylodictis olivaris* IN THE UPPER GILA RIVER BASIN, NEW MEXCIO, AND POTENTIAL IMPACTS ON NATIVE FISHES

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Abstract

Negative interactions with nonnative fish are often cited as a leading cause of declining native fish populations, but quantifying these interactions is difficult. Movement ecology and consumptive demand estimates of nonnative fish predators is needed to better understand potential impacts these organisms are having on native species. The objective of this thesis were to estimate the consumptive demand of Flathead Catfish *Pylodictis olivaris* on native fishes across an elevational gradient, and characterize the movement at hourly, daily, and seasonal scales of this introduced predator. This research was conducted in the upper Gila River basin of southwestern New Mexico. Bioenergetics modeling was used to estimate consumptive demand; model results were coupled with measured densities and size structure of Flathead Catfish populations, and 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 large-bodied individuals. Potential annual consumptive demand of Flathead Catfish on native fish across our nine sampling sites ranged from 0.0 to 3.1 $g/m^2/yr$, which exceeded native fish productivity at one site. To characterize the movement of Flathead Catfish, we used radio telemetry and tracked individuals from May 2014 to June 2015. Movement behaviors varied among individuals with a majority moving <150 m from capture location and some more mobile, moving substantial distances (692-42,840 m). During the course of the study, activity was greatest in summer and fall, and individuals moving substantial distances moved downstream to warmer river reaches before the winter. Nightly movements only involved short distances (5 m) and no fish exceeded a single movement >80 m. Daily activity was greatest during evening but late afternoon activity was observed in summer and fall. Results from this study identify areas within the upper Gila River where introduced Flathead Catfish consumption is likely to negatively impact native fish populations and managers can use this information to understand potential overlap with native species, target future removal efforts in areas where these fish are concentrated, and avoid stocking native fishes in reaches where Flathead Catfish tend to aggregate.

Table of Contents

List of Figures

List of Tables

Acknowledgements

Preface

Chapter two has been accepted in the *North American Journal of Fisheries Management* with Keith Gido and James Whitney as co-authors. Chapter three is formatted for *Ecology of Freshwater Fish* with Keith Gido as a co-author.

Chapter 1 - An Overview of Fish Movement and Introduced Fish Populations

Fish movement studies are broad and well-studied, with literature easily available examining drivers of movement linked to behavior, environmental gradients, biological interactions, and landscape attributes (Boehlert and Mundy 1988; Martel and Dill 1995; Schlosser 1995; Winemiller and Jespen 1998). Understanding fish movement in lotic systems contributes not only to how individuals and species behave within a system, but it allows us to expand our knowledge on local and regional scales of predator prey interaction, resource availability, energy transfers, and links between source and sink populations (Hall 1972; Schlosser 1995; Winemiller and Jepsen 1998). Despite the immense background on fish movement studies and the well-known ecological importance of movement, some have argued information on spatial and temporal patterns of fish movement is still limited (Gido and Jackson 2010; Radinger and Wolter 2014).

Movement studies often examine fish populations as a homogenous entity where mobility is considered an equal parameter for all individuals (Gerking1959; Gowan et al. 1994). However, in more recent years a concept of heterogeneity in the extent of movements within and among populations has been developed (Rodriguez 2002). Many fish populations are now often considered to have stationary and mobile components (Radinger and Wolter 2014). Knowledge of intra- and inter-population differences in movement is important when managing a fish population because differences in movement behaviors will influence the stability of populations, ecosystem effects, and metacommunity dynamics.

Understanding community and metacommunity processes is useful when managing and conserving species (Lafferty et al. 1999; Espeland et al. 2008), but these processes are often

highly complex and can be challenging to address; fortunately though, quantifying movement can help elucidate these complex processes (Leibold et al. 2004). Information on species movements can further our knowledge on recolonization rates, genetic exchange, habitat selections, and establishment rates (Labbes and Fausch 2000; Crook 2004; Espeland et al. 2008; Hudy and Shiflet 2009). Fish populations are reliant on these different elements and movement information can be extremely valuable when addressing the complexity of fish communities. For example, movement studies can help managers understand recolonization rates which advance our knowledge on how species recover from disturbances. Movement studies can also enhance genetic studies to show how populations within a system are connected and possibly reliant on each other. This knowledge can then aid in understanding how future changes in a system will influence a community or population, as well as identify current issues that are obstructing a species overall success.

Of particular relevance to this thesis is movement of nonnative fish, which have multiple negative interactions with the organisms and their surrounding environment. Negative interactions often include changes to the environment, parasitism, predation, and competition (Lowe et al. 2000), but the specific interactions nonnative fish have on native biota is often species-specific. Predation is one negative interaction though that can be considered to potentially affect all species of fish, due to the susceptibility to predation of all fish at some point in their lives (larval and juvenile stages). A major problem in ecology is the lack of understanding in the responses of predators and prey within a system (Sih 1984). Prey exhibit multiple behavioral responses when predators are present that ultimately influence their distribution and survival (Huffaker 1958; Werner and Hall 1988; Sih et al. 1998). Movement of predators is driven by the distribution and densities of their prey; understanding movement of

nonnative predators can help identify if predators are targeting areas of high native fish densities or are in areas depleting native fish. Also, a predator's movement behavior will greatly influence their impact on prey and is dependent on the predator's goal, which is maximizing the benefit/cost ratio (Sih 1984). An individual can increase their benefit/cost ratio in one of two ways, either by increasing their benefit (consumption) or decreasing their costs, thus consumption rates of an individual will vary depending on which of these two strategies is selected. For example, mobile individuals are likely to have higher costs because moving more is more energetically costly, so with this increase in cost an individual is forced to increase their benefit (consumption) to maintain a high benefit/cost ratio. Conversely, more sedentary individuals are decreasing their energy used (cost), which allows for lower rates of consumption while still maintaining high benefit/cost ratios. Managers can use movement information to identify which nonnatives have a greater potential to threaten native fish populations. Fish that exhibit greater movements have a greater probability to negatively impact native fish populations because they can target reaches of high prey densities and consume greater quantities of prey to make up for the increase in activity. This knowledge can aid in developing management strategies for conserving native fish populations by identifying species or individuals within a population that are having relatively higher rates of predation, managers can then use this information to target individuals in specific areas and time periods if removal is deemed necessary, also this information can identify areas where stocking of native fish should be concentrated and avoided.

This thesis addresses the concerns of an introduced fish species in relation to potential impacts on an imperiled fish community. In chapter two I model the consumptive demand of the Flathead Catfish, *Pylodictis olivaris*, throughout the upper Gila River basin and relate these

estimates to native fish production. In chapter three I describe movement behaviors of Flathead

Catfish at different spatial and temporal scales.

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Chapter 2 - Introduced Flathead Catfish Consumptive Demand on Native Fishes of the Upper Gila River, New Mexico.

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 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. Potential annual consumptive demand of Flathead Catfish on native fish across our nine sampling sites ranged from 0.0 to 3.1 g x m^{-2} x yr^{-1}, 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.

Introduction

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 these experiments (Carpenter 1996; Lima 1998).

Bioenergetics modeling can be used to estimate consumptive demand of nonnative fish, thus, allowing for quantitative ranking of predatory threats 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 individual fish growth rate (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 nonnative Smallmouth Bass *Micropterus dolomieu* had similar total piscivory estimates as 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 ten times greater than 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 if 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).

Native species declines in the upper Gila River basin have accompanied nonnative fish introductions despite the relatively low anthropogenic activities and no impoundments that impede dispersal (Propst et al. 2008). The historical fish assemblage of the upper Gila River was

composed of 11 species, all of which have experienced population declines over the past decades, resulting in two extirpations as well as five state and federal listings. With declining native fishes and minimal anthropogenic effects, arguments have been made that nonnative fishes are 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 *Pylodictis 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 it is difficult to obtain population estimates due to its rarity, a few individual Flathead Catfish may have disproportionally large impacts on native fishes because of their ability to reach large sizes, travel large distances, and 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 have variable 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, consumptive demand is likely to vary spatially throughout the basin. As a first step in understanding their predatory 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 productivity of potential native fish prey to evaluate the predatory threat to native fishes along an elevation and stream-size gradient.

Methods

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 varied among sites with mean summer (June to August) air temperatures ranging between 20.6° and 24.8° C and mean winter (November to February) air temperatures between 4.0° and 6.8° C, depending on elevation [National Oceanic and Atmospheric Administration (NOAA) stations USC00293530 and USC00297340]. From 2008-2014 stream discharge typically peaked during spring (March-April) (mean = 5.5 m^3/s; SD = 6.4), primarily due to snowmelt, followed by summer baseflows (May-June) (mean = 1.6 m^3/s; SD = 1.4). Discharge then increases in the late summer (July-August) due to monsoonal rains (mean = 3.3 m^3/s; SD = 3.8) [United States Geological Survey (USGS) gaging station 09430500].

Fish sampling and productivity estimates.– Fish communities were sampled in the spring, summer, and fall along the upper Gila River from 2008-2014 or 2012-2014 (see Figure 1.1) 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 x 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 174m to 310m. Known capture efficiencies for each species in the upper Gila River (see Whitney et al. 2014) allowed us to estimate total fish biomass (g/m^2) 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 production (g x m^{-2} x yr^{-1}) which was related to

estimates of consumption to assess the potential mortality 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 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 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 to be 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); these North Carolina rivers were composed of fish, crayfish, and aquatic insects, all of which are present in the Gila River. After total consumption estimates were calculated, consumption was multiplied by 0.75, thus reported consumption is only that of fish and ignores the consumption of crayfish and aquatic insects. This correction was possible because all prey categories have similar energy densities (see below). Because juvenile Flathead Catfish (<100mm) are primarily insectivores (Etnier and Starnes 1993; Jackson 1999) they were excluded from bioenergetics modeling. Feeding was assumed to only occur when water temperatures were >10° C because Flathead Catfish feeding and movement has not been

documented at lower temperatures (Daugherty and Sutton 2005; Bourret et al. 2008). Also, there is minimal or no prey activity 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 (mm/yr) estimates and were used to obtain growth (g/yr) 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 consumption (g x m^{-2} x yr^{-1}) was calculated using Flathead Catfish biomass, which was 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 asl) and one low (1,360 m asl) elevation site from 2008 to 2014 (HOBO Water Temperature Pro v2).

Results

Size distribution of Flathead Catfish varied longitudinally with large individuals (>500 mm TL) frequently absent at lower sites and mean size of individuals ranging from 71 to 587 mm TL (Figure 1.2). Temperature was higher at downstream, low elevation sites (mean = 15.5° C; SD = 5.4) than 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. 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 greater for older fish (Figure 1.3). 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 1.3). Seven native fish species were available for consumption in the upper Gila River (Table 1.1), but Sonora Sucker, Desert Sucker,

13

and Longfin Dace dominated the assemblage. Flathead Catfish consumption on native fish varied across sites in the upper Gila River from 0.0 to 3.1 g x m^{-2} x yr^{-1} but was less variable than among site variation in native fish productivity, which ranged from 0.13 to 23.3 g x m^{-2} x yr^{-1} (Figure 1.4). Potential annual consumptive demand of Flathead Catfish exceeded native fish productivity at downstream site D (Figure 1.1). 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 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 1.4).

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 1.2), 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 with 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, with younger fish in downstream, warmer waters and larger fish in upstream, cooler waters (Franssen el al. 2014). The scarcity of small individuals at upstream sites might also be related to these sites rarely having water temperatures exceeding 20° C, which is below the spawning temperature (22-29° C) of the Flathead Catfish (McInerny and Held 1995). High elevation sites could possibly be at the lower thermal limits at which fast growing juveniles can

14

persist, allowing for only large adults to be present. Not only are upstream sites dominated by larger, more prey-demanding individuals, but some also have larger population sizes (Figure 1.2). 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 via regulation of 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 days) longer with water temperatures greater than this 10° C threshold than the upper sites. Not only does this provide a growth advantage for Flathead Catfish at lower sites, but also 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 (<100mm) 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 the negative impacts on native fish may occur through competition for invertebrate prey rather than 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 the potential of both native fishes and Flathead Catfish populations to co-occur within the upper Gila River basin, albeit in different reaches. However, understanding the behavior of Flathead Catfish is important in determining if there are episodic movements into areas of high native fish densities because large Flathead Catfish have periodically occurred in these reaches (Propst et al. 2014). Recognizing the drivers of variation in native fish productivity is important in identifying if 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 discharge, nonnative fishes, and habitat characteristics (Stefferud et al. 2011). Finally, native fish productivity was likely greater at our sample sites before 2011 due to large wildfires and drought that decreased fish production in 2011, 2012, and 2013 (Whitney et al. 2015), so our estimates of both Flathead Catfish and native fish biomass at sites that only included samples during 2011-2014 (sites B, D, H and I) might be much reduced compared to sites that incorporates samples from non-fire, non-drought 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

16

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 1.3). 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 to 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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Figures and Tables

Figure 1.1 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). Grey circles represent the native fish production at each site and black area of circle represents the proportion of native fish production consumed by Flathead Catfish. Fish communities were sampled from 2008-2014 at A, C, E, F, and G sites and from 2012-2014 at B, D, H, and I sites. Temperature was recorded at sites C and F between 2008 and 2014.
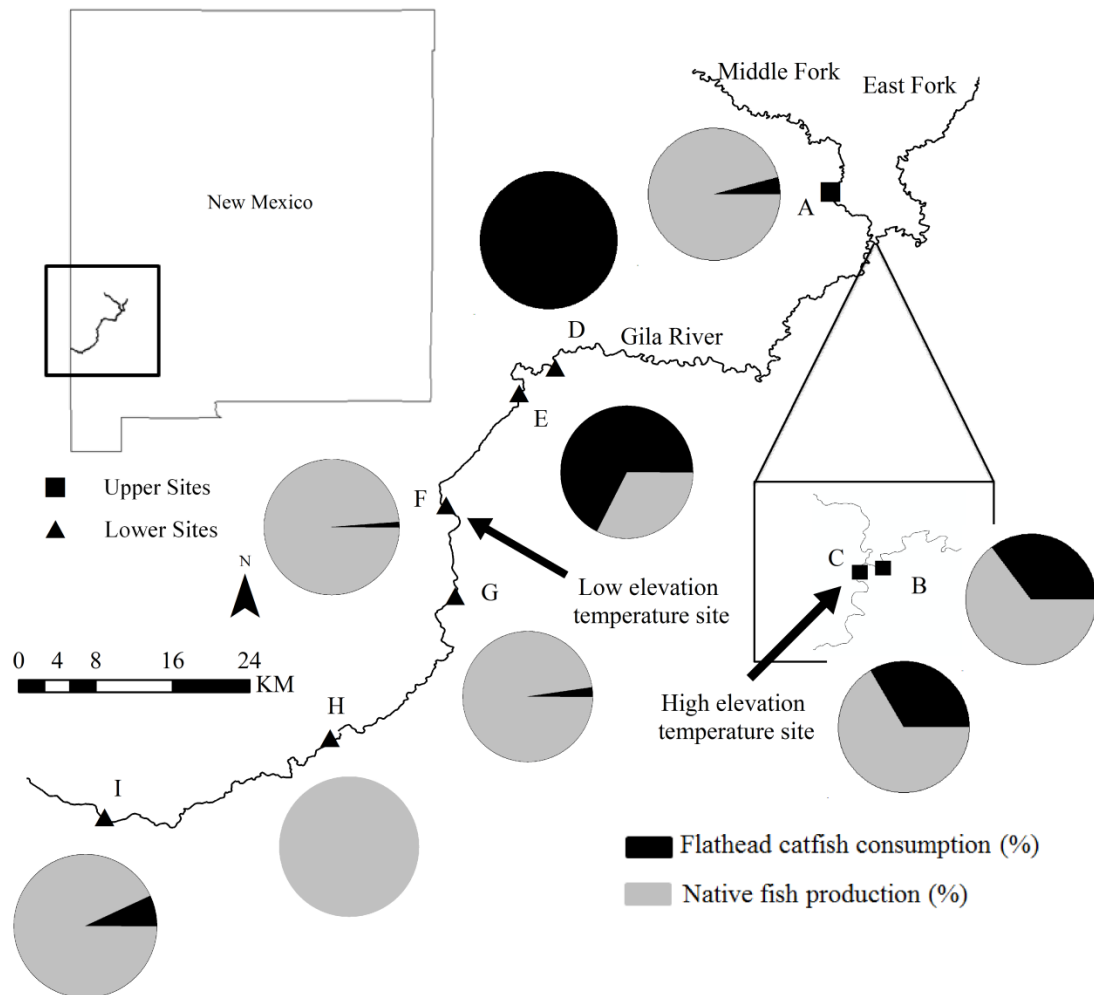
Figure 1. 2 Flathead Catfish length distributions and mean lengths at nine sites positioned longitudinally on the upper Gila River, New Mexico. Letters in each panel denote sites ordered longitudinally (site A is furthest site upstream). Grey bars represent individuals <100mm. Fish communities were sampled from 2008-2014 at A, C, E, F, and G sites and from 2012-2014 at B, D, H, and I sites.
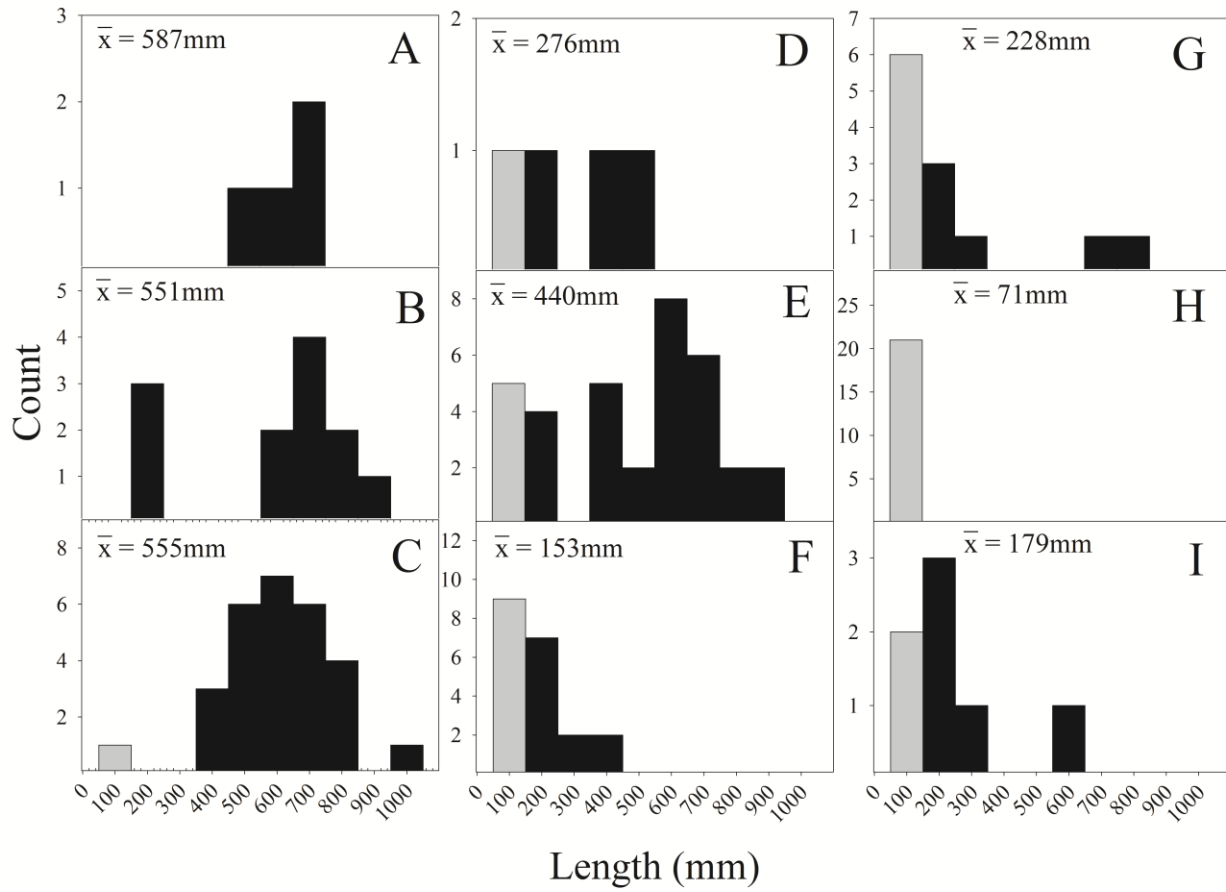
Figure 1. 3 3-D mesh plot showing relationship of temperature and age class to daily individual Flathead Catfish consumption.
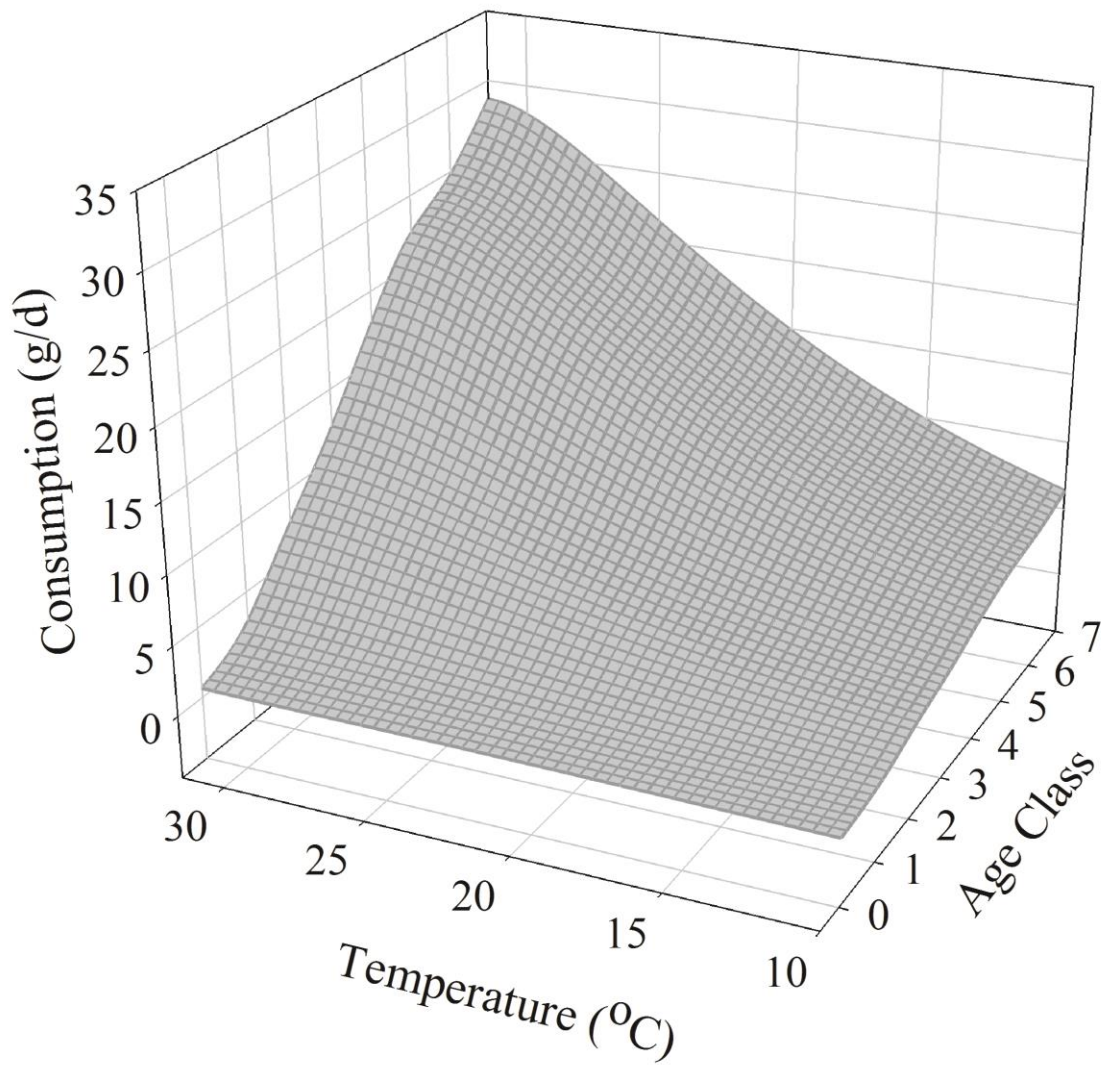
Figure 1. 4 Native fish productivity (g ^{x} m^{-2} ^{x} yr^{-1}) (grey) and removal of native fish through consumption (g ^{x} m^{-2} ^{x} yr^{-1}) by Flathead Catfish (black), weighted by Flathead Catfish average total length and biomass at each site.
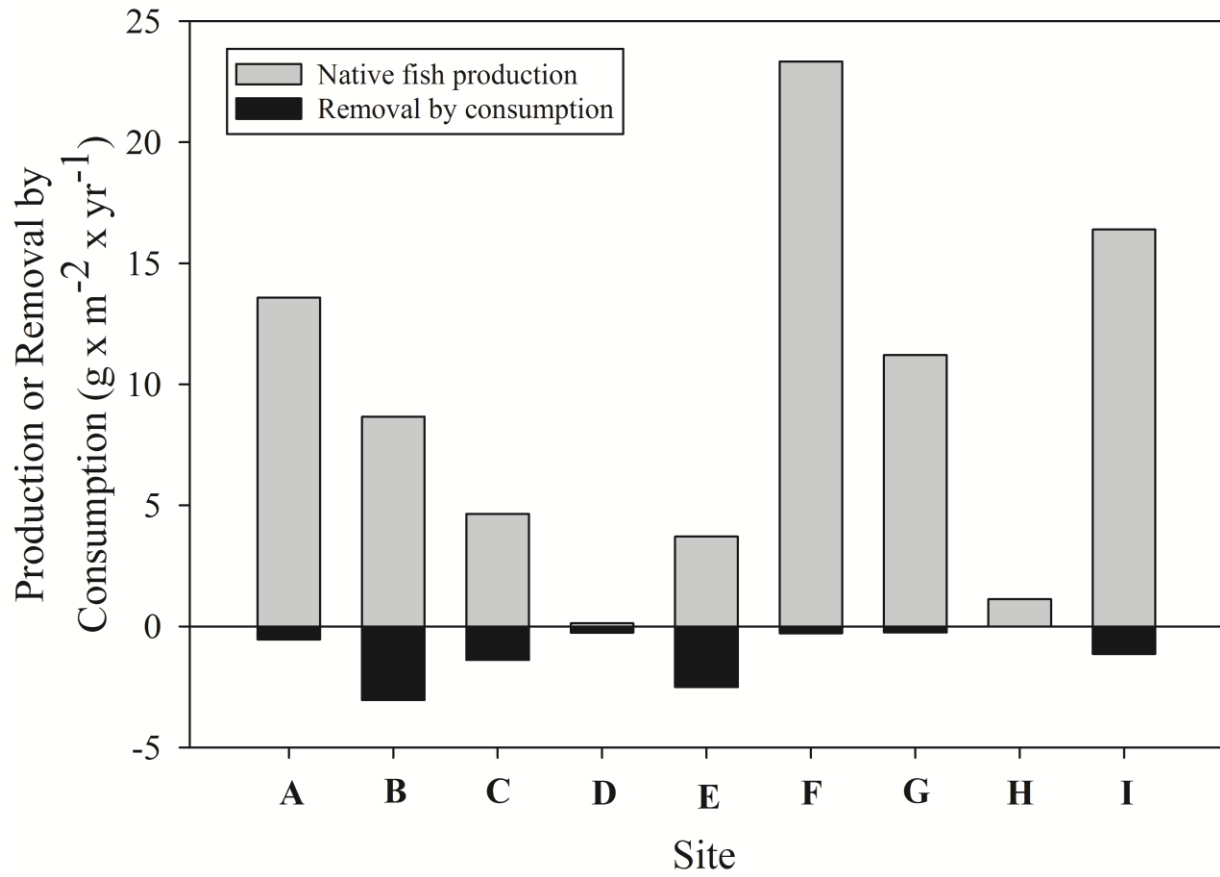
Table 1.1 Site specific relative biomass (%) of seven native fish species across nine sites located in the upper Gila River Basin, New Mexico.

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

Chapter 3 - Movement of the introduced flathead catfish *Pylodictis olivaris* in the upper Gila River basin, New Mexico, and potential impacts on native fishes

Abstract

Movement ecology of nonnative fish predators is needed to better understand potential impacts these organisms are having on native species. We used radio telemetry to observe nonnative flathead catfish *Pylodictis olivaris* at hourly, daily, and seasonal scales from May 2014 to June 2015 in the upper Gila River basin, New Mexico. Movement behaviors varied among individuals with a majority moving <150 m from capture location and some more mobile, moving substantial distances (692-42840 m). During the course of the study, activity was greatest in summer and fall, and individuals moving substantial distances moved downstream to warmer river reaches before the winter. Nightly movements only involved short distances (5 m) and no fish exceeded a single movement >80 m. Daily activity was greatest during evening but late afternoon activity was observed in summer and fall. Managers can use this information to understand potential overlap with native species, target future removal efforts in areas where these fish are concentrated, and avoid stocking native fishes in reaches where flathead catfish tend to aggregate.

Introduction

There has been much discussion over how much fish move during their lives, from the restricted movement paradigm that posits adult fish in streams are sedentary (Gerking 1959) to research by Gowan et al. (1994) showing substantial movement of adult fish. Radinger & Wolter (2014) preformed a quantitative meta-analysis of freshwater fish movement and found variation among species and families, but also within-population variation with stationary and mobile individuals. Regardless of how much fish move, it is well-documented that some level of dispersal is often crucial for survival and reproduction of stream fishes (Power 1987; Harvey 1991; Fausch & Young 1995).

Flathead catfish *Pylodictis olivaris* has been considered a species that exhibits restricted movement behaviors (Funk 1957; Travnichek 2004) with a few highly mobile individuals often present in a population (Grace 1985; Dames et al. 1989). Flathead catfish have been introduced outside their native ranges throughout North America to create angling opportunities (Fuselier 2014). Because they grow to large sizes and are highly piscivorous as adults (Pine et al. 2005; Kwak et al. 2006), their presence is thought to negatively impact native fish (Pine et al. 2005; Whitney et al. 2014). Thus, they are of concern to river ecologist and fisheries managers tasked with conservation of native fish communities (Baumann & Kwak 2011). With the increasing decline of native fishes throughout North America (Jelks et al. 2008), basic movement ecology of nonnative predators, such as flathead catfish, is needed to understand its effect on imperiled native species. Moreover, identifying potential spawning, feeding, and overwintering movements might help parameterize bioenergetics models that aid managers in assessing impacts and controlling populations of introduced species (Hedden et al., in press).

The objective of this study was to use radio telemetry to describe movement of flathead catfish to give insights of interactions with native fishes in the upper Gila River basin in New Mexico, which contains several imperiled fish species that have not evolved with piscivorous fish predators. The native fish fauna in this basin has declined over the past century, with documented declines over the past several decades, even though there has been relatively limited anthropogenic alterations and no impoundments impeding dispersal (Propst et al. 2008). Some contend that the primary threat to native fishes in the American Southwest are nonnative fishes, such as the flathead catfish (Clarkson et al. 2005; Stefferud et al. 2011). Flathead catfish movement in the Gila River, New Mexico was examined at nightly, daily, and seasonal intervals, to gain insights on their manner and level of their effect on native fishes. Information gained from this study will aid managers in determining appropriate actions for managing a nonnative predator to reduce impacts they might have on native fishes, especially imperiled species.

Methods

Study area.–This study was conducted in the upper Gila River basin in southwest New Mexico (Figure 2.1). From its origins in the Mogollon Mountains, the Gila River flows southwesterly through New Mexico then in a westerly direction across Arizona to join the Colorado River. After its three source tributaries join, the river enters a 50-km long canyon reach where it experiences a drop in elevation from 1695m to 1410m before entering a lower gradient valley reach. The upper Gila River is one of the last free flowing systems in the Colorado River basin with comparatively few human modifications. Discharge in the Gila River is variable within a given year and is typically driven by spring snowmelt and summer monsoons (Figure 2.2).

Fish sampling and tracking.–Flathead catfish specimens were captured in the upper Gila River drainage in May 2014 (Figure 2.1) using a backpack electroshocker (Smith and Root LR 20B backpack electrofisher). All flathead catfish collected were immobilized with Tricaine Methanesulfonate (MS-222), total length and mass determined, and surgically implanted with a radio transmitter following procedures of Hart & Summerfelt (1975). Fish were implanted with one of three different-sized transmitters (9g, 12x43x12mm; 11g, 12x54x12mm; and 25g, 17x70x15mm), making up less than 3% of an individual's mass to ensure transmitters did not interfere with behavior or swimming performance. Individuals were released at the site of capture after recovery from surgery. Fish were tracked at seasonal and nightly time intervals between July 2014 to June 2015 using a three element yagi and handheld receiver (Model R410 receiver, Advanced Telemetry Systems). Fish were located during spring post-snowmelt runoff baseflows (April-June), late summer flows driven by monsoonal rains (July-September), stable fall and winter discharge (October-January), and elevated discharge during the spring due to snowmelt runoff (February-March) (Figure 2.2). A subset of fish were located at 3-hr intervals throughout the night in each season.

Data analysis.– To evaluate patterns of diel activity, four of the radio transmitters were equipped with sensors that recorded activity and temperatures each minute. Activity values were averaged for each day to identify shifts in daily and seasonal movement behaviors. Activity sensors record activity as a percent of time moving. Sensors were calibrated with a flathead catfish held in captivity and exposed to swimming trials to better understand this relative activity metric; however, activity was not calibrated to energy expenditure.

Results

Of the eleven individuals implanted with transmitters, four were successfully recaptured and three were not relocated at the end of the study (Figure 2.3). All recaptured individuals grew during the study, but growth of downstream individuals (below RKM 25) was greater (350-380g) than that of the most upstream recaptured fish (Number 10; 130g) (Table 2.1; Figure 2.1). Overall movement distances (from May 2014-June 2015) can be characterized into three groups, short movements within a pool-riffle complex (<100m), intermediate movements into neighboring habitat complexes (719-1511 m) and substantial movements into different stream reaches (7355-42840 m) (Table 2.1).

On average, over 70% of individuals moved <150 m in each of the five seasonal tracking events, but three individuals exhibited long distance movements (>5000 m) (Figure 2.3). Some individuals moved considerable distances (692-1529 m) in all seasons, except winter (January-March) when no fish moved. Greatest seasonal movements occurred in late spring-early summer (2 fish; May-July) and autumn-winter (2 fish; October-January) (Figure 2.3). Activity sensors were recovered from three of the four fish; seasonal average activity (%) was greatest during spring and early autumn (May-October) with sharp declines in activity in fall and winter (October-March), then activity gradually increased in the spring (March-June) (Figure 2.4).

Direct observations of nightly movements typically revealed relatively short distance movements (5 - 15 m), with movements never exceeding 80 m (Figure 2.5). When movement was documented, fish moved short distances from deep undercut banks into the open waters or below riffles. Hourly activity, from activity sensors peaked shortly after sunset (hours 20-23) with the least movement occurring after sunrise (hours 8-11). Daily activity was similar in the

29

summer and early fall (May–October) with overall much higher activity across all times of day compared to winter and early spring (October–March) (Figure 2.6).

Discussion

The flathead catfish in this study consisted of both sedentary and mobile individuals. Five of the 11 fish remained in the habitat they were initially captured in for the duration of the study (Table 2.1). The six mobile individuals can be divided into two groups, one group consisting of three individuals, demonstrated movement between nearby habitats, suggesting a larger home range than a single pool and its immediate vicinity. The second group, moved substantial distances downstream in late summer and fall. Fish traveling the greatest distances were all initially captured in the upper reaches of the study area, with the exception of Fish 10 (Table 2.1), which was last detected in October 2014, possibly before the individual made a large downstream movement. Large downstream movement might be driven by temperature regimes in the upper Gila River basin, where upstream waters are often 2.6° C cooler than downstream (Hedden et al., in press). Flathead catfish may move to upstream reaches during summer and early autumn when water is comparatively warm and native prey are abundant (Whitney et al. 2014). As water cools in late autumn, they return to downstream reaches. Upstream reaches are also occupied by larger individuals, which presumably have higher survival rates than younger fish at lower water temperatures (Patton and Hubert 1996). Unfortunately, transmitters expired at similar times when water temperature and fish activity began to rise, thus we likely missed observations of upstream movements in our study.

Daily tracking of flathead catfish indicated that movement was limited at night and all individuals stayed within 80 m of their daylight locations. Increased movement, however, during some nights was recorded on activity tags (Figure 2.4). This increased activity was often constant

30

for several hours, indicating possible large movements or activity associated with spawning and nest construction; both male and female flathead catfish use their tails and mouths to create spawning cavities in stream banks and wood piles (Becker 1983; Cross 1967). No large distance movements were documented during nightly tracking indicating that flathead catfish are largely sedentary and move substantial distances infrequently.

Diel activity was greatest after sunset, supporting studies finding flathead catfish to be primarily nocturnal organisms. Despite most evidence indicating flathead catfish are nocturnal, activity did increases slightly in the early afternoon in summer and fall, suggesting possible day time feeding events, similar to findings of Baumann & Kwak (2011) who reported stomachs being full in the late afternoon. When an individual moved at night, it moved from deep undercut banks into open shallow water where potential prey were more abundant. Native Sonora sucker *Catostomus insignis* and desert sucker *Pantosteus clarkii*, move into shallow waters for foraging primarily during the evening to avoid piscivorous avian predators present during the day (Booth et al. 2013), thus flathead catfish may be targeting these habitats at night and feeding on naive native fishes that have not evolved with this piscivorous fish predator.

Flathead catfish are highly piscivorous organisms as adults and thus can pose a threat to native fishes (Pine et al. 2005; Pilger et al. 2010). Nightly movement of flathead catfish into habitats used by potential prey suggests their distribution in the upper Gila River drainage might be influenced at least partially, by availability of prey. Of the four flathead catfish stomach examined from fish recovered at the end of this study, two were empty, one contained a large nonnative American bullfrog *Rana catesbeiana* and one contained a nonnative virile crayfish *Orconectes virilis*. Although our sample size was too small for a rigorous diet analysis it would be unlikely to find native fishes in the diet because native fish densities are very low in the

canyon bound reaches where most of our flathead catfish occupied (Whitney et al. 2014). Flathead catfish in this study and numerous others show some individuals are highly mobile (Travnichek 2004; Vokoun & Rabeni 2005) thus individual impacts on native fish are possible, but dependent on their movement into reaches with higher densities of native fishes. These highly mobile fish that move into areas of high native biomass (e.g., Propst et al. 2014) could be a great threat to native fishes because if they target reaches where native fish are in high abundances, a single individual can consume large amounts of native fishes (Hedden et al., in press). Even if some individuals are sedentary their entire lives they still have the ability to have negative interactions with native fish. Allow a majority of fish resided in areas of low native abundance; they are positioned within the basin between two separate hotspots of native fish abundances (Hedden et al., in press). These sedentary flathead catfish could thus be acting as a dispersal barrier to native fishes.

Managing a riverine system for the conservation of native fish is difficult, especially in a system such as the upper Gila River where native fish biomass is highly variable and driven by both biotic and abiotic factors (Propst et al. 2008; Whitney et al. 2014; Whitney et al. 2015). A better understanding on the population size of this fish is needed to completely understand the impact they are having on native fishes. But managers can still use this information to understand potential overlap with native species and if removal is deemed necessary, target future efforts in areas where these fish are concentrated and stock native fishes in reaches within the river where flathead catfish have limited access due to physiological constraints. With the understanding of how introduced predators are targeting different habitats for feeding, spawning, and overwintering within a year can greatly enhance managers' abilities to successfully conserve native fishes.

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Figures and Tables

Figure 2.1 Gila River located in southwestern New Mexico. The reach within the river all flathead catfish occurred in tagging locations and final known locations. Numbers correspond to Fish ID numbers in Table 1. River kilometers abbreviated RKM.
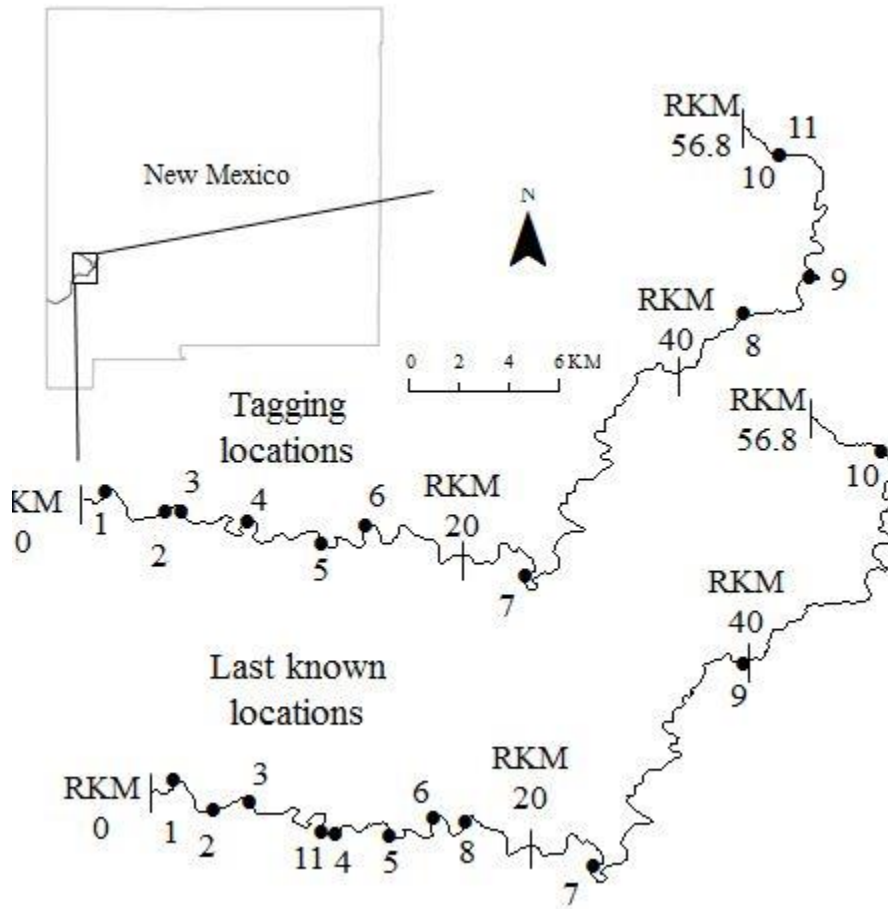
Figure 2. 2 Daily discharge in the Gila River, New Mexico from May 2014 thru June 2015. United States Geological Survey (USGS) gaging station 09430500.
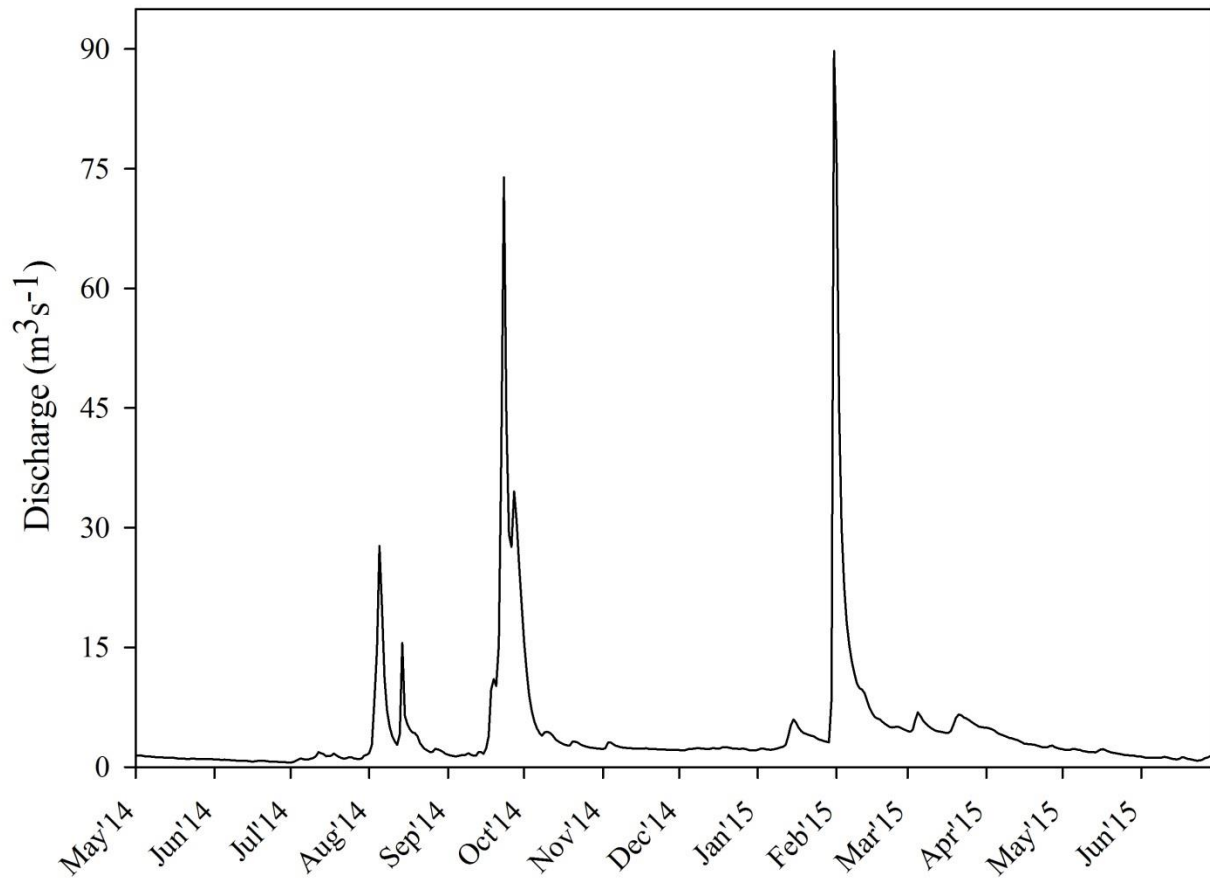
Figure 2. 3 Distances moved by flathead catfish in the upper Gila River basin, New Mexico, from May 2014-June 2015. Individuals are depicted by a single line with dots representing river kilometer location (see figure 2.1), black dots indicate capture or tracking location, open dots last known detection location but not recaptured, and grey dots last detection location and recaptured. Numbers correspond to Fish ID numbers in Table 1.
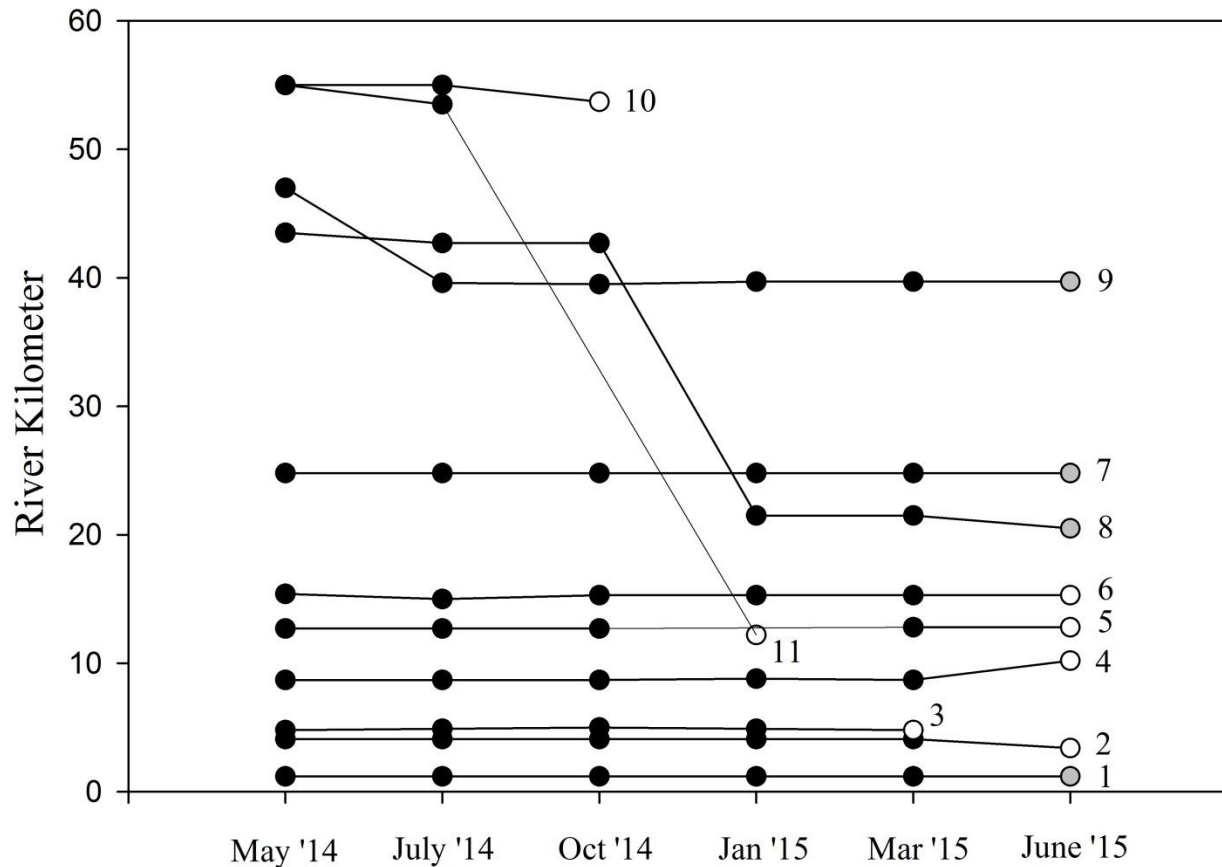
Figure 2. 4 Average daily (line) and seasonal (bars) activity (%) of three Flathead Catfish in the upper Gila River basin from May 2014 through June 2015. Fish ID numbers correspond to Table 1.
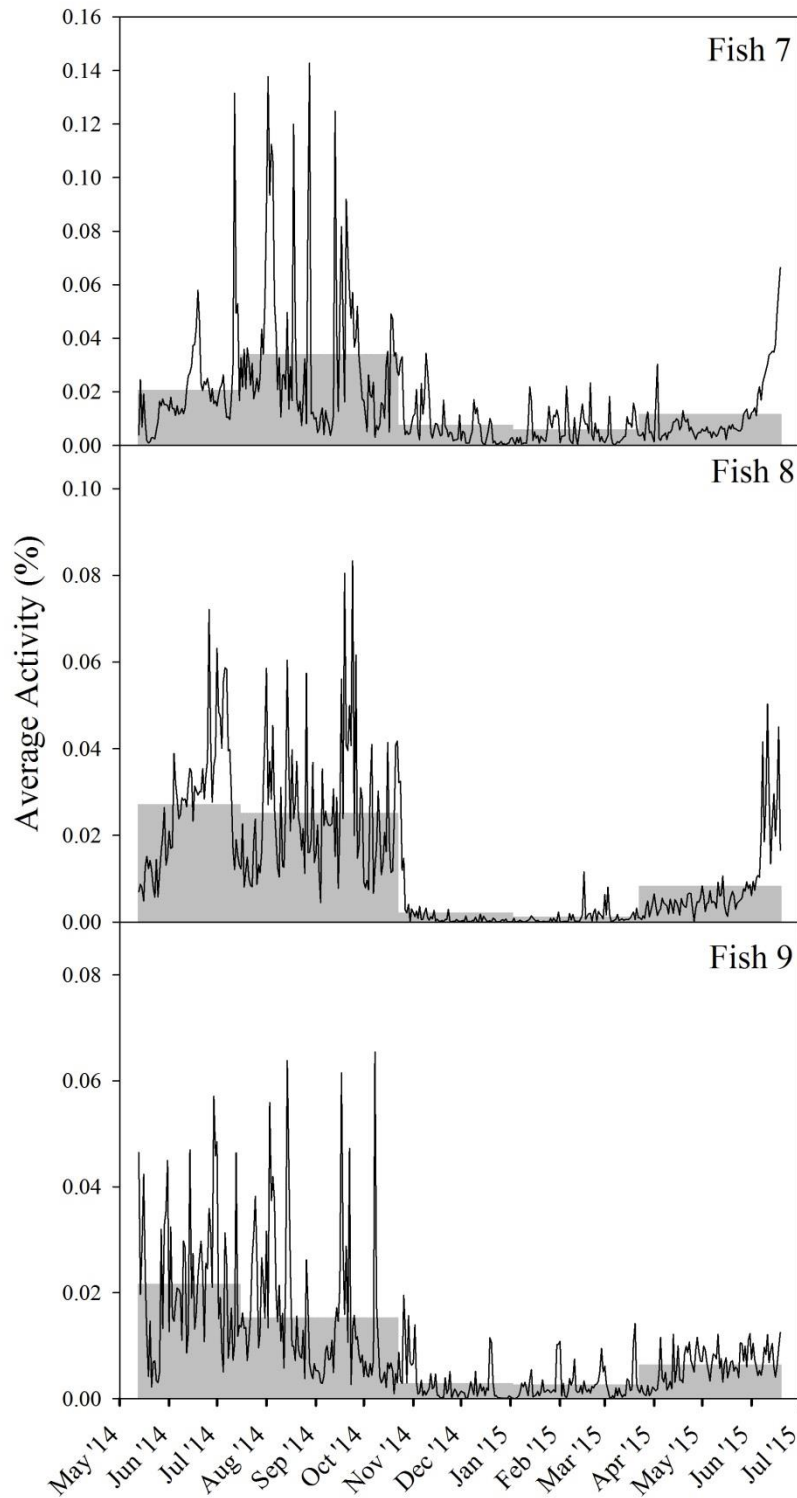
Figure 2. 5 Nightly movement of ten tracking events of Flathead Catfish in the upper Gila River basin, New Mexico.
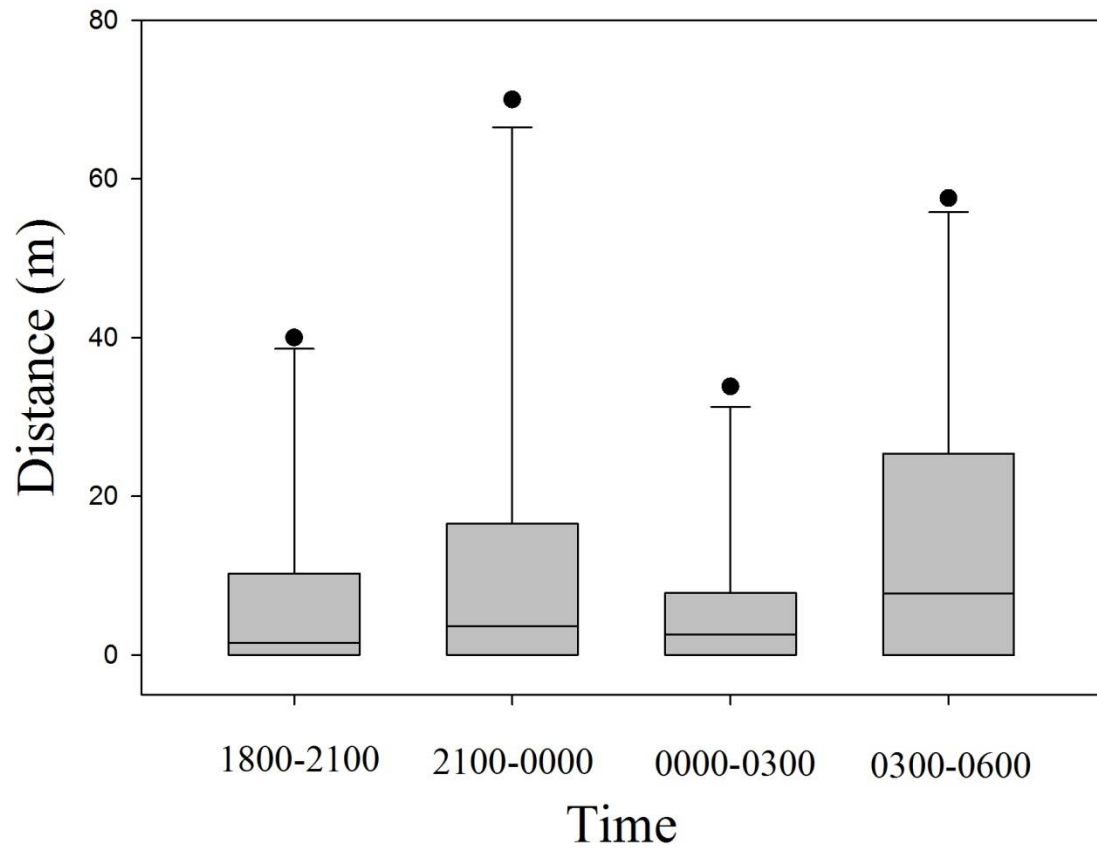
Figure 2. 6 Average hourly activity (%) of Flathead Catfish in the upper Gila River basin, New Mexico, from radio transmitter activity sensors at different times of the year from May 2014 – June 2015.
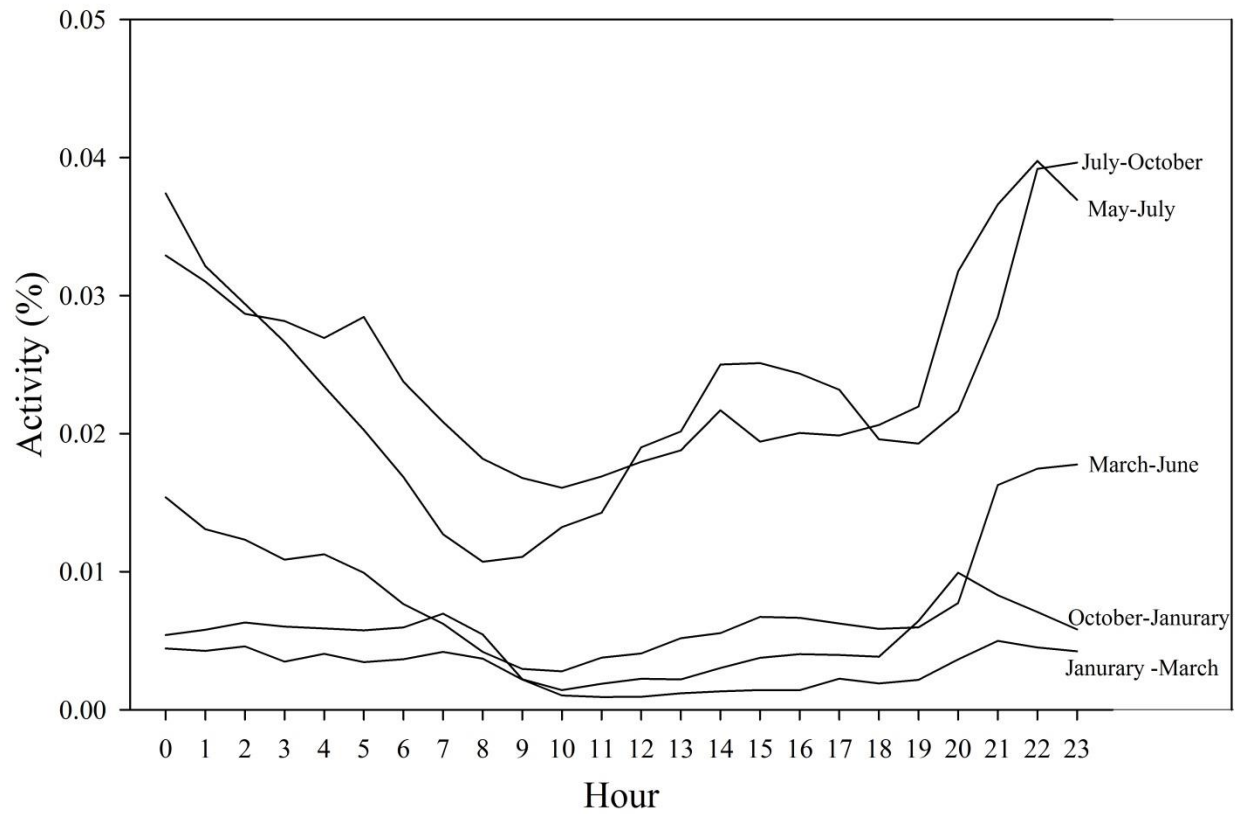
Table 2.1 Flathead catfish initial total length (TLi), final total length (TLf), intital mass (Mi), final mass (Mf), change in total length (dTL), change in mass (dM), and distance and direction traveled between beginning of study (May 2014) and end of study (June 2015) along with sex of individuals if recaptured from the upper Gila River basin, New Mexico. Fish ordered depending on tagging location, from downstream to up.

Fish ID	TLi	Mi	TLf	Mf	dTL	dM	Distance	Direction	Sex
1	461	960	495	1330	34	370	8.7	Downstream	F
2	765	>5000	-	-	-	-	719.02	Downstream	-
3	319	345	-	-	-	-	12.6	Upstream	-
4	473	1125	-	-	-	-	1511.38	Upstream	-
5	575	1950	-	-	-	-	18.2	Upstream	-
6	765	4900	-	-	-	-	76.67	Downstream	-
7	705	4300	740	4680	35	380	7.58	Upstream	M
8	605	2750	647	3100	42	350	22930.85	Downstream	M
9	700	4350	730	4480	30	130	7354.87	Downstream	F
10	325	395	-	-	-	-	1289.17	Downstream	-
11	604	2800	-	-	-	-	42839.98	Downstream	-