RELATIVE IMPACT OF PREDATION BY NONNATIVE FISHES ON NATIVE FISHES IN THE VERDE RIVER, ARIZONA

by

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In loving memory of

Charles Lorne Crowder

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ESTIMATED DISTRIBUTION, RELATIVE ABUNDANCE, DENSITY, AND STANDING CROP OF FISHES IN THE VERDE RIVER, ARIZONA

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ABSTRACT

We estimated the distribution, relative abundance, density, and standing crop of native and nonnative fishes in the Verde River, Arizona from March 2002 through January 2003. We examined the estimated densities and standing crops of fishes by section of river (Section I, II, III, IV) and environment type (pool, riffle, run). Estimated densities of fish were also examined by season (spring, summer, winter). Over 30,700 fish were collected, comprising 6 native species and 13 nonnative species. Three native species and 7 nonnative species were found throughout the entire river. Nonnative fishes were approximately 2.6 times (95% C. I. 2.2 to 3.1 times) more dense per $100m^2$ of river than native fishes, and their standing crop was approximately 2.8 times (95% C. I. 2.0 to 4.0 times) that of native fishes per $100m^2$ of river. Native fishes were most dense in Sections I and IV (highest and lowest elevations), while their standing crop was greatest in Section I. Nonnative fishes were most dense in Section I, and had the greatest standing crop in Sections I and II. The highest standing crops of native fish were in pools and runs, and of nonnative fish in pools. There was no difference in native fish densities by environment type, but nonnative fishes were most dense in riffles. The ranges of estimated annual standing crops of fish in this desert river were similar to those of other temperate and tropical rivers around the world.

INTRODUCTION

Native fishes in the desert Southwest are one of the most imperiled taxa in the region. Habitat loss, hydrological changes, deterioration of water quality, and negative interactions with introduced nonnative fishes are all thought to contribute to the decline of native fishes in the Southwest, and are all the result of anthropogenic impacts (Minckley and Douglas 1991; Girmendonk and Young 1997; Rinne 1994). Currently, twenty-five of the remaining 34 native fish species in Arizona are listed as threatened or endangered under the federal Endangered Species Act, or as Wildlife of Special Concern in Arizona (Arizona Game and Fish Department 2003).

Negative interactions with introduced fishes are often implicated in the declines of Southwestern fishes. Over a ten-year period, Rinne et al. (1998) found that nonnative fishes seem to be replacing native species in the Verde River. The exact mechanisms for declines in native fish populations caused by nonnative fishes are unknown, but competition, predation, hybridization, the introduction and transfer of parasites and disease, and the loss of habitat are all suspected (Moyle et al. 1986; Rinne and Minckley 1991; Rinne 1992a; Marsh and Douglas 1997). Understanding the current distribution and abundance of native and nonnative fishes within specific environment types is essential groundwork for evaluating the effects of nonnative fishes on native desert fishes.

The density and standing crop that fishes can obtain in various environment types are basic measures of productivity commonly used to manage species and understand their ecology (Bennett 1970). Estimates of fish densities and standing crops have been made for various lakes, reservoirs, and rivers throughout the world (Mahon et al. 1979;

Wiley et al. 1980; Heidinger 1989; Formigo and Penczak 1998; Penczak et al. 1998), but there is little information available regarding the densities and standing crops achieved by fishes in Southwestern desert rivers. Calculating the density and standing crop of fishes in the Verde River would provide important information on the basic productivity of both native and nonnative fishes in a typical Southwestern desert river system, and would be useful for understanding the interactions among native and nonnative fishes in these ecosystems. The goals of our study were: 1) to estimate the distribution, percent relative abundance, density, and standing crop of native and nonnative fishes in the Verde River, Arizona and 2) to examine the relationship between fish density and standing crop to section of river (Section I, II, III, and IV), environment type (pool, riffle, run), and season (spring, summer, winter) for each species.

STUDY AREA

Six of the ten native fishes historically found in the Verde River are listed as federally threatened (FT), federally endangered (FE), or as Wildlife Species of Concern in Arizona (WSCA) (Table 1). These species include Gila topminnow *Poeciliopsis occidentalis*, FE, WSCA; razorback sucker *Xyrauchen texanus*, FE, WSCA; Colorado pikeminnow *Ptychocheilus lucius*, FE, WSCA; loach minnow *Tiaroga cobitis*, FT, WSCA; spikedace *Meda fulgida*, FT, WSCA; and roundtail chub *Gila robusta*, WSCA (Arizona Game and Fish Department 2003).

The Verde River is one of the last remaining perennial rivers in Arizona. It drains much of central Arizona, with its headwaters at Mt. Floyd near Seligman, Arizona, and perennial flow starting just below Sullivan Dam at Del Rio Springs and the Granite Creek confluence, 40 km north of Prescott, Arizona (Williams 1996). We designated the dam as kilometer 0 (the northern boundary) of our study area. The river runs approximately 318 km from Sullivan Dam downstream to its confluence with the Salt River, approximately 56 km northeast of Phoenix (Fig. 1). River elevation ranges from 400 m to 1,329 m above sea level, with an average gradient of 2.84 m/km. The Verde watershed drains an area of approximately 8,148 km^2. The Verde River shares many abiotic and biotic features of other desert rivers, and has been subjected to a similar degree of human impact.

METHODS

Study Design

Following the designations of Rinne et al. (1998), we divided the river into four sections (Fig. 1) based on the degree of human impact (Table 2). Sullivan Dam to Tapco, an abandoned coal-fired power plant in the town of Clarkdale (Girmendonk and Young 1997), was designated as Section I, and was the most pristine section of the river with the lowest flow. Clarkdale to Beasley Flats Recreation Area contained large-scale human development and water diversions, and was designated Section II. Section III ran from Beasley Flats to Horseshoe Dam, and was federally designated as “Wild and Scenic” in 1984 (Slingluff 1990). The river from Bartlett Dam to the Salt River confluence was designated Section IV, a larger-scale river characterized by much higher, regulated flows. The section of river between Horseshoe Dam and Bartlett Dam was excluded from sampling because of its distinctiveness as a closed system.

We selected a stratified random sample of three sites from available road access points within each of the four sections of river (Fig. 1), for a total of 12 sample sites (Table 3). We systematically chose one of each environment type (pool, riffle, run) for sampling at every site monthly from March 2002 to January 2003. We used definitions from Arend (1999) to guide our selection of pools, riffles, and runs. We measured the surface area, temperature, and maximum depth of the water for each environment type sampled. Sample months were grouped into three seasons according to water temperatures: March - May 2002 was defined as the spring season, June - September 2002 as the summer season, and October - January 2003 as the winter season.

Fish collection

We used block nets to separate and ensure closure of one pool, riffle, and run at each sample site. Each block net was 30.5 x 1.8 m wide, with 3.2 cm bar mesh, with a lead line stabilized by cement weights. We used Smith-Root Model 12-B (battery powered) and Model 15 (generator powered) backpack electrofishing units to collect fish in shallow areas and along shorelines, and a Coffelt VVP-15 raft electrofishing unit to collect fish in deeper pools and runs (Reynolds 1983). Backpack shocker settings averaged 60 Hz at 6 ms and 300 volts, and the Coffelt VVP-15 settings on the raft averaged 300 volts, 7 amps, 40% pulse width, and 60 Hz.

Electrofishing took place during the day, from approximately 0800 to 1600 hours. Multiple electrofishing passes were conducted in each block-netted pool, riffle, and run until depletion, or the subsequent number of total fish caught in each pass was substantially reduced. Each fish captured was identified and measured to the nearest mm (total length). At least the first 50 individuals of each species caught were weighed to the nearest 0.1 g. All fish were held in a live car and released at the end of the sampling period.

Environment types

We used a combination of recorded environment type surface area measurements and aerial photographs (Salt River Project 2002; USGS 2002a) to estimate the proportion of pools/runs to riffles available within 400m of each sampling station. The average ratios of pools/runs to riffles were similar among the four sections (within 3% of each other), which allowed us to compare the percent relative abundance, estimated density, and standing crop of native and nonnative fishes across the river.

Percent relative abundance

We calculated the percent relative abundance of native and nonnative fishes in each pool, riffle, and run sampled on each day. We averaged the relative abundances of native and nonnative fishes over the year by section and environment type, and compared them with previous work done by Rinne et al. (1998). We examined relative abundances by environment type within each section because the amount of pools, riffles, and runs available within each section was not quantified.

Density and Standing Crop Estimates

We used the Zippin removal method (Zippin 1956; Zippin 1958) in the computer program Capture (White et al. 1992) to estimate the population size (number of individuals) of each fish species within each block-netted pool, riffle, and run at every site (12 sites), for each month (10 months). The Zippin method assumes 1) a closed population, 2) equal probability of capture for all animals, and 3) a constant probability of capture from sample to sample (Zippin 1956; Seber 1982). Removal methods for fish population estimates are used when there is a high catchability of fish, and equal effort is given in each sample period (Van den Avyle 1993).

If the number of individual fish caught within one species did not decrease with additional electrofishing passes, we used the total number of fish caught as a conservative population estimate for that species. This usually occurred in numbers of less than ten with larger sized species, and in multiples of ten with smaller sized species. We divided the species-specific population estimates by the total surface area of the environment type sampled to obtain relative densities. We averaged the densities for all species over the year by section of river, environment type, and season.

The mean individual weight of each species was calculated for each pool, riffle, and run sampled each day. When weight data was unavailable, we averaged total lengths of all fish caught within a species and used length-frequency histograms to estimate the mean individual weight (Anderson and Gutreuter 1983). The standing crop per unit area of each species was estimated by multiplying the mean individual weight by the density estimate (Burns 1971; Mahon et al. 1979). Standing crop estimates for each species were averaged over the year by section of river, environment type, and season.

Statistical Analyses

We log10 (x +1) transformed the estimated densities and standing crops of total fish captured (native and nonnative fishes combined) to meet the assumptions of normality and homogeneity of variance. We used multiple regression analysis and linear contrasts to test for and quantify differences between the estimated densities and standing crops of total fish in the river by section, environment type, and season.

Because estimated densities and standing crops for individual species included numerous zeroes and violated the assumptions of normality and homogeneity of variance, we conducted a two part statistical analysis for grouped native and nonnative fish, and by individual species. We used Kruskal-Wallis nonparametric single factor analysis of variance (K-W ANOVA) by tied ranks tests (Zar 1999) to compare estimated densities and standing crops of grouped native fish combined, grouped nonnative fish combined, and each individual species by section of river and environment type. Only densities were compared by season. If a difference was detected, we used nonparametric multiple comparison tests for mean ranks with ties and unequal sample sizes (Zar 1999) to identify wherein the difference lay. Due to the statistical analyses used, and that every fish species was not captured on every occasion, we did not test for interactions among section, environment type, or season. We report simple means and standard errors of the estimated densities and standing crops for each fish species, which include extreme outliers. We excluded threadfin shad and Colorado pikeminnow from our statistical analysis because only one and two fish, respectively, were captured throughout the year.

RESULTS

Distribution and species richness

Over 30,700 fish were collected in the Verde River throughout the year. Nineteen species of fish were observed (Table 4), comprising 6 native species from 2 families (includes 2 stocked species) and 13 nonnative species from 7 families (includes 1 stocked species). Ten of the 19 species were found throughout the river. Section IV had the most number of unstocked fish species (15 species), followed by Section III (13 species), Section II (13 species), and Section I (11 species). Table 4 provides a list of species, median lengths, and elevation and water temperature ranges where each species was most prevalent during this study.

Three native species, desert sucker *Catostomus clarki*, Sonora sucker *Catostomus insignis*, and roundtail chub were found throughout the river (Table 4). Colorado pikeminnow and razorback sucker were only found in Sections II and III, respectively, where they were being repatriated. Longfin dace were only caught in Section IV.

Seven nonnative species were found throughout the river (Table 4). These included channel catfish *Ictalurus punctatus*, common carp *Cyprinus carpio*, flathead catfish *Pylodictis olivaris*, green sunfish *Lepomis cyanellus*, mosquitofish *Gambusia affinis*, red shiner *Cyprinella lutrensis*, and yellow bullhead *Ameiurus natalis*. No bluegill *Lepomis macrochirus* or largemouth bass *Micropterus salmoides* were observed in Section I. Rainbow trout *Oncorhynchus mykiss* were observed in Sections II, III, and IV, close to where they were stocked. No smallmouth bass *Micropterus dolomieu* were observed in Section IV, while threadfin shad *Dorosoma petenense* and tilapia *Tilapia spp* were only observed in Section IV.

Percent relative abundance

The percent relative abundance of native fishes decreased steadily in pools from Sections I to IV (44.6 to 9.7%), but increased steadily in runs from Sections I to IV (11.9 to 50.3%) (Fig. 2). The percent relative abundance of native fishes decreased steadily in riffles from Sections I to Section III (30.6 to 0.9%), but was greatest in Section IV (63.9%).

Total fish overall

After accounting for environment type, season, and origin (native vs. nonnative) of fish, the highest densities and standing crops per unit area of total fish (native and nonnative combined) caught were in Section I (multiple regression and linear contrasts, $F_{1,693} = 27.96$, $P<0.001$; $F_{1,693} = 56.84$, $P<0.001$, respectively). Total fish densities were 1.7 times greater (95% C.I. 1.4 to 2.1 times) and standing crops 4.8 times greater (95% C.I. 3.2 to 7.2 times) in Section I than in Sections II, III, and IV. Estimated densities of total fish were 1.6 times greater (95% C.I. 1.3 to 1.9 times) during the spring and summer than the winter (linear contrasts, $F_{1,693} = 20.28$, $P<0.001$). Densities of total fish were 1.8 times greater (95% C.I. 1.5 to 2.1 times) in riffles than pools or runs, while standing crop estimates were 3.3 times greater (95% C.I. 2.3 to 4.8 times) in pools than riffles or runs (linear contrasts, $F_{1,693} = 35.70$, $P<0.001$; $F_{1,693} = 38.84$, $P<0.001$, respectively). Nonnative fishes were approximately 2.6 times (95% C.I. 2.2 to 3.1 times) more dense and their standing crops were approximately 2.8 times (95% C.I. 2.0 to 4.0 times) that of native fishes across the river (Fig. 3, multiple regression and linear contrasts, $F_{1,693}$ = 112.86, $P<0.001$; $F_{1,693}$ = 32.97, $P<0.001$, respectively).

Section

Tables 6 and 7 provide density and standing crop estimates for every fish species by section of river and environment type. Grouped native fish densities overall were highest in Section I and IV of the river (Table 5; K-W tests, $P<0.05$), while their standing crops were greatest in Section I (K-W tests, $P<0.05$). Sonora suckers were most dense in sections I and IV (K-W tests, $P<0.05$), while the greatest standing crops were in Sections I, II, and IV (K-W tests, $P<0.05$). The highest densities and standing crops of desert suckers were in Sections I and IV (K-W tests, both $P<0.05$). Razorback sucker and longfin dace densities and standing crops were highest in the only sections they were caught, Sections III and IV, respectively (K-W tests, both $P<0.05$). Our data only suggested a difference in roundtail chub densities across sections of river (K-W tests, $X^2 = 6.77$, $P = 0.08$).

The highest densities of grouped nonnative fishes overall were in Section I (Table 5; K-W tests, $P<0.05$), and the highest standing crops of grouped nonnative fishes were in Sections I and II (K-W tests, $P<0.05$). The greatest densities of largemouth bass were in Section II (K-W tests, $P<0.05$, while the greatest standing crops of largemouth bass were in Sections II and IV (K-W tests, $P<0.05$). Densities and standing crops of smallmouth bass were greatest in Section I, green sunfish in Sections I, II, and III, and bluegill in Sections II, III, and IV (K-W tests, all $P<0.05$). Yellow bullhead densities and standing crops were greatest in Sections I and IV, channel catfish in Sections III and IV, and flathead catfish in Section III (K-W tests, all $P<0.05$). The highest densities and standing crops of common carp and mosquitofish were in Sections I and IV, red shiners in Section III, rainbow trout in Sections II, III, and IV, and tilapia in Section IV (K-W tests, all $P<0.05$).

Environment type

Tables 8 and 9 provide the estimated densities and standing crops of each fish species by environment type. There was no difference in grouped native fish densities overall by environment type (Table 5; K-W tests, $X^2 = 0.21$, $P = 0.90$), but grouped native fish standing crops were highest in pools and runs (K-W tests, $P<0.05$). Among environment types, the highest densities (Table 8) and standing crops (Table 9) of Sonora suckers and roundtail chub were in pools and runs, desert suckers in riffles and runs, longfin dace in riffles, and razorback suckers in pools (K-W tests, all $P<0.05$).

Grouped nonnative fish densities were highest in riffles (Table 5; K-W tests, $P<0.05$), while standing crops were greatest in pools (K-W tests, $P<0.05$). Yellow bullhead and mosquitofish were most dense and had the greatest standing crop in riffles and runs, and flathead catfish and red shiners in riffles (K-W tests, both $P<0.05$). The highest densities and standing crops of green sunfish, largemouth bass, and rainbow trout were greatest in pools and runs, and of bluegill and common carp in pools (K-W tests, all $P<0.05$). There was no difference in estimated densities or standing crops among environment types for channel catfish, smallmouth bass, or tilapia (K-W tests, $P> 0.20$).

Season

Tables 10 and 11 provide the estimated densities and standing crops of fishes in the river by season. The highest densities of grouped native fish occurred during the spring and summer (K-W tests, both $P<0.05$). Desert sucker was the only native species that showed a difference in estimated densities by season, being highest during the spring and summer (K-W tests, $P<0.05$).

Densities of grouped nonnative fishes were greatest during the spring and summer seasons (K-W tests, $P<0.05$). Smallmouth bass and green sunfish densities were highest during the spring and summer, rainbow trout during the spring and winter, and tilapia during the summer (K-W tests, all $P<0.05$). There was no difference in the estimated densities among seasons for channel catfish, flathead catfish, yellow bullhead, bluegill, largemouth bass, common carp, red shiner, or mosquitofish (K-W tests, $P>0.10$).

DISCUSSION

Distribution

Colorado pikeminnow, razorback sucker, and rainbow trout were only found close to where they were being stocked by the Arizona Game and Fish Department (Jahrke and Clark 1999). Of the fish species not being stocked, 3 of 4 native fish species and 7 of 12 nonnative fish species were found throughout the river (Table 4). Longfin dace were the only unstocked native species not found throughout the river. Longfin dace were only captured in Section IV, although historical records show that they were once found throughout the mainstem of the Verde River (Girmendonk and Young 1997; Rinne et al. 1998). J. Rinne (unpublished data) recorded 7 longfin dace in the upper Verde from

1999-2003, compared to 1,400 in 1994. There were extant populations in tributaries to the Verde River above Horseshoe Dam such as Red Creek (D. Weedman, personal communication), which may serve as source populations to the mainstem of the Verde during natural flooding events (Rinne et al. 1998).

Some of the nonnative fish species in the Verde River may be limited in their distribution by temperature and elevation preferences. Largemouth bass and bluegill are warm water species that were not captured in Section I. Smallmouth bass had the reverse pattern, and were not captured in Section IV of the river. However, Bryan et al. (2000) found one smallmouth bass in Section IV in 1999, but only at one sample site nearest to Bartlett Dam. Smallmouth bass may prefer or be more tolerant of higher elevations and cooler waters than largemouth bass. There was some overlap in distribution between the two species (Table 4).

Beecher et al. (1988) found that species richness was generally higher at low elevation, low gradient, large drainage area, and high stream order. We found this pattern in the Verde River, where species richness (excluding stocked fish) increased from Section I (11 species) to Section IV (15 species) of the river (Table 4). The increase in the number of species in Section IV could be the result of more habitat or niches for species to occupy, or the result of more human- induced introductions that are also prevented from moving upstream by Bartlett Dam.

Percent relative abundance

Several studies have documented a correlation between declining native fish abundance with increasing nonnative fish abundance (Meffe et al. 1983; Castleberry and

Cech 1986; Baltz and Moyle 1993; Rinne et al. 1998). Monitoring the percent relative abundance of native and nonnative fishes in the river can be useful for monitoring and quantifying the speed at which nonnative species are displacing native species.

We observed the highest percent relative abundance of native fishes in pools in Section I, and in riffles and runs in Section IV. Rinne et al. (1998) found the highest proportion of native fishes in Section I, and the lowest proportion in Section IV, although data from individual years within their study illustrate variable annual fish community structures among sections similar to our findings. Changes in percent relative abundances of native and nonnative fishes may be due to normal temporal fluctuations in fish community structure within the river caused by hydrographic changes (e.g. flooding or drought, controlled water releases below Bartlett dam), or the result of a long-term shift in fish community structure.

Total fish

It is important to estimate both density and standing crop of fishes when considering management. Densities alone could misrepresent fish community structure in the system, because many small fish may constitute the same percentage of total standing crop as one large fish. Standing crop estimates are often used to assess the health of sport fish populations for recreational or stocking purposes, but are also widely used for characterizing both marine and freshwater fisheries (Carlander 1955; Hoyt et al. 1979).

A comparison of total fish standing crop in a desert river (Verde River Sections I, II, III, & IV) versus temperate and tropical rivers is given in Table 12. Surprisingly, each section in the Verde River has a similar standing crop to various temperate and tropical rivers across the world (Table 12). Welcomme (1985) points out that although it is commonly thought that tropical waters are more productive than temperate waters, existing observations lend little support to the idea. Our data of standing crop within a Southwestern desert river supports his point. The variation in standing crops within and among riverine systems is a result of many complicated habitat and environmental factors that contribute to the productivity of the system, including stream order and elevation, discharge, channelization, depth, velocities, substrate type, temperature, fish population dynamics, and cover and trophic characteristics within streams (Hynes 1972; Welcomme 1985; Hoyer and Canfield 1991).

Hoyer and Canfield (1991) compared standing crop of fishes in 79 rivers across Wyoming, Vermont, Florida, Iowa, Ontario, Washington, and Missouri, and found that the average total fish standing crop values for each geographic region showed no relation to latitude, but were correlated to total phosphorus concentrations. Hoyer and Canfield (1991) suggest that phosphorus may be a key factor influencing total fish standing crop in streams. Burns (1971), however, found that only living space variables (surface area, volume, length, and flow) correlated significantly with biomass, and that physical and chemical factors did not seem useful for predicting carrying capacity in seven California coastal streams.

Section

Welcomme (1985) suggests that in general there is a progressive increase in standing crop from upstream to downstream with the widening of the river channel.

However, the estimated density and standing crop of all fishes combined in the Verde River were much higher in the upper- and lower- most sections (Sections I and IV) of river compared to the middle sections (Sections II and III). Several things could be contributing to the lower densities and standing crops of fishes in the middle section, including the deterioration of water quality that begins in Section II with the onset of groundwater pumping, irrigation, and the increase in sediment and turbidity levels caused by urban runoff, mining, agriculture, cattle grazing, and other habitat modifications (Thornburg and Tabor 1991; Butterwick 1995; Rinne et al. 1998; Hoffmann 2002). More research is needed to determine why the middle sections of the Verde River had such a lower density and standing crop of total fish than the upper and lower sections of river.

We estimated high densities and the greatest standing crops of native fish in Section I, even though no recent spawning events of native species were captured. It is interesting that native fish densities and standing crops were high in Section I where nonnative fish were also most dense and had high standing crops. Fish composition may influence the degree of native and nonnative fish interactions. Because this was an observational study, we can only speculate as to why such high densities and standing crops of native and nonnative fishes were found in Section I. Headwaters generally have the highest inputs of allochthonous organic material (Horne and Goldman 1994) that may provide fishes in Section I with a rich supply of preferred foods.

Section IV below Bartlett Dam also had high densities of native fish, but not as great of native fish standing crops as Section I. Several factors may have contributed to the estimated high densities of native fish in Section IV, including that it was the only section where we captured large numbers of recently hatched larval Sonora and desert suckers. Reproduction of fish in rivers appears to be correlated primarily with temperature and flow (Welcomme 1985). The lower Verde River winter-spring flows from Bartlett Dam have mimicked natural flooding, which may trigger spawning by native fishes and provide more spawning and rearing habitat for native fishes during the spring and summer (Bryan et al. 2000). Sonora and desert suckers usually spawn in the winter and spring (Sublette et al. 1990), but we captured recently hatched Sonora and desert suckers in Section IV in early summer (late May and June), coincident with peak flow releases from Bartlett Dam (Fig. 4). The warmer water temperatures in the lower Verde may also trigger emigration of native fishes from the Salt River ready to spawn (Bryan et al. 2000). Native fishes may concentrate in Section IV because Bartlett Dam precludes movement upriver. Further research is needed to determine the extent to which water flow below Bartlett Dam triggers spawning, and if flow should be controlled accordingly.

Environment type

Estimating the densities and standing crops of native and nonnative fishes within specific environment types is crucial to evaluating their interactions. While it is difficult to determine habitat preferences of fishes in nature, fish distributions and abundances are often used to infer them (Tyus 1991). The environment types where we found the highest densities and standing crops of native and nonnative fishes are consistent with the literature (Sublette et al. 1990; Rinne 1992b; Brouder et al. 2000; Bryan et al. 2000; Allison 2002). Nonnative fishes in the Verde were found in similar environment types as where they are native (Minckley 1973; Page and Burr 1991).

Nonnative fishes may be competing with native fishes occupying the same environment type. Several studies have examined how nonnative fishes may compete directly with native fishes for food and space (Gido and Propst 1999; Blinn et al. 1993; Robinson et al. 2000), and how they may affect native fishes indirectly by altering the grazing of invertebrates and changing algal species composition (Townsend 2003). The presence of nonnative fishes may alter the habitat (Moyle et al. 1986) or cause a shift in habitat use by native fishes (Brown and Moyle 1991; Blinn et al. 1993), thus preventing native fishes from carrying out their life cycles. Loach minnow, gila topminnow, speckled dace, spikedace, and longfin dace all utilize riffles (Minckley 1973; Rinne 1992b), and have all dramatically declined in number and distribution across the river. Nonnative red shiners, mosquitofish, flathead catfish, and yellow bullhead were also dense in riffles across the river (Table 5), and may have contributed to declines.

Season

We estimated more total fish in the spring and summer, which corresponds with spawning events of many native and nonnative fishes found in the Verde River (Minckley 1973; Sublette et al. 1990). We estimated lower densities of fish overall in the winter, possibly due to high mortality rates in young-of-year fish, or decreased capture efficiency due to less fish movement in lower water temperatures.

Data limitations

The density and standing crop estimates have some limitations. We did not take into account other environmental measures such as stream flow, substrate, vegetation cover, and food availability, which may all influence the estimated distribution, density, and standing crop of fishes throughout the river (Welcomme 1985; Horne and Goldman 1994; Barrett and Maughan 1995).

The Zippin method was used to estimate sizes of fish populations, and occasionally the assumptions were violated. The large mesh size of block nets precluded the capture of small fish, so the assumption of a closed population was violated. Because small fish may have escaped capture, densities of smaller sized individual fish and smaller sized fish species such as red shiners and mosquitofish were probably underestimated. Density estimates were conservative because they were based on the total number of individuals actually caught.

Relative density estimates are useful to detect spatial or temporal differences in densities across areas, so sampling should be carried out with as similar conditions as possible (Seber 1982). Because each of our sites was sampled on separate days, weather and water conditions were not necessarily homogeneous for comparative purposes, and therefore the assumption of equal probability of capture for all animals across the river was violated. This assumption may have also been violated because we did not consider different diel movement patterns of fish, or different susceptibilities of fish to capture by electrofishing.

We only sampled fish at river access points available by road, and although our sites were selected at stratified random, 7 of the 12 sites were open to public fishing. The effects of angling pressure on these estimates, especially for nonnative sport fish, should be considered. Brana et al. (1992) found a difference in age and size structure of brown trout populations at exploited versus unexploited mountain stream sites, but did not show a reduction in fish density. Clady (1975) concluded in his two year study on exploited populations of smallmouth and largemouth bass in lakes that there were no changes in annual natural mortality, growth, standing crop, or production attributable to reductions in numbers of fish caused by angler harvest. However, Welcomme (1985) cautions that as fishing pressure increases there is a probable reduction in mean standing crop. The effects of angling may be a reason we only caught four flathead catfish over 400mm (between 400-505 mm), while larger ones exist in the river (Weedman, personal communication).

Management implications

Most of the native fishes that have declined dramatically in the Verde River are small species that utilize riffles (loach minnow, speckled dace, spikedace, longfin dace, and gila topminnow; Minckley 1973; Rinne 1992b). Small fish have a higher risk of being eaten by large fish because they are still small as adults, especially if they did not evolve with the predator (Johnson et al. 1993; Lima and Dill in Baber 2003) and utilize the same space (Ruppert 1993). Larger species may also be impacted by predation during egg and larval stages. In the Colorado River system, nonnative red shiners preyed on larval razorback suckers and Colorado pikeminnow utilizing the same space (Ruppert 1993). Razorback sucker and Colorado pikeminnow populations have also declined dramatically in the Verde River, but are being repatriated by the Arizona Game and Fish Department (Jahrke and Clark 1999).

The density estimates of nonnative predators will be multiplied by their estimated consumption rates (Leslie 2003) to estimate the loss of native fishes to predation by nonnative fishes in the Verde River (Chapter 2). Patterns of prey fish population declines result when predators consume more prey fish than prey fish are manufacturing. When coupled with production, standing crop estimates can be used to assess and quantify the availability of prey to predators (Ney 1990).

We recommend continued long-term monitoring of the estimated distribution, percent relative abundance, density, and standing crop of fishes in the Verde River. Monitoring will help detect changes in fish community structure, and provide useful information that will help guide reintroduction efforts and other management actions.

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Table 1. Fish species historically found in the Verde River, with their origin, common name, status, abbreviated and scientific names, family, and source if not found in this study.

ORIGIN	COMMON NAME	STATUS	ABBREV	SPECIES NAME	FAMILY	SOURCE
Native	* CO pikeminnow	FE, WSCA	COP	*Ptychocheilus lucius*	Cyprinidae	
	* Desert sucker		DSS	*Catostomus clarki*	Catostomidae	
	Gila topminnow	FE, WSCA	GIT	*Poeciliopsis occidentalis*	Poeciliidae	Minckley 1973
	Loach minnow	FT, WSCA	LOM	*Tiaroga cobitis*	Cyprinidae	Rinne et al. 1998
	* Longfin dace		LFD	*Agosia chrysogaster*	Cyprinidae	
	* Razorback sucker	FE, WSCA	RZB	*Xyrauchen texanus*	Catostomidae	
	* Roundtail chub	WSCA	RTC	*Gila robusta robusta*	Cyprinidae	
	* Sonora sucker		SNS	*Catostomus insignis*	Catostomidae	
	Speckled dace		SDD	*Rhinichthys osculus*	Cyprinidae	Rinne et al. 1998
	Spikedace	FT, WSCA	SKD	*Meda fulgida*	Cyprinidae	Rinne et al. 1998
Nonnative	Black crappie		BKC	*Pomoxis nigromaculatus*	Centrarchidae	Bryan et al. 2000
	* Bluegill		BLG	*Lepomis macrochirus*	Centrarchidae	
	* Channel catfish		CCF	*Ictalurus punctatus*	Ictaluridae	
	* Common carp		CRP	*Cyprinus carpio*	Cyprinidae	
	Fathead minnow		FHM	*Pimephales promelas*	Cyprinidae	Bryan et al. 2000
	* Flathead catfish		FHC	*Pylodictis olivaris*	Ictaluridae	
	* Green sunfish		GRS	*Lepomis cyanellus*	Centrarchidae	
	* Largemouth bass		LMB	*Micropterus salmoides*	Centrarchidae	
	* Mosquitofish		MSQ	*Gambusia affinis*	Poeciliidae	
	* Rainbow trout		RBT	*Oncorhynchus mykiss*	Salmonidae	
	* Red shiner		RSN	*Cyprinella lutrensis*	Cyprinidae	
	Sailfin molly		SAF	*Poecilia mexicana*	Poeciliidae	Bryan et al. 2000
	Shortfin molly		SHM	*Poecilia latipinna*	Poeciliidae	Bryan et al. 2000
	* Smallmouth bass		SMB	*Micropterus dolomieu*	Centrarchidae	
	* Threadfin shad		TFS	*Dorosoma petenense*	Clupeidae	
	* Tilapia		TLP	*Tilapia spp.*	Cichlidae	
	Yellow bass		YWB	*Morone mississippiensis*	Percichthyidae	Bryan et al. 2000
	* Yellow bullhead		YBH	*Ameiurus natalis*	Ictaluridae	

* Species encountered in this study

FE = Federally Endangered

FT = Federally Threatened

WSCA = Wildlife of Special Concern in Arizona

Table 2. The Verde River was divided up into four sections based on the degree of human impact (Rinne et al. 1998). The approximate length, elevation and temperature ranges of sample sites, and median stream flow for each section is given.

Section	Approximate Length (km)	Elevation ranges of sample sites	Temperature ranges (C)	Median stream flow (m3/sec)*	Human impact
I	69	1158 - 1288	6.9 - 28.0	0.71	From headwaters to Sycamore creek; most pristine section; few road access points
II	49	936 - 1032	9.0 - 28.0	3.82	From Tapco at Clarkdale to Beasley Flats; start of human development, water diversions; many road access points
III	90	648 - 911	9.0 - 29.0	6.26	From Beasley flat to Sheeps Bridge above Horseshoe reservoir; federally designated "Wild and Scenic"; few road access points
IV	41	415 - 486	9.0 - 33.0	9.71	Below Bartlett Dam to Salt River; higher, regulated flows; separated from first three sections by two dams

Table 3. Site name, number, and coordinates of sample sites along the Verde River.

Site Name	Site #	Latitude	Longitude
Game and Fish Property	1	34.8683	-112.4014
Perkinsville Bridge	2	34.8946	-112.2077
Aston Property	3	34.8648	-112.0852
Perkins Property	4	34.7955	-112.059
Black Bridge	5	34.5733	-111.8556
White Bridge	6	34.5528	-111.8506
Kovacavich Property	7	34.4938	-111.816
Childs	8	34.3582	-111.7105
Sheeps Bridge	9	34.0769	-111.7079
Needle Rock	10	33.7714	-111.6647
Ft. McDowell	11	33.6379	-111.6686
Beeline Hwy	12	33.5818	-111.6718

Table 4. Number of individuals, section of river, median lengths, elevation, and temperature ranges of where each fish species was caught in the Verde River from March 2002- January 2003.

			Section				Length (mm)		Elevation (m)		Water temperature (C)	
Origin	Species	N	I	II	III	IV	Range	Median	Range	Median	Range	Median
Native	CO pikeminnow*	2		X			329-375	352	936	936	22	22
	Desert sucker	10022	X	X	X	X	13-486	126	415-1288	486	7-33	19
	Longfin dace	316				X	25-90	56	415-486	415	12-33	18
	Razorback sucker*	17			X		310-508	455	648-835	825	18-29	21
	Roundtail chub	158	X	X	X	X	27-457	366	415-1288	936	9-27	18
	Sonora sucker	4444	X	X	X	X	11-750	191	415-1288	486	7-33	22
Nonnative	Bluegill	25		X	X	X	19-190	130	415-940	486	14-33	23
	Channel catfish	284	X	X	X	X	31-573	271	415-1288	415	9-30	22
	Common carp	799	X	X	X	X	21-950	397	415-1288	1196	7-33	19
	Flathead catfish	184	X	X	X	X	27-505	115	415-1288	825	10-33	22
	Green sunfish	869	X	X	X	X	12-216	85	415-1288	1196	7-29	19
	Largemouth bass	1210		X	X	X	12-515	134	415-1032	825	9-33	21
	Mosquitofish	1911	X	X	X	X	9-56	27	415-1288	430	9-33	21
	Rainbow trout*	32		X	X	X	225-356	265	415-940	936	13-24	13
	Red shiner	8186	X	X	X	X	9-98	52	415-1288	911	7-33	21
	Smallmouth bass	1640	X	X	X		10-340	109	648-1288	1196	7-28	20
	Threadfin shad	1				X	51	51	430	430	27	27
	Tilapia	197				X	21-317	179	415-486	486	9-33	20
	Yellow bullhead	342	X	X	X	X	12-328	110	415-1288	940	7-33	21

* Stocked species

Table 5. Sections, environment types, and seasons where and when fish were most dense according to K-W tests where *P* <0.05 for all fish species caught in the Verde River from March 2002- January 2003.

			Section					Environment type				Season			
Origin	Species	N	I	II	III	IV	No diff	Pool	Riffle	Run	No diff	Spr	Sum	Win	No diff
Native	Grouped native	14959	X			X					X	X	X		
	CO pikeminnow*	2													
	Desert sucker	10022	X			X			X	X		X	X		
	Longfin dace	316				X			X						X
	Razorback sucker	17			X			X							X
	Roundtail chub	158					X	X		X					X
	Sonora sucker	4444	X			X		X		X					X
Nonnative	Grouped nonnative	15680	X						X			X	X		
	Bluegill	25		X	X	X		X							X
	Channel catfish	284			X	X					X				X
	Common carp	799	X			X		X							X
	Flathead catfish	184			X				X						X
	Green sunfish	869	X	X	X			X		X		X	X		
	Largemouth bass	1210		X				X		X					X
	Mosquitofish	1911	X			X			X	X					X
	Rainbow trout	32		X	X	X		X		X		X		X	
	Red shiner	8186			X				X						X
	Smallmouth bass	1640	X								X	X	X		
	Threadfin shad*	1													
	Tilapia	197				X					X		X		
	Yellow bullhead	342	X			X			X	X					X

* No statistical analyses performed

Table 6. Average densities of fishes (# individuals/ 100m2) in the Verde River from Mar 2002- Jan 2003.

Section I	POOL (n=30)		RIFFLE (n=29)		RUN (n=30)	
	Density	SE	Density	SE	Density	SE
Bluegill						
Channel catfish	0.01	0.01	0.04	0.04	0.02	0.01
Colorado pikeminnow						
Common carp	2.15	0.62	0.15	0.09	0.63	0.28
Desert sucker	2.23	0.62	11.42	4.43	0.75	0.26
Flathead catfish	0.02	0.02	0.28	0.12	0.02	0.01
Green sunfish	1.85	0.59	0.41	0.19	1.75	0.64
Largemouth bass						
Longfin dace						
Mosquitofish	0.03	0.02	0.13	0.06	3.65	1.4
Rainbow trout						
Razorback sucker						
Red shiner	2.29	1.06	14.31	6.87	13.55	8.15
Rountail chub	0.22	0.08	0.05	0.03	0.08	0.03
Smallmouth bass	4.44	1.01	7.00	2.73	4.89	1.01
Sonora sucker	5.22	1.19	0.43	0.13	0.75	0.2
Threadfin shad						
Tilapia						
Unknown Catastomus						
Yellow bullhead	0.13	0.08	1.04	0.43	0.71	0.19

Section II	POOL (n=30)		RIFFLE (n=30)		RUN (n=30)	
	Density	SE	Density	SE	Density	SE
Bluegill	0.00	0.00			0.01	0.01
Channel catfish	0.02	0.02	0.01	0.01	0.01	0.01
Colorado pikeminnow					0.01	0.01
Common carp	0.21	0.08			0.07	0.04
Desert sucker	0.37	0.17	0.37	0.17	0.66	0.22
Flathead catfish	0.03	0.02	0.11	0.04	0.10	0.04
Green sunfish	0.37	0.09	0.11	0.06	0.27	0.07
Largemouth bass	1.49	0.28	0.38	0.11	0.99	0.24
Longfin dace						
Mosquitofish	0.16	0.08	1.92	0.86	0.72	0.58
Rainbow trout	0.10	0.06			0.05	0.04
Razorback sucker						
Red shiner	1.70	0.99	29.53	11.34	2.06	1.20
Rountail chub	0.09	0.04	0.03	0.02	0.07	0.04
Smallmouth bass	0.87	0.16	1.24	0.43	0.96	0.24
Sonora sucker	0.95	0.19	0.02	0.01	0.80	0.25
Threadfin shad						
Tilapia						
Unknown Catastomus						
Yellow bullhead	0.08	0.04	0.34	0.15	0.19	0.07

Cont. Table 6. Average densities of fishes (# individuals/ 100m2) in the Verde River from Mar 2002- Jan 2003.

Section III	POOL (n=28)		RIFFLE (n=30)		RUN (n=27)	
	Density	SE	Density	SE	Density	SE
Bluegill	0.02	0.01			0.01	0.01
Channel catfish	0.03	0.02	0.22	0.10	0.05	0.02
Colorado pikeminnow						
Common carp	0.25	0.10			0.04	0.02
Desert sucker	0.08	0.05	0.22	0.11	1.13	0.44
Flathead catfish	0.02	0.02	0.87	0.22	0.07	0.04
Green sunfish	0.39	0.16	0.43	0.16	1.04	0.41
Largemouth bass	0.43	0.14	0.12	0.04	0.58	0.15
Longfin dace						
Mosquitofish	2.24	1.65	0.27	0.10	0.61	0.44
Rainbow trout	0.01	0.01				
Razorback sucker	0.07	0.03				
Red shiner	3.75	2.52	29.73	6.13	5.58	1.63
Rountail chub			0.00	0.00	0.16	0.06
Smallmouth bass	0.04	0.03	0.25	0.10	0.25	0.06
Sonora sucker	0.08	0.06	0.01	0.01	0.48	0.22
Threadfin shad						
Tilapia						
Unknown Catastomus						
Yellow bullhead	0.00	0.00	0.04	0.03	0.00	0.00

Section IV	POOL (n=30)		RIFFLE (n=30)		RUN (n=30)	
	Density	SE	Density	SE	Density	SE
Bluegill	0.05	0.04			0.02	0.01
Channel catfish	0.82	0.54	0.15	0.08	0.07	0.03
Colorado pikeminnow						
Common carp	0.38	0.16	0.18	0.11	0.09	0.03
Desert sucker	0.09	0.06	43.17	13.64	23.02	6.98
Flathead catfish	0.01	0.00	0.08	0.04	0.01	0.01
Green sunfish	0.48	0.22	0.08	0.05	0.02	0.01
Largemouth bass	1.26	0.27	0.30	0.10	0.60	0.19
Longfin dace			2.13	1.03	0.46	0.38
Mosquitofish	1.20	0.51	3.12	1.12	8.46	4.18
Rainbow trout	0.01	0.01				
Razorback sucker						
Red shiner	0.01	0.01	4.01	1.33	0.44	0.14
Rountail chub	0.00	0.00			0.09	0.04
Smallmouth bass						
Sonora sucker	0.34	0.19	9.07	2.69	12.56	5.54
Threadfin shad	0.01	0.01				
Tilapia	0.45	0.24	0.07	0.02	0.37	0.15
Unknown Catastomus			0.17		0.16	
Yellow bullhead	0.06	0.03	0.23	0.07	0.16	0.06

Table 7. Average standing crop of fishes (g fish/ 100m2) in the Verde River from Mar 2002- Jan 2003.

Section I	POOL (n=30)		RIFFLE (n=29)		RUN (n=30)	
	Biomass	SE	Biomass	SE	Biomass	SE
Bluegill						
Channel catfish	12.97	12.97	4.70	4.70	0.15	0.11
Colorado pikeminnow						
Common carp	1334.14	486.88	21.15	13.37	206.39	111.68
Desert sucker	538.92	139.65	1395.66	589.87	142.31	66.70
Flathead catfish	8.53	7.07	19.33	10.10	1.94	1.91
Green sunfish	37.02	9.17	5.50	2.43	22.62	8.52
Largemouth bass						
Longfin dace						
Mosquitofish	0.02	0.02	0.08	0.05	2.49	1.04
Rainbow trout						
Razorback sucker						
Red shiner	2.41	1.30	32.48	16.86	22.18	14.24
Rountail chub	64.64	31.09	16.61	16.58	15.70	10.07
Smallmouth bass	178.40	43.89	200.09	55.50	122.89	19.33
Sonora sucker	2717.77	665.89	134.80	61.36	321.82	126.52
Threadfin shad						
Tilapia						
Unknown Catastomus						
Yellow bullhead	10.28	5.70	17.45	6.34	25.83	9.01

Section II	POOL (n=30)		RIFFLE (n=30)		RUN (n=30)	
	Biomass	SE	Biomass	SE	Biomass	SE
Bluegill	0.11	0.11			0.27	0.27
Channel catfish	1.69	1.42	0.05	0.05	0.55	0.39
Colorado pikeminnow					2.20	2.2
Common carp	352.73	154.76			85.02	46.4
Desert sucker	112.11	61.36	23.01	9.85	190.89	87.52
Flathead catfish	8.23	5.91	2.96	1.2	22.50	10.63
Green sunfish	8.93	2.48	1.00	0.53	4.13	1.04
Largemouth bass	140.56	38.77	3.10	1.01	51.73	13.61
Longfin dace						
Mosquitofish	0.13	0.07	0.94	0.46	0.32	0.26
Rainbow trout	22.39	14.58			11.93	8.29
Razorback sucker						
Red shiner	3.71	2.55	50.75	18.05	5.10	3.46
Rountail chub	35.20	19.53	0.30	0.27	29.67	16.67
Smallmouth bass	72.79	16.64	23.67	6.78	53.26	15.24
Sonora sucker	682.31	143.76	0.62	0.50	626.28	224.54
Threadfin shad						
Tilapia						
Unknown Catastomus						
Yellow bullhead	2.91	1.33	3.70	1.96	14.29	4.91

Cont. Table 7. Average standing crop of fishes (g fish/ 100m2) in the Verde River from Mar 2002- Jan 2003.

Section III	POOL (n=28)		RIFFLE (n=30)		RUN (n=27)	
	Biomass	SE	Biomass	SE	Biomass	SE
Bluegill	1.49	1.09			0.37	0.37
Channel catfish	9.99	7.27	3.26	2.41	0.65	0.47
Colorado pikeminnow						
Common carp	324.98	124.18			84.99	46.96
Desert sucker	29.34	20.83	29.58	19.73	492.61	190.05
Flathead catfish	2.04	1.12	21.17	5.33	1.85	0.94
Green sunfish	6.85	2.26	9.03	3.18	9.36	3.45
Largemouth bass	60.48	25.00	2.65	0.90	3.04	11.64
Longfin dace						
Mosquitofish	1.44	1.01	0.08	0.03	0.21	0.12
Rainbow trout	4.00	4.00				
Razorback sucker	57.48	27.27				
Red shiner	3.21	1.72	56.09	16.92	5.86	1.64
Rountail chub			0.04	0.04	74.78	29.28
Smallmouth bass	1.74	1.35	8.24	3.28	12.02	3.22
Sonora sucker	76.13	56.37	6.32	6.32	452.27	209.43
Threadfin shad						
Tilapia						
Unknown Catastomus						
Yellow bullhead	0.58	0.58	0.08	0.06	0.14	0.14

Section IV	POOL (n=30)		RIFFLE (n=30)		RUN (n=30)	
	Biomass	SE	Biomass	SE	Biomass	SE
Bluegill	3.03	2.02			0.83	0.63
Channel catfish	252.47	152.26	5.31	4.31	8.94	6.83
Colorado pikeminnow						
Common carp	682.40	296.83	67.66	67.33	83.13	31.62
Desert sucker	18.72	11.48	283.68	112.34	2963.44	1276.72
Flathead catfish	5.15	3.27	0.99	0.54	2.03	1.26
Green sunfish	11.44	5.21	1.07	0.65	0.61	0.38
Largemouth bass	261.90	82.27	9.01	5.02	80.48	19.82
Longfin dace			3.07	1.35	0.36	0.26
Mosquitofish	0.48	0.19	1.27	0.51	2.54	1.40
Rainbow trout	2.72	2.72				
Razorback sucker						
Red shiner	0.02	0.02	7.66	3.18	7.75	6.80
Rountail chub	0.88	0.88			33.22	17.39
Smallmouth bass						
Sonora sucker	166.81	117.95	1367.86	1310.32	1083.92	467.68
Threadfin shad	0.02	0.02				
Tilapia	59.72	44.20	0.86	0.48	11.12	3.91
Unknown Catastomus			0.01	0.01	0.08	0.08
Yellow bullhead	6.60	3.15	3.69	1.00	5.27	1.78

Table 8. Estimated densities of fishes (# individuals/ 100m2) in the Verde River by environment type from March 2002- Jan 2003.

Species	Pool (n=118)		Riffle (n=119)		Run (n=117)	
	Density	SE	Density	SE	Density	SE
Bluegill	0.02	0.01			0.82	0.00
Channel catfish	0.22	0.14	0.16	0.03	0.34	0.01
Colorado pikeminnow					0.00	0.00
Common carp	0.76	0.18	0.82	0.04	0.21	0.08
Desert sucker	0.71	0.18	13.82	3.91	6.52	1.99
Flathead catfish	0.02	0.01	0.34	0.07	0.52	0.01
Green sunfish	0.78	0.17	0.26	0.06	0.76	0.20
Largemouth bass	0.80	0.12	0.25	0.04	0.54	0.09
Longfin dace			0.54	0.27	0.12	0.10
Mosquitofish	0.89	0.42	1.37	0.37	3.44	1.17
Rainbow trout	0.03	0.02			0.15	0.01
Razorback sucker	0.02	0.01				
Red shiner	1.91	0.70	19.44	3.76	5.45	2.17
Rountail chub	0.08	0.02	0.22	0.01	0.99	0.02
Smallmouth bass	1.36	0.31	2.81	0.71	1.56	0.32
Sonora sucker	1.67	0.36	2.40	0.76	3.73	1.49
Threadfin shad	0.00	0.00				
Tilapia	0.12	0.06	0.17	0.01	0.94	0.04
Unknown Catastomus					0.04	
Yellow bullhead	0.07	0.02	0.45	0.12	0.27	0.06

Table 9. Estimated standing crop of fishes (g fish/ 100m2) in the Verde River by environment type from March 2002- Jan 2003.

Species	Pool (n=118)		Riffle (n=119)		Run (n=117)	
	Standing crop	SE	Standing crop	SE	Standing crop	SE
Bluegill	1.15	0.58			0.37	0.19
Channel catfish	70.28	39.64	3.32	1.68	2.62	1.77
Colorado pikeminnow					0.56	0.56
Common carp	679.47	155.76	22.29	17.26	115.65	33.77
Desert sucker	177.24	43.47	424.73	153.62	958.97	345.29
Flathead catfish	6.05	2.48	11.04	2.91	7.23	2.88
Green sunfish	16.22	2.99	4.14	1.05	9.17	2.44
Largemouth bass	116.67	25.27	3.72	1.33	40.92	7.19
Longfin dace			0.77	0.36	0.09	0.07
Mosquitofish	0.50	0.25	0.60	0.18	1.42	0.46
Rainbow trout	7.33	3.93			3.06	2.15
Razorback sucker	13.64	6.77				
Red shiner	2.32	0.83	36.78	7.62	10.34	4.16
Rountail chub	25.61	9.55	4.13	4.04	37.50	9.59
Smallmouth bass	64.27	13.58	56.81	15.44	47.94	7.71
Sonora sucker	924.98	200.30	379.24	330.77	625.40	145.86
Threadfin shad	0.00	0.00				
Tilapia	15.18	11.35	0.22	0.12	2.85	1.09
Unknown Catastomus			0.00	0.00	0.02	0.02
Yellow bullhead	5.17	1.71	6.13	1.73	11.67	2.78

Table 10. Estimated densities (# individuals/100m2) of fishes by season across the river between March 2002- January 2003.

Species	Spring		Summer		Winter	
	Density	SE	Density	SE	Density	SE
Bluegill	0.00	0.00	0.02	0.01	0.00	0.00
Channel catfish	0.01	0.04	0.19	0.11	0.05	0.02
Colorado pikeminnow			0.00	0.00		
Common carp	0.26	0.07	0.38	0.10	0.40	0.17
Desert sucker	6.73	2.32	8.11	2.65	5.89	2.67
Flathead catfish	0.13	0.04	0.19	0.05	0.08	0.03
Green sunfish	0.64	0.13	0.65	0.13	0.49	0.22
Largemouth bass	0.50	0.10	0.65	0.09	0.34	0.06
Longfin dace	0.32	0.23	0.04	0.02	0.36	0.22
Mosquitofish	1.39	0.52	2.38	0.80	1.74	0.83
Rainbow trout	0.04	0.02	0.00	0.00	0.00	0.00
Razorback sucker	0.01	0.01	0.01	0.00		
Red shiner	6.48	1.35	14.67	3.55	3.73	0.89
Rountail chub	0.06	0.02	0.07	0.02	0.06	0.02
Smallmouth bass	1.95	0.41	2.01	0.61	0.92	0.22
Sonora sucker	4.16	1.59	2.72	0.68	0.80	0.35
Threadfin shad			0.00	0.00		
Tilapia	0.09	0.07	0.09	0.03	0.04	0.02
Unknown Catastomus	0.05					
Yellow bullhead	0.17	0.05	0.31	0.07	0.25	0.11

Table 11. Estimated standing crop (g fish/100m2) of fishes by season across the river between March 2002- January 2003.

Species	Spring		Summer		Winter	
	Standing crop	SE	Standing crop	SE	Standing crop	SE
Bluegill	0.15	0.08	1.00	0.50	0.20	0.10
Channel catfish	27.34	13.61	41.42	31.52	1.54	0.70
Colorado pikeminnow			0.46	0.46		
Common carp	257.65	86.42	236.05	68.10	336.60	138.23
Desert sucker	549.20	210.00	614.48	248.97	356.36	155.28
Flathead catfish	9.18	3.27	9.45	2.36	5.21	2.77
Green sunfish	13.48	2.74	11.25	2.25	4.10	1.82
Largemouth bass	43.09	11.28	62.13	17.30	53.09	16.30
Longfin dace	0.21	0.14	0.03	0.02	0.73	0.39
Mosquitofish	0.93	0.33	1.04	0.36	0.47	0.18
Rainbow trout	10.07	4.77	0.38	0.38	0.79	0.79
Razorback sucker	9.26	5.90	4.29	3.46		
Red shiner	13.72	3.54	28.66	6.88	2.96	0.66
Rountail chub	16.02	6.41	22.64	6.76	28.32	11.46
Smallmouth bass	72.63	15.49	59.18	12.51	35.64	8.27
Sonora sucker	894.41	375.77	566.52	127.15	484.60	200.58
Threadfin shad			0.00	0.00		
Tilapia	15.10	12.40	2.71	0.92	1.29	0.67
Unknown Catastomus	0.03	0.02				
Yellow bullhead	8.24	2.32	7.66	1.90	7.00	2.29

Table. 12 A comparison of the average total fish standing crop (biomass) and species richness in the Verde River from March 2002- January 2003 to other temperate and tropical rivers around the world.

River	Biomass (kg/ha)	Species richness	References
Amazon Manaus, Brazil	1600.0		Bayley 1983; Welcomme 1985
Big Springs Creek, Idaho, USA	84.2	4	Goodnight and Bjornn 1971; Welcomme 1985
Bulu, Malaysia	21.5	16	Watson and Balon 1984; Randall et al. 1995
Clemons Fork, Kentucky 1, USA	54.9	1	Lotrich 1973; Welcomme 1985
Clemons Fork, Kentucky 2, USA	63.6	8	Lotrich 1973; Welcomme 1985
Clemons Fork, Kentucky 3, USA	71.5	15	Lotrich 1973; Welcomme 1985
Deer Creek, Oregon, USA	84.7	4	Chapman 1965; Welcomme 1985
Florida (N=15), USA	95.1		Hoyer and Canfield 1991
Iowa (N=12), USA	251.0		Hoyer and Canfield 1991
Kaha, Malaysia	38.5	32	Watson and Balon 1984; Randall et al. 1995
Kejin 1, Malaysia	173.1	23	Watson and Balon 1984; Randall et al. 1995
Kejin 2, Malaysia	71.0	19	Watson and Balon 1984; Randall et al. 1995
Lawa 1, Malaysia	30.5	25	Watson and Balon 1984; Randall et al. 1995
Lawa 2, Malaysia	21.3	29	Watson and Balon 1984; Randall et al. 1995
Lemhi River (upper), Idaho, USA	212.0	5	Goodnight and Bjornn 1971; Welcomme 1985
Missouri (N=1), USA	57.0		Hoyer and Canfield 1991
Needle Branch, Oregon, USA	45.9	3	Chapman 1965; Welcomme 1985
Payau, Malaysia	27.1	23	Watson and Balon 1984; Randall et al. 1995
Utrata 1, Poland	310.5	3	Penczak 1981; Mahon and Balon 1985
Utrata 2, Poland	142.5	8	Penczak 1981; Mahon and Balon 1985
Utrata 3, Poland	86.6	4	Penczak 1981; Mahon and Balon 1985
Utrata 4, Poland	45.6	5	Penczak 1981; Mahon and Balon 1985
Utrata 5, Poland	10.8	8	Penczak 1981; Mahon and Balon 1985
Utrata 6, Poland	40.9	5	Penczak 1981; Mahon and Balon 1985
Verde River S1, Arizona, USA	255.3	11	
Verde River S2, Arizona, USA	88.4	15	
Verde River S3, Arizona, USA	60.9	15	
Verde River S4, Arizona, USA	250.2	16	
Vermont (N=19), USA	7.4		Hoyer and Canfield 1991
Warkocz, Poland	307.5	7	Mahon and Balon 1985; Randall et al. 1995
Washington (N=2), USA	52.0		Hoyer and Canfield 1991

Fig. 1. The four sections of the Verde River based on the degree of human impact (Rinne et al. 1998). Three sites were sampled within each section.

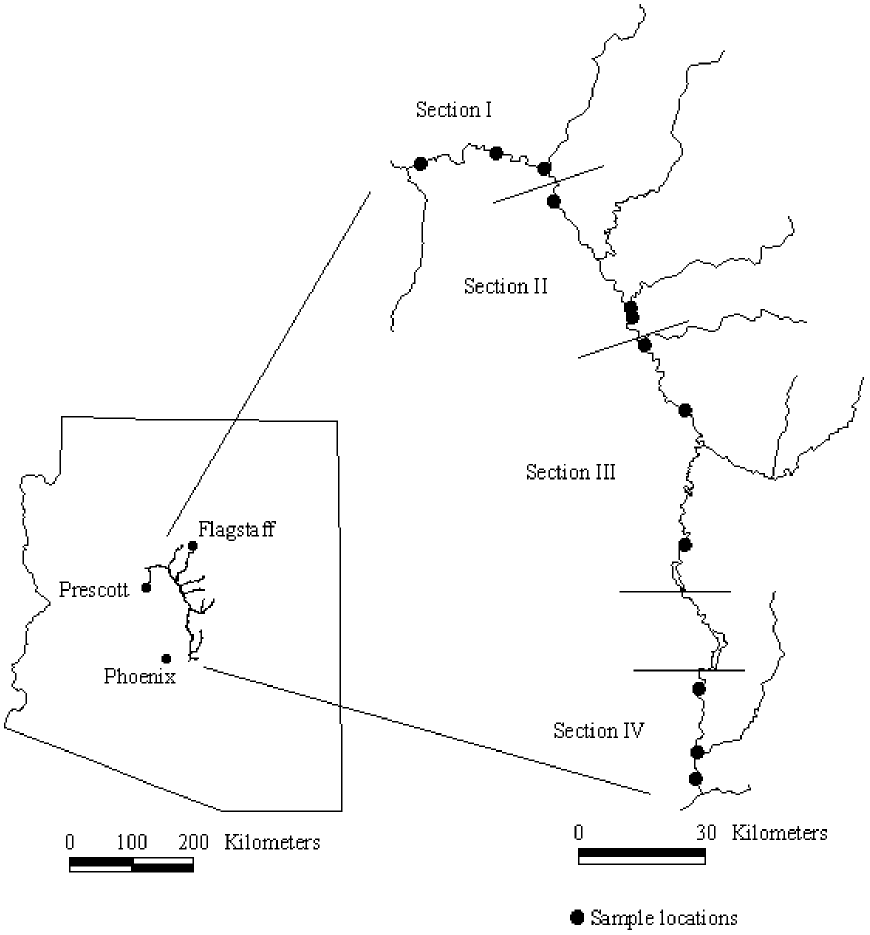


Fig. 2. The percent relative abundances of native and nonnative fishes in the Verde River by section and environment type, from March - January 2003.

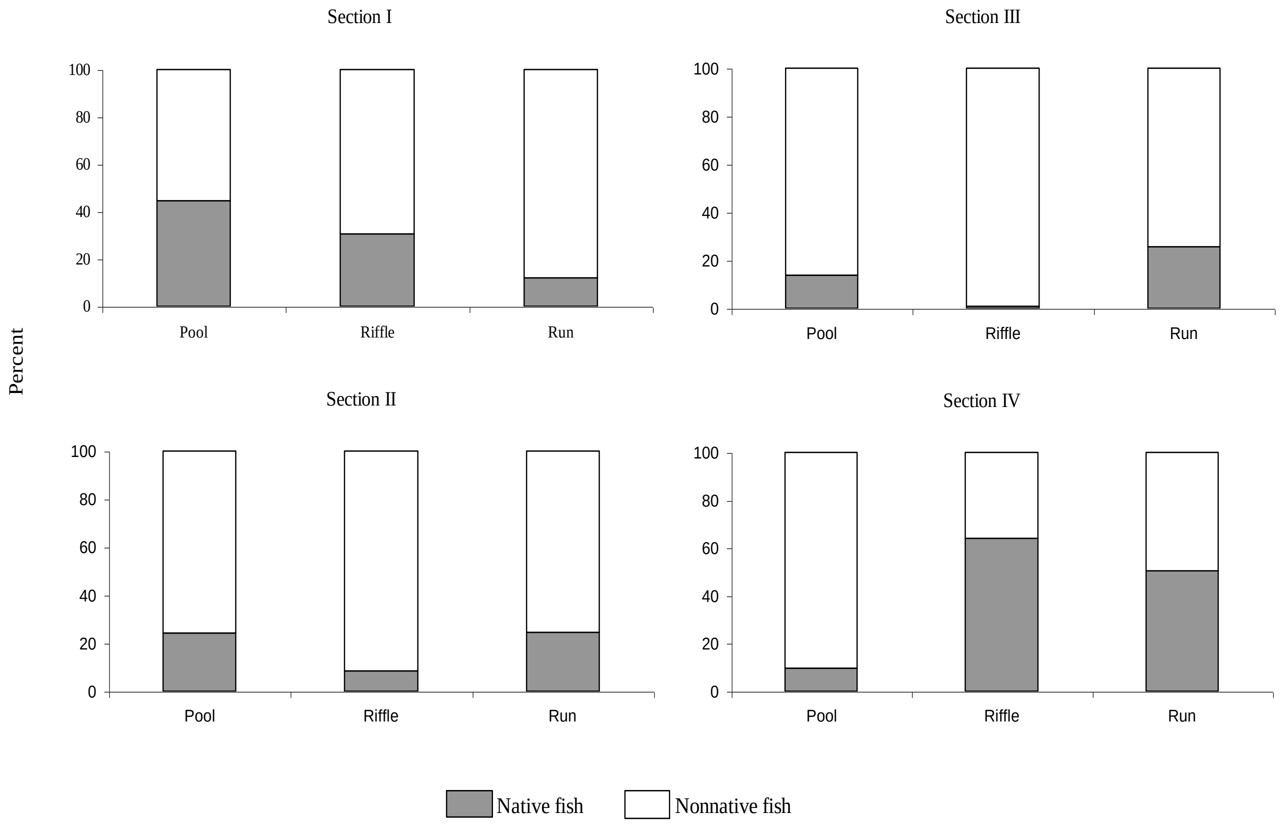


Fig. 3. Average [log transformed scale] density (# fish/ 100m2) and standing crop (g fish/ 100m2) of native and nonnative fishes in pools, riffles, and runs across the Verde River from March 2002- January 2003.

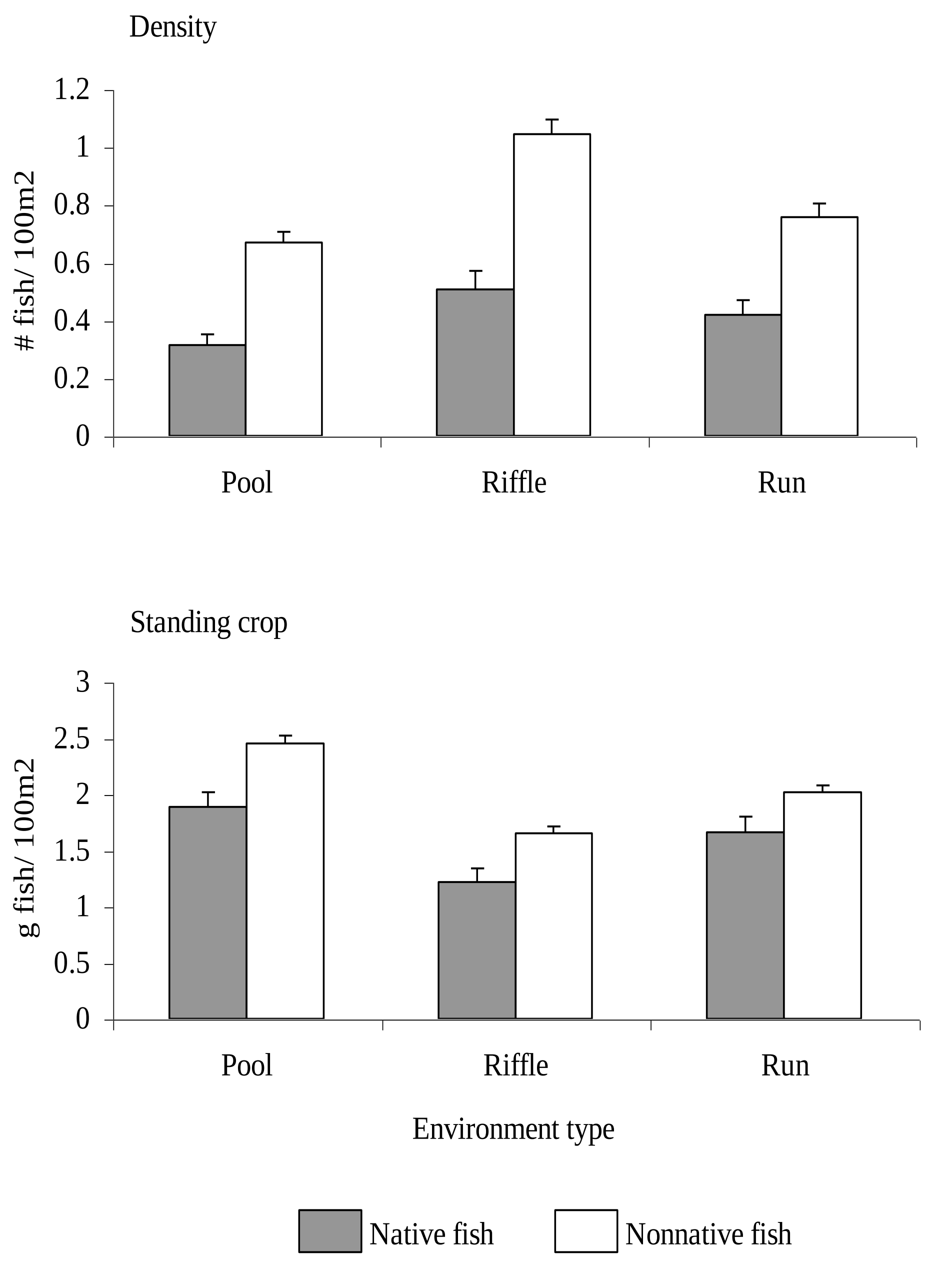
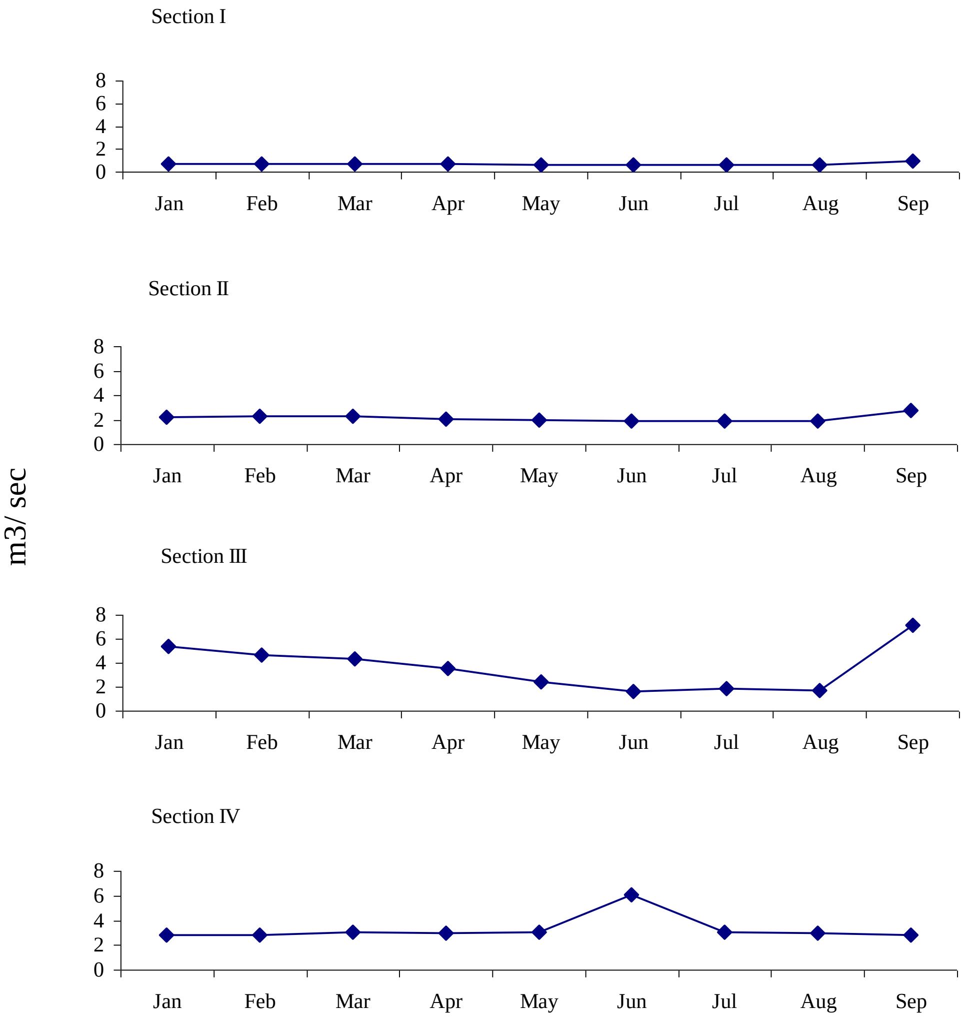


Fig. 4. Average monthly flows (USGS 2002b) in each section of the Verde River from Jan - Sep 2002.



ESTIMATED LOSS OF TOTAL AND NATIVE PREY FISH TO PREDATION BY NONNATIVE FISHES IN THE VERDE RIVER, ARIZONA

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ABSTRACT

Predation by nonnative fishes may be contributing to the decline of native fishes in the Southwest. We conducted field investigations from March 2002 through January 2003 to estimate the loss of native fishes to predation by nonnative fishes in the Verde River, Arizona by section of river (Section I, II, III, IV), environment type (pool, riffle, run), and season (spring, summer, winter). We observed predation on native fishes only in the highest and lowest sections of river (Sections I and IV). We estimated that largemouth bass *Micropterus salmoides* caught in pools and runs in Section IV consumed the most native fish, with an average 582.3 mg of native prey fish eaten/ $100m^2$ of pools/ day (SE = 111.7) and 238.7 mg of native prey fish eaten/ $100m^2$ of runs/ day (SE = 52.6). Age 1 and 2+ largemouth bass consumed more total prey fish than age 0 largemouth bass. Smallmouth bass was the only predator observed to consume native prey fish in Section I. To impact those predators currently consuming the most native fishes in the Verde River, managers should target management efforts at age 1 and 2+ largemouth bass in Section IV, and at smallmouth bass in Section I.

INTRODUCTION

There is a growing and widespread pattern of native fish population declines with increasing nonnative fish populations around the world (Ross 1991; Lassuy 1995; Tyus et al. 2000; Townsend 2003). Nonnative fishes may have detrimental effects on native fish populations through predation, competition, hybridization, the introduction and transfer of parasites and diseases, or by altering the environment (Moyle et al. 1986; Rinne and Minckley 1991; Rinne 1994; Marsh and Douglas 1997). Nonnative fishes pose a threat to the preservation of endemic fishes in the aquatic systems where they are introduced.

From 1900 to about 1970, over 60 species of fish were introduced to Arizona for purposes of sport, bait, biological control, or by accident (Rinne 1992). Over a dozen nonnative fishes have been introduced into the Verde River basin, where native fish populations are declining rapidly (Rinne et al. 1998). Nonnative fish introductions have been implicated in native fish declines in the Verde, although the exact mechanisms at work are unknown. Predation on native fishes by nonnative fishes may be high and limit native fish recruitment, which may be a leading cause of native fish declines (Meffe 1985; Rinne 1992; Marsh and Douglas 1997). Studies in the Southwest have documented predation by nonnative fishes on native fishes (Marsh et al. 1989; Blinn et al. 1993; Marsh and Douglas 1997; Brandenburg and Gido 1999; Robinson et al. 2000) but few have quantified the estimated loss of native fishes to nonnative fishes through predation, or have examined the spatial and temporal variation of predation by species and age class of nonnative predator.

Leslie (2003) identified the top six nonnative predators in the Verde River from March 2002- 2003 based on the percentage of total prey fish (native, nonnative, and unknown prey fish species) in their diet. The top six nonnative predators (all predators) were largemouth bass *Micropterus salmoides*, flathead catfish *Pylodictis olivaris*, channel catfish *Ictalurus punctatus*, smallmouth bass *M. dolomieui*, yellow bullhead *Ameriurus natalis*, and rainbow trout *Oncorhynchus mykiss* (the only stocked nonnative species; Leslie 2003). Our objective was to quantify the estimated loss of total and native prey fish to the top six predators in the Verde River, by species and age class of predator, geographic area (section of river), environment type (pool, riffle, run) and time of year (season). Because Arizona fisheries managers want to conserve and enhance native fish populations in the Verde River while maintaining an economically valuable sport fishery of nonnative fishes, this information could be used to focus management efforts on the most damaging nonnative predators, within particular sections and environment types, and at certain times of year.

STUDY AREA

The Verde River is located in central Arizona and flows approximately 318 km, from 40 km north of Prescott to 56 km northeast of Phoenix. Elevation ranges from 400 to 1,329 m above sea level, with an average gradient of about 2.84 m/km. Chapter 1 provides a more detailed description of the study area.

METHODS

Study Design

We divided the river into four sections based on the degree of human impact (Rinne et al. 1998). Section I was the most pristine, stream-like section of the river;

Section II contained much human development and water diversions; Section III had few road access points and was federally designated as “Wild and Scenic” in 1984; Section IV was a much larger scale river, characterized by regulated flows from Bartlett Dam. We selected a stratified random sample of three sites from available road access points within each of the four sections of river, comprising 12 sample sites. We sampled one of each environment type (pool, riffle, run) at every site. Each site was sampled monthly for 10 months, from March 2002 to January 2003. See Chapter 1 for a more detailed description of the geographic sections and sample sites.

Sample months were grouped into three seasons according to water temperatures and distinct growth periods of nonnative fishes. March - May 2002 was designated as spring, June - September 2002 as summer, and October 2002- January 2003 as winter. Our seasonal designations comprised 94 days of spring, 126 days of summer, and 145 days of winter (25.8, 34.5, and 39.7% of the year, respectively).

Fish and diet collection

Fish were collected within one pool, riffle, and run at each site every month from March 2002-January 2003 using a combination of backpack and raft electrofishing units. Chapter 1 discusses methods of fish collection in more detail. We used the Seaburg lavage technique (1957) and dissection methods to collect stomach contents of nonnative fishes, and identified prey fish in their diet using species-specific diagnostic bones (Hansel et al. 1988). See Leslie (2003) for a detailed description of diet analysis.

Age Classes

We used length-frequency histograms pooled by individuals within each section of river to divide the total catch of each predator species into three age classes (age 0, 1, 2+) for each environment type sampled. We multiplied the proportion of each age class captured by the density estimate (Chapter 1) to estimate the density of each predator by age class. Only stocked age 1 rainbow trout were found in the river.

Estimated Loss

We estimated the loss (consumption) of total and native prey fish to all predators (predation impact) only within sections of river and seasons when prey fish was found in their diet (Leslie 2003). We multiplied the estimated average consumption rates of nonnative predators (mg fish eaten$\cdot$individual$^{-1}\cdot$day^{-1}) by density estimates of nonnative predators (number of individuals$\cdot$100m^{-2}) to estimate the loss of total and native prey fish to the top six nonnative predators (Tabor et al. 1993). We averaged the loss of total and native prey fish to all predators by species and age class of predator, section of river, environment type (run, riffle, pool), and season. For comparative purposes, we assumed a predation impact of zero for each age class of predator within environment types where no individuals were caught or where no total or native prey fish was found in their diet.

Statistical analyses

Estimates of total prey fish loss to all predators combined were log10 (x +1) transformed to meet the assumptions of normality and homogeneity of variance. We used multiple regression analysis and linear contrasts to test for and quantify differences between the estimated loss of total prey fish in the river by section, environment type, and season.

The data of estimated total and native prey fish lost to each predator species had numerous zeroes resulting from no observed predation impact within any given environment type sampled, so the assumptions of normality and homogeneity of variance were violated regardless of the transformation. Thus, we performed a two-part analysis. We used a Kruskal-Wallis nonparametric single factor analysis of variance (K-W ANOVA) by tied ranks tests (Zar 1999) to compare the estimated loss of total and native prey fish to each predator by age class, section of river, environment type, and season. If a difference was detected, we used nonparametric multiple comparison tests for mean ranks with ties (Zar 1999) to identify wherein the difference lay.

Environment types (pool, riffle, run) were not combined for any reported means because the proportion of pools, riffles, and runs available throughout the river was not quantified. However, average ratios of pools/runs to riffles were similar among the four sections (Chapter 1), which allowed us to compare estimates of total and native prey fish lost to predators across sections of river.

Due to the kind of statistical analyses performed, and to the fact that total and native prey fish were not observed in the diets of all predator species on all occasions, no tests for interactions between age class, section, environment type, or season were performed. We used simple means and standard errors to report the estimated loss of total and native prey fish to all predators across the river, by age class and environment type. All zeros of no estimated predation impacts were included in these means. Because we did not observe any native prey fish in the diet of rainbow trout (Leslie 2003) and the sample size for total prey fish in their diet was so small (n = 3), no statistical tests were performed on this species.

RESULTS

Estimated loss overall

The greatest mass of total prey fish consumed by all predators combined occurred in Sections I and IV (multiple regression and linear contrasts, $F_{1,352} = 74.73$, $P<0.001$). The amount of total prey fish eaten was 5.4 times greater (95% C.I. 3.7 to 7.9 times) in Sections I and IV than in Sections II or III. The mass of total prey fish eaten was an estimated 3.2 times greater (95% C.I. 2.1 to 4.8 times) by predators captured in pools and runs than by those captured in riffles (linear contrasts, $F_{1,352} = 31.85$, $P<0.001$). The estimated mass of total prey fish eaten was 7.0 times greater (95% C.I. 4.8 to 10.3 times) during the summer than the spring and winter (Fig. 1; linear contrasts, $F_{1,352} = 96.50$, $P<0.001$). The predators that consumed the most total prey fish among environment types were largemouth bass in pools, smallmouth bass in riffles, and both largemouth and smallmouth bass in runs (K-W ANOVA, $P<0.05$).

We only observed predation on native fishes in Sections I and IV. The greatest mass of native prey fish eaten by all predators combined occurred in Section IV (K-W ANOVA, $P<0.05$), by predators caught in pools and runs (K-W ANOVA, $P<0.05$), and during the summer (Fig. 2; K-W ANOVA, $P<0.05$). Of all predators, largemouth bass consumed the most native prey fish (K-W ANOVA, $P<0.05$).

Section

Most of the predation by flathead catfish on total prey fish occurred in Sections III and IV (Table 1; Fig. 3), and on native prey fish in Section IV (Table 2, Fig. 4; K-W ANOVA, both $P<0.05$). The greatest loss of total and native prey fish to channel catfish and largemouth bass occurred in Section IV (K-W ANOVA, all $P<0.05$). The highest predation of total and native prey fish by smallmouth bass occurred in Section I (K-W ANOVA, both $P<0.05$). The greatest loss of total prey fish to yellow bullhead occurred in Sections I and IV, and of native prey fish in Section IV (K-W ANOVA, both $P<0.05$).

Environment type

The greatest estimated loss of total prey fish to flathead catfish occurred in riffles (Table 1, Fig. 5; K-W ANOVA, $P<0.05$), while there was no difference among environment types in the amount of native prey fish eaten by flathead catfish (Table 2, Fig. 6; K-W ANOVA, $X^2 = 3.5$, $P = 0.17$). Channel catfish had a higher predation impact on native fishes in pools and runs than in riffles (K-W ANOVA, $P<0.05$), but there was no difference in total prey fish consumed by channel catfish among environment types (K-W ANOVA, $X^2 = 3.12$, $P = 0.21$). Largemouth bass consumed the most total and native prey fish in pool and run environment types (K-W ANOVA, both $P<0.05$). There was no difference in total or native prey fish eaten by smallmouth bass among pools, riffles, or runs (K-W ANOVA, $X^2 = 0.03$, $P = 0.98$; $X^2 = 1.83$, $P = 0.40$, respectively). Yellow bullheads consumed the most total prey fish in riffles and runs (K-W ANOVA, $P<0.05$), while there was no difference in native prey fish consumed by yellow bullheads among environment types (K-W ANOVA, $X^2 = 3.55$, $P = 0.17$, respectively).

Season

Flathead catfish ate the greatest amount of total prey fish during the summer (Table 1), and the greatest amount of native prey fish during the spring and summer (Table 2; K-W ANOVA, both $P<0.05$). Channel catfish ate the most total and native prey fish during the spring and summer (K-W ANOVA, both $P<0.05$). Largemouth bass consumed the most total prey fish during the summer (K-W ANOVA, $P<0.05$), but there was no difference in consumption of native prey fish by season (K-W ANOVA, $X^2 = 1.43$, $P = 0.49$). The highest predation of total and native prey fish by smallmouth bass occurred during the summer (K-W ANOVA, both $P<0.05$). Yellow bullheads consumed the most total prey fish in the summer and the most native prey fish in the spring and summer (K-W ANOVA, both $P<0.05$).

Age class

Age 1 and 2+ channel catfish consumed the greatest amount of total prey fish (Table1), and age 2+ channel catfish consumed the greatest amount of native prey fish (Table 2; K-W ANOVA, both $P<0.05$). Consumption of total or native prey fish did not differ among age classes of flathead catfish (K-W ANOVA, $X^2 = 1.93$, $P = 0.38$; $X^2 = 0.46$, $P = 0.79$, respectively). Age 1 and 2+ largemouth bass consumed the most total prey fish per day than age 0 largemouth bass (K-W ANOVA, $P<0.05$), but there was no difference in the amount of native prey fish eaten per day by age class (K-W ANOVA, $X^2 = 0.45$, $P = 0.80$). The highest predation of total and native prey fish by smallmouth bass occurred in age 1 fish (K-W ANOVA, both $P<0.05$). Age 0 and 1 yellow bullheads consumed more total and native prey fish than age 2+ yellow bullheads (K-W ANOVA, $P<0.05$).

DISCUSSION

The consumption of prey is influenced by the size and number of prey available, prey habits and habitat preferences (Keast 1985), the availability of refugia to escape predation (Meffe 1985), and the availability of alternative food items for predators (Ruppert et al. 1993). Most of the native fishes that have declined dramatically in the mainstem of the Verde River (loach minnow, speckled dace, spikedace, longfin dace, and gila topminnow) are small fish (<80 mm). Fishes with small body sizes as adults have a higher vulnerability to predation because they are less than the gape width of many predators throughout their lives. Additionally, native desert fish species lack the evolutionary anti-predatory defenses against the introduced predators (Johnson et al. 1993; Lima and Dill 1990).

We estimated the loss of both total and native prey fish to predators because many piscivorous fish are opportunistic feeders (Horne and Goldman 1994), and consumption generally underestimates demand when there is a food shortage (Ney 1990). Assuming total prey fish were not limiting, we assumed the loss of total prey fish by the top six nonnative predators in the Verde River a reasonable indicator of the predation potential to native fishes (Fig. 3).

Section

The estimated loss of native prey fish to the top six nonnative predators can be partially explained in the context of numbers of native prey fish available. We observed predation on native fishes by nonnative fishes only in Sections I and IV (Fig. 4), which coincided with the highest estimated densities of native fishes (Chapter 1). The greatest amount of native fish consumed by predators occurred in Section IV, the only section where longfin dace and recently hatched Sonora and desert suckers were captured.

Environment type

Although we could not determine the environment types where total and native prey fish were actually consumed by predators, we could estimate which environment types to capture the predators that consumed the most fish. The environment types where predators had the greatest predation impact coincided with greatest estimated densities for those predators (Chapter 1).

Overlap in environment type use between native fishes and nonnative predators may affect the degree of predation. Larvae of razorback suckers utilize slow moving pools and backwaters (Ruppert et al. 1993) that many nonnative predators also utilize (Chapter 1). This overlap in environment type use may have made larval razorback suckers in the Verde River more vulnerable to predation by nonnative fishes than larval Sonora and desert suckers which utilize riffles (Sublette at al. 1990). Predation by nonnative fishes at the larval stage may be one reason why razorback suckers became extirpated from the Verde River while Sonora and desert suckers are able to persist.

Season

The highest consumption of total and native prey fish by all predators occurred in the summer (Fig. 3), when water temperatures and growth rates for nonnative fishes were highest (Leslie 2003), and estimated densities of native and nonnative fishes were also high (Chapter 1).

Age class

It is important to consider both estimated consumption rates and densities of each age class of predators present when investigating loss of prey fish to predators (Rieman et al. 1991). While Leslie (2003) found largemouth bass age 0 fish to have the highest consumption rate of total prey fish, largemouth bass age 1 and 2+ had a greater impact because they made up a higher percentage of the population than age 0 fish. Conversely, because few large flathead catfish were caught in the Verde River (only four over 400 mm), the predation impact of age 2+ flathead catfish was low even though their estimated consumption rates were high (Leslie 2003).

Future Research

No native prey fish were found in the diet of rainbow trout, but other prey fish did occur in the diet of 9.3% of rainbow trout caught (n=3; Leslie 2003). The low number of rainbow trout captured (n=32) made their estimated predation impact on total prey fish low compared to the other predators (Fig. 3). However, over 22,000 individuals were stocked into the river in 2002 (Andy Clark, personal communication), so there is cause for concern. Currently rainbow trout stockings in the Verde River occur in the spring and winter, which overlaps with the spawning times of many native fishes. Rainbow trout prefer cold-water, but we captured these fish until the middle of August in water temperatures reaching 24ºC. The long survival window of catchable trout and their potential picsivory may result in detrimental effects to native fishes. Additional research is needed to better understand interactions among rainbow trout and native fishes in the Verde River.

We examined the impact of predation by nonnative fishes on native fishes in the Verde River, but more research is needed on other ways nonnative fishes may be negatively interacting with native fishes and reducing their numbers. The 13 nonnative fishes in the Verde River may also have a competitive impact, introduce and spread diseases and parasites, and alter the habitat of native fishes (Moyle et al. 1986).

Other human caused declines in native fish populations should also be researched, including habitat alteration, deterioration of water quality, and hydrological changes. Baltz and Moyle (1993) found that assemblages of native fishes in a California stream were able to resist invasion by nonnative fishes as long as the environment was relatively undisturbed by humans. While the mechanism of invasion resistance may be a combination of both biotic and environmental factors, they argue that maintaining environmental complexity such as a natural flow regime is critical to maintaining native fish assemblages (Baltz and Moyle 1993).

Management Implications

Several studies show that the removal of predaceous fishes can effectively lower their densities, and increase the fish survival and population numbers for the species of concern. Four years of sea lamprey control in Lake Superior reduced spawning runs of sea lamprey by 86% (Smith and Tibbles 1980). In the first year of targeted removal efforts at predaceous fishes in Cultus Lake, British Columbia, survival rates of young sockeye salmon increased more than three-fold (Foerster and Ricker 1941). In the lower Columbia and Snake Rivers of the Pacific Northwest, modeling indicated that five years of removal efforts targeted at predaceous northern pikeminnow decreased potential predation on juvenile salmonids by an estimated 25% (Friesen and Ward 1999). Meachum and Clark (1979) found that one year of Arctic char confinement at a single location within the Wood River system, Alaska saved an estimated 906,933 sockeye salmon smolt from predation, without appearing to be detrimental to the Arctic char sport fishery.

Sih et al. (1998) warns that multiple predator effects on prey cannot simply be calculated by summing the effects of individual predator types. The possibility exists that removal of certain predators may cause a competitive release, or compensatory response, by other predators (Rieman and Beamesderfer 1990; Zimmerman and Parker 1995). Removal of top predators may increase the recruitment and survival not only of native fish, but also of other nonnative species that may negatively interact with native fish. However, Beamesderfer et al. (1996) suggests that predator removal will restructure rather than deplete a targeted species population, and may not reduce densities enough to elicit a compensatory response.

To meet the goal of conserving and enhancing native fish populations while maintaining an economically valuable sport fishery, an adaptive management approach could be initiated. Removal efforts targeting age 1 and 2+ largemouth bass in Section IV, and age 1 smallmouth bass in Section I would focus efforts on those fishes currently having the greatest predation impact on native fishes in the Verde River. Survival of young native fishes may be increased if provided with predator free spawning and rearing grounds (Tyus and Saunders III 2000). If desired, removal efforts in small sections, to first gage the response of both native and nonnative fishes in the river, could be implemented before more costly large-scale efforts are attempted. A preliminary study of nonnative fish removal in the upper Verde River has proved beneficial to native fish recruitment in its early stages (Rinne 2001; Rinne, personal communication).

Mechanical removal of the most damaging predaceous fishes in the Verde River would be advantageous, but mechanical removal requires a lot of manpower, time, and money. One possibility to aid in the mechanical removal of nonnative predators is intensive angling (Tyus and Saunders III 2000). Gerhardt and Hubert (1991 *in* Tyus) showed fishing pressure could effectively eliminate large channel catfish at some Wyoming locations. Age 1 and 2+ largemouth bass and age 2+ channel catfish in the lower Verde River are prime candidates for anglers. There is currently no size or take limit of unstocked nonnative fishes in the Verde River and nonnative populations are still thriving, so a bounty program may be necessary to increase harvest of nonnative fishes. Bounty programs have worked effectively on the Columbia River for removal of northern pikeminnow (Beamesderfer et al. 1996).

Stocked rainbow trout provide a valuable sport fishery, so conservative management options may be desirable to maintain the fishery while protecting the native fish species. Robinson et al. (2000) recommended limiting trout stockings to reservoirs, stocking only one adult size, and keeping them out of areas with sensitive native fish populations. If rainbow trout stockings continue in the Verde River, stocking them into Bartlett Reservoir, or limiting them to Sections II and III where native fish densities are lowest (Chapter 1) would be a conservative management strategy to reduce potential interactions with native fishes.

CONCLUSION

In summary, predation on native fishes by the top six nonnative predators varied substantially by species and size class of predator, section of river, environment type, and season. We only observed predation on native fishes in Sections I and IV, where native fish densities were greatest. Predation by all predators was greatest during the summer. We estimated that largemouth bass caught in pools and runs in Section IV consumed the greatest amount of native fish. Age 1 and 2+ largemouth bass consumed more total prey fish than age 0 largemouth bass. Smallmouth bass was the only nonnative species observed to consume native prey fish in Section I. For effective management of these nonnative predators, managers should target management efforts at age 1 and 2+ largemouth bass in Section IV, and at smallmouth bass in Section I.

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Table 1. Sections, environment types, seasons, and age classes where and when the most total prey fish were lost to each predator according to K-W tests where *P* <0.05 in the Verde River from March 2002- January 2003.

	Section					Environment type				Season				Age Class			
Species	I	II	III	IV	No diff	Pool	Riffle	Run	No diff	Spr	Sum	Win	No diff	0	1	2+	No diff
Combined overall*	X			X		X		X			X						
Channel catfish				X					X	X	X				X	X	
Flathead catfish			X	X			X				X						X
Largemouth bass				X		X		X			X				X	X	
Smallmouth bass	X								X		X				X		
Yellow bullhead	X			X			X	X		X				X	X		

* multiple comparison with linear contrasts test

Table 2. Sections, environment types, seasons, and age classes where and when the most native prey fish were lost to each predator according to K-W tests where *P* <0.05 in the Verde River from March 2002- January 2003.

	Section					Environment type				Season				Age Class			
Species	I	II	III	IV	No diff	Pool	Riffle	Run	No diff	Spr	Sum	Win	No diff	0	1	2+	No diff
Combined overall				X		X		X			X						
Channel catfish				X		X		X		X	X					X	
Flathead catfish				X					X	X	X						X
Largemouth bass				X		X		X					X				X
Smallmouth bass	X								X		X				X		
Yellow bullhead				X					X	X	X			X	X		

Fig. 1. Estimated loss of total prey fish (mg total fish/ 100m2/ day) consumed in each environment type by all six predators combined during the spring, summer, and winter seasons between March 2002-03.

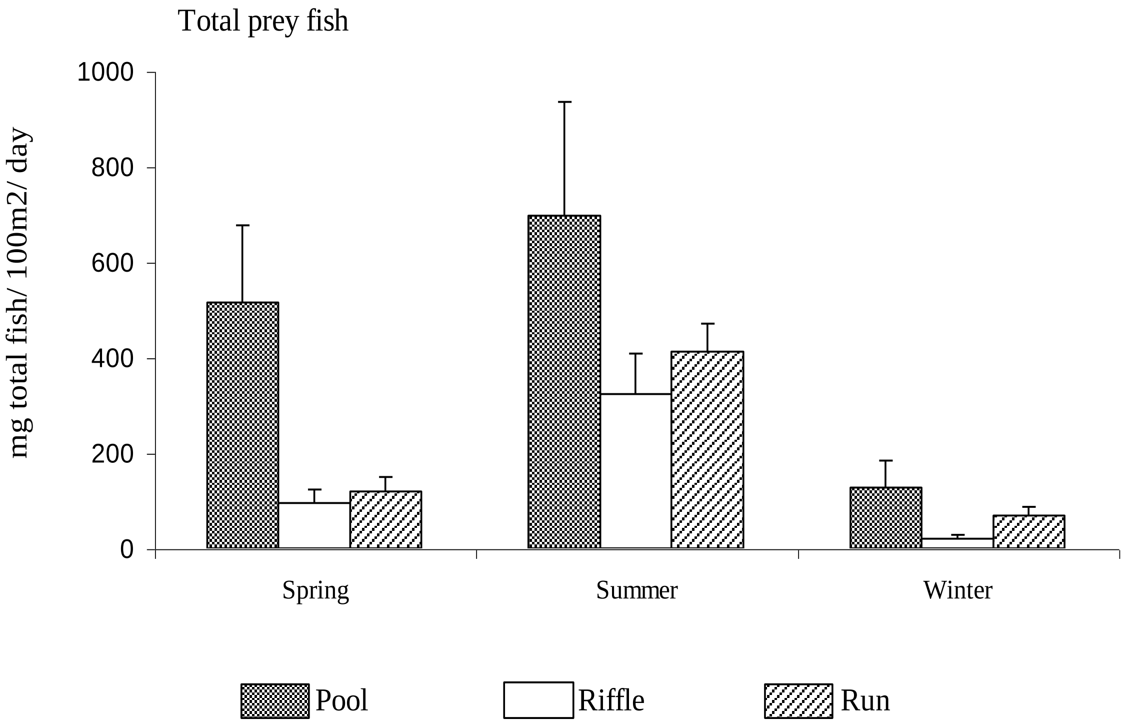


Fig. 2. Estimated loss of native prey fish (mg native fish/ 100m2/ day) consumed in each environment type by all six predators combined during the spring, summer, and winter seasons between March 2002- Januray 2003.

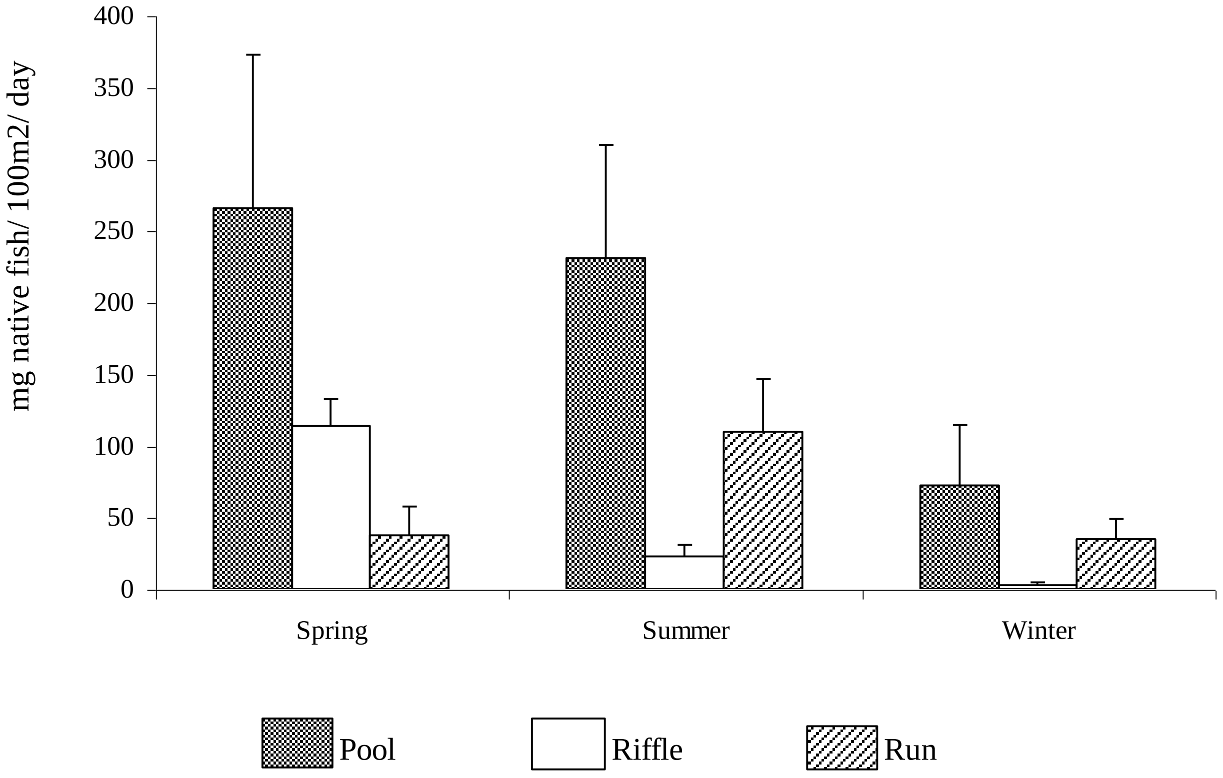


Fig. 3. Estimated loss of total prey fish (mg total fish/ 100m2/ day) to channel catfish (CCF), flathead catfish (FHC), largemouth bass (LMB), rainbow trout (RBT), smallmouth bass (SMB), and yellow bullhead (YBH) in the Verde River from March 2002- January 2003.

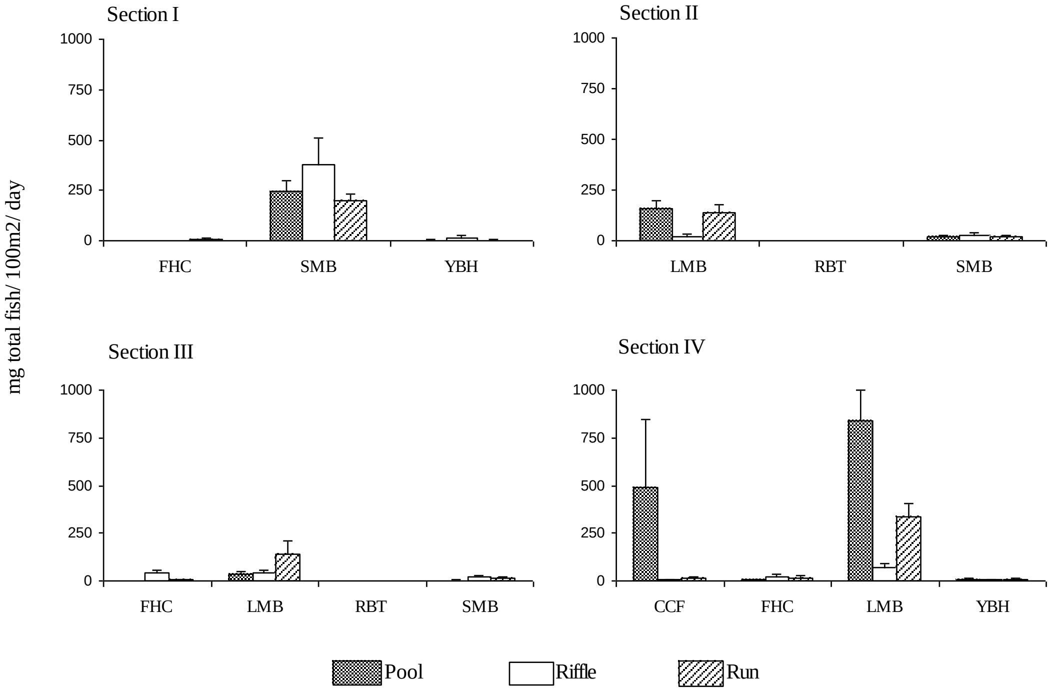


Fig. 4. Estimated loss of native prey fish (mg native fish/ 100m2/ day) to channel catfish (CCF), flathead catfish (FHC), largemouth bass (LMB), smallmouth bass (SMB), and yellow bullhead (YBH) in the Verde River from March 2002- Januray 2003.

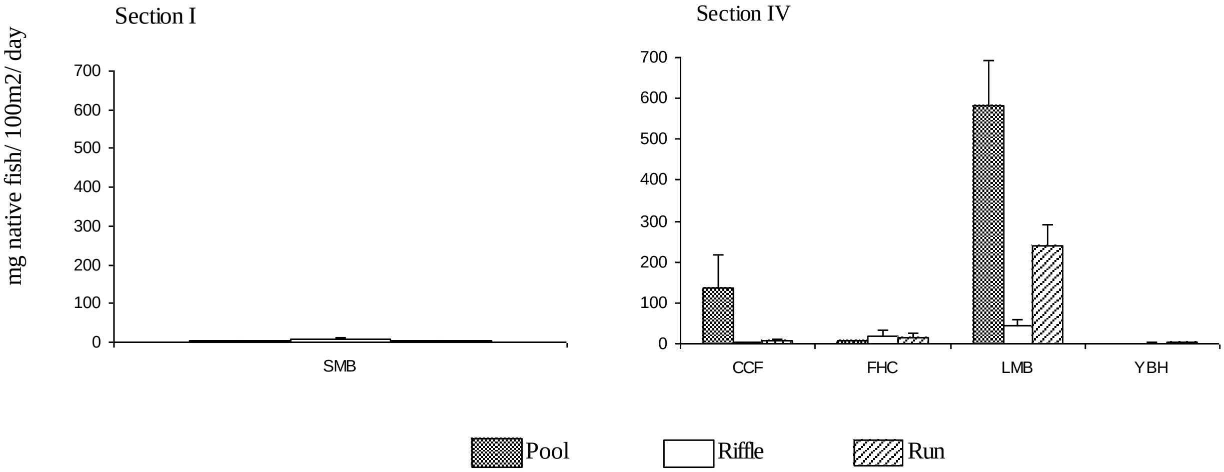


Fig. 5. The estimated loss of total prey fish (mg total fish/ 100m2/ day) to channel catfish (CCF), flathead catfish (FHC), largemouth bass (LMB), smallmouth bass (SMB), and yellow bullhead (YBH) by environment type and age class in the Verde River from March 2002-January 2003.

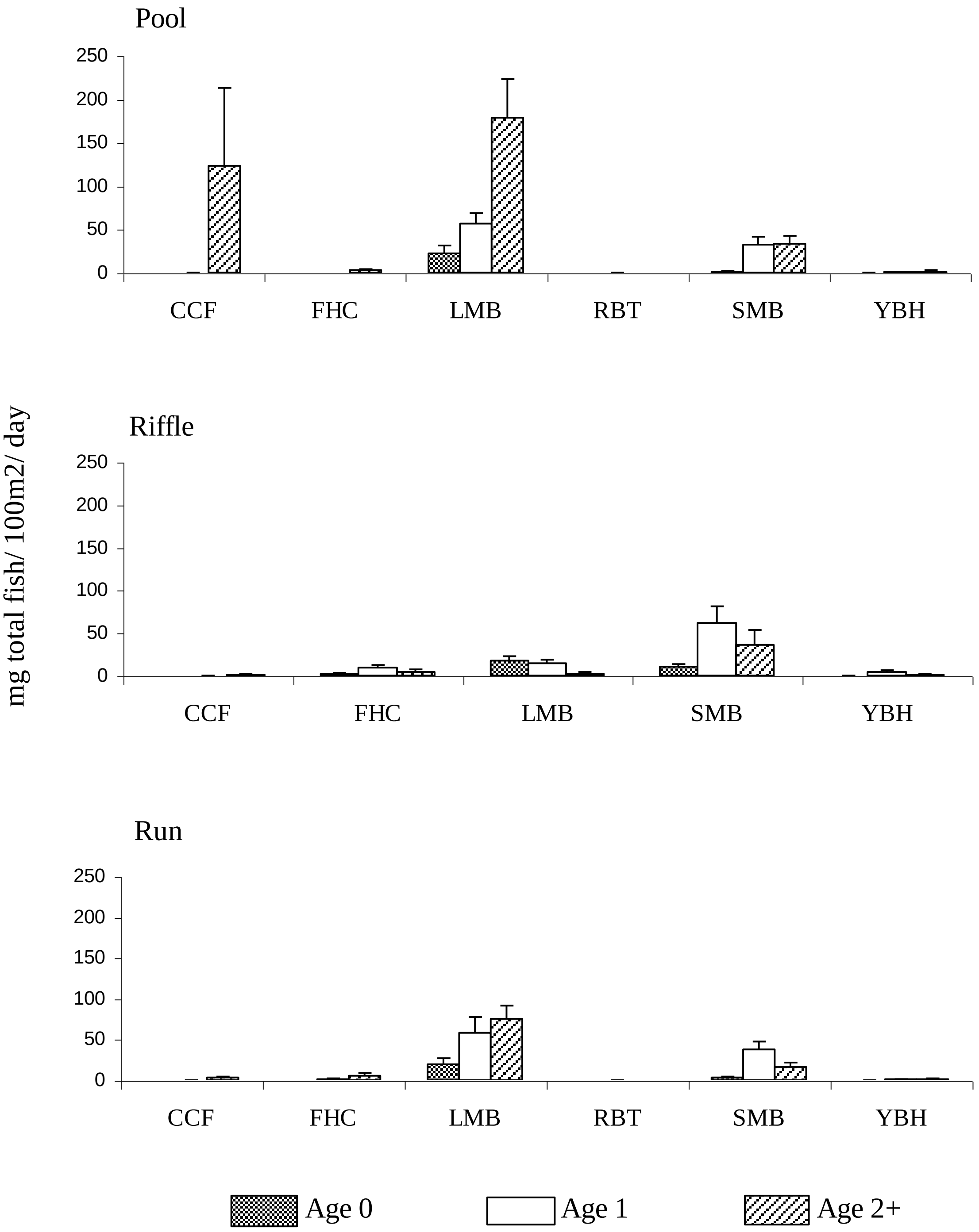
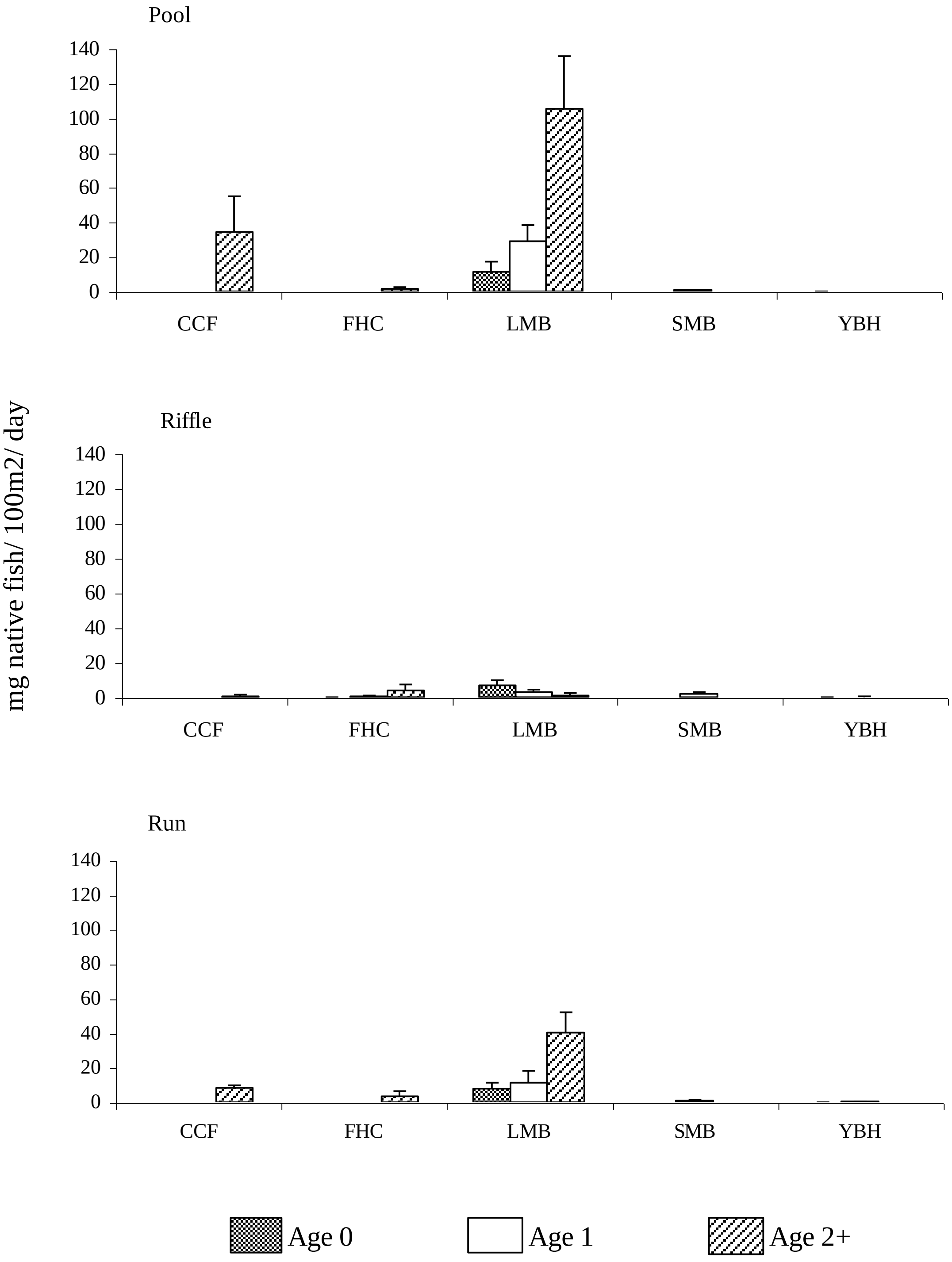


Fig. 6. The estimated loss of native prey fish (mg native fish/ 100m2/ day) to channel catfish (CCF), flathead catfish (FHC), largemouth bass (LMB), smallmouth bass (SMB), and yellow bullhead (YBH) by environment type and age class in the Verde River from March 2002- January 2003.



Pool

Riffle

Run