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Influence of Species, Size Class, Environment, and Season on Introduced Fish Predation on Native Fishes in the Verde River System, Arizona

by
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Influence of Species, Size Class, Environment and Season on Introduced Fish Predation on Native Fishes in the Verde River System

Executive Summary

Nonnative fishes were introduced throughout the Western United States for sport, food and biological control primarily in the early part of the last century and in the late 19^{th} century. Currently, most sportfisheries in the West are supported by introduced species, which have greatly benefited the economy of the region. For example, recreational fishing was worth over 6 billion dollars to the economies of 11 Western states in 2001 alone.

Unfortunately, introduced fish have also been implicated in declines of native fish assemblages in many western rivers, along with water diversion and habitat loss. Because of these declines, many native species of western rivers are listed as threatened and endangered under the U.S. Endangered Species Act.

Arizona river systems, such as the Verde, Gila and Salt historically supported rich populations of native fishes, and recovery of these fishes is of high priority. The relative importance of the effects of nonnative aquatic predators on the native fish community of the Verde River system, Arizona was identified as a sensitive element in 2000 for the Arizona Game and Fish Department IIPAM Heritage Program.

Previous research projects determined that non-native species can affect native fish by predation in Arizona river systems; however, there is much less information about exactly where and when impacts occur, and which introduced species are responsible for a majority of the impact. Knowledge of where and when specific bottlenecks occur which limit native fish production is useful to managers when designing introduced species control programs. Introduced species control programs can then be focused in habitats, at times of year, and on specific introduced species to maximize their efficacy, with the least impact to valuable sport fisheries. The primary goal of our study was to examine the impacts of total populations of introduced fishes (predation rates of introduced fish species x population size) and size groups within these populations to identify where control programs might be targeted in the Verde River system for maximum benefit.

In addition, much still remains to be learned about the basic ecology of 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. Estimates of fish densities and standing crops have been made for various lakes, reservoirs, and rivers throughout the world, but there is little information available regarding the densities and standing crops achieved by fishes in Southwestern desert rivers. A secondary goal of our study was to provide information on the basic biology of native and nonnative fishes in the Verde River such as their distribution, standing crops and densities.

Study Area

The Verde River, located within the Gila River basin, is one of the last remaining perennial rivers in Arizona. The Verde River flows approximately 300 km from Sullivan Lake to its confluence with the Salt River approximately 56 km northeast of Phoenix. The Verde River watershed drains 17,212 km^2 from its origin at an elevation of 1,325 m in the forested mountains of northern Arizona to the Sonoran desert scrub communities at its confluence at an elevation of 402 m. The first 200 km of the Verde River are free flowing, and Horseshoe and Bartlett Dams control the flow in the lower 100 km of river. Considerable groundwater pumping occurs within the Verde River basin to support 20 communities and many nearby agriculture activities.

The Verde River system contains a variety of native and nonnative fish species, (see Table 1.1). Historically, the Verde River was home to 10 native fish species. Five of these species are federally listed as threatened or endangered: razorback sucker *Xyrauchen texanus*, Colorado pikeminnow *Ptychocheilus lucius*, loach minnow *Tiaroga cobitis*, spikedace *Meda fulgida*, and Gila topminnow *Poeciliopsis occidentalis occidentalis*.

Objectives

Objectives for this project were as follows:

1. Estimate diet and consumption rates of introduced fishes on native fishes by environment type, season, species and size class in the Verde River, Arizona.
2. Estimate population sizes, biomass and distribution of various native and introduced fishes and their size classes by environment type, and season.
3. Multiply consumption rates of introduced predators by their estimated population sizes to get total impact of introduced fishes on native fishes by species, size class, environment type and season.
4. Synthesize information to prioritize where, when and what species currently provide the greatest predation threat to native species in the Verde River. Provide information to managers so they can focus management strategies on particular introduced species, size groups, seasons and/or environments to have the greatest possibility of reducing predation impacts on native fishes.

Overview of Methods

We conducted our study from the upstream reaches of the Verde River to its confluence with the Salt River (Figure 1.1). We surveyed the river once per month from March 2002 to January 2003. First, we subdivided the Verde River into the 4 divisions corresponding to those outlined in Rinne et al. (1997, Figure 1.1) Then, within each division, we randomly chose 3 sampling sections that contained riffle, run and pool environment types for a total of 12 sampling sections across the river overall. On each sampling trip, each environment type was first enclosed by block nets. Fish in the environment type were then captured using a raft electrofishing boat to sample midwater sites and deep pools, and backpack electrofishing units to sample shallow areas. Environment types were electrofished in the same manner for three or more passes until depletion to obtain population estimates by removal method. Environment types where fish were captured (pool, riffle, run) were recorded, as well as water temperatures in each environment type. Captured fish were anesthetized and stomach contents of introduced fish were obtained using gastric lavage techniques or by sacrificing those fish without true stomachs. Area of each environment type was measured for density estimates.

Stomach contents were preserved with ethanol and transported back to the laboratory. Contents were then separated into fish, insects, zooplankton, crayfish, and amphibian categories and wet weight was obtained for each proportion. Fish prey were identified to species using diagnostic bones when possible. Diagnostic bone keys were prepared from hatchery and field-collected specimens of the fish species found in the Verde River. Growth rates of predators were estimated by examining movement of length-frequency modes for particular age classes and by following growth of tagged fishes. Water temperatures were measured at the time and in locations of fish capture.

The proportion of native fish in predator diet, growth rates of the predators and water temperatures recorded at field sites were entered into the Wisconsin bioenergetics model to estimate the feeding rates in grams per hour of each predator. The Wisconsin bioenergetics model was chosen because of its close approximation to standard field estimates of fish predation in numerous studies. Consumption rates were calculated by predator species and size group in each of the three environment types (riffle, run, pool) and by season. Feeding rates in grams of native fish per hour were converted to number of native fish consumed per hour by using length-weight regressions developed for each native species.

Number of native fish per hour consumed per predator was multiplied by the removal population estimate of each predator species at each site to estimate impact of each fish species and size group. Impact estimates were also subdivided by environment type, and season.

Summary of Results

This report is organized into four chapters. The first chapter discusses diets of introduced fishes and identifies species of nonnative fishes with diets containing the highest percentage of fish. Furthermore, it characterizes changes in the percentage of fish in predator diets across the Verde River, by season and environment (i.e., pools, riffles, and runs). The second chapter quantifies consumption rates of native fishes by nonnative piscivores to identify which species and age classes of nonnative fishes exhibited the highest daily consumption rates; the season when consumption rates of native fishes were the highest; and the geographic region in which consumption primarily occurred. The third chapter describes the distribution, abundance and standing crop of native and nonnative fishes across the Verde River from the headwaters to the confluence with the Salt River in 2002-2003. In the fourth chapter, population densities of various introduced predators were multiplied by consumption rates of individual fish to report total impact by species, size class, season, and environment.

Our findings were as follows:

- Over 30,700 fish were collected, comprising 6 native species and 13 nonnative species. Only three native species, desert sucker *Catostomus clarki*, Sonora sucker *C. insignis*, and roundtail chub *Gila robusta* were found throughout the river (Table 3.4). Colorado pikeminnow and razorback sucker were only found in Sections II and III respectively, where they were being repatriated. Longfin dace *Agosia chrysogaster* were only caught in Section IV.
- The degree of piscivory varied considerably among introduced fish species. Tilapia *Tilapia spp.*, common carp *Cyprinus carpio*, red shiner *Cyprinella lutrensis*, mosquitofish *Gambusia affinis,* and threadfin shad *Dorosoma petenense* were primarily herbivores and/or insectivores (diet < 0.5% fish). Bluegill *Lepomis macrochirus*, rainbow trout *Oncorhynchus mykiss,* and green sunfish *L. cyanellus* were primarily insectivores and less than four percent of their diet consisted of fish. Largemouth bass *Micropterus salmoides*, flathead catfish *Pylodictis olivaris,* channel catfish *Ictalurus punctatus*, smallmouth bass *M. dolomieui*, and yellow bullhead *Ameriurus natalis* contained the highest percentage of fish in their diets.
- Native fish were found in the diets of largemouth bass, flathead catfish, channel catfish, and yellow bullhead only below Bartlett Dam and in the diet of smallmouth bass in the headwaters of the Verde River.
- The percentage of native fish in the diets of piscivores was highest in spring and summer in pools and riffles. Sonora and desert suckers primarily occurred in the diet of primary piscivores in pools, and longfin dace occurred in their diets in riffles. Overall, largemouth bass had the highest percentage of fish and native fish in their diet (16.7%, and 8.3% respectively); four times that of any other piscivore in the Verde River.
- Rates of consumption of both native fish and total fish also varied considerably among different introduced species. Largemouth bass had the highest overall daily ration of fish and native fish, more than twice that of any other species. The daily ration of fish consumed by largemouth bass was highest below Bartlett Dam where native fish densities were the highest and when native fishes were spawning (spring and summer). Finally, daily ration of juvenile largemouth bass (< age 1) was higher than other juvenile nonnative fishes, which corresponds with overlap in use of habitat with age 0 native fishes. Although fish were a small percentage of the diet of rainbow trout, they had the second highest daily ration of fish (exclusively nonnative), while all other species had similar lower daily rations of fish and native fish.

- The diet of rainbow trout consisted of only a small percentage (3.83%) of fish. However, individual rainbow trout exhibited a high average consumption rate of fish, probably due to the high metabolic demands of the rainbow trout in the warm waters of the Verde River. Our sample size of rainbow trout was small (n=32), so it was difficult to make conclusions about the impact of this species. Future studies directed specifically at piscivory of rainbow trout in the Verde River are needed to better define their impact.
- Nonnative fishes were approximately 2.6 times (95% C. I. 2.2 to 3.1 times) denser 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.
- Some researchers have speculated that small abundant species such as bluegill, green sunfish, red shiner, and mosquitofish may have the largest predation impact on native desert fishes through their sheer numbers. Because of extremely low piscivory (red shiner, green sunfish, and mosquitofish) or low densities (bluegill), we did not find this to be true in our study. Traditional piscivores such as black basses had the greatest impact.
- Largemouth bass, the predator with the highest percentage of fish in their diet and the highest consumption rate of native and total fish, also had the largest impact. 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.
- Largemouth bass were concentrated in pools and runs. We found no differences in smallmouth bass densities among environment types.
- To focus efforts on those predators currently consuming the most native fishes in the Verde River, managers should target control efforts at age 1 and 2+ largemouth bass in Section IV, and at smallmouth bass in Section I.

Table of Contents

List of Tables

List of Figures

Chapter 1: Diet of Nonnative Fishes in the Verde River, Arizona

Laura Leslie, Cristina E. Velez and Scott A. Bonar

Abstract

The importance of native fishes as prey for nonnative fishes was estimated by environment type, season, and river section across the entire 300 km of the Verde River, Arizona, from March 2002 to January 2003. Tilapia *Tilapia spp.*, common carp *Cyprinus carpio*, red shiners *Cyprinella lutrensis*, mosquitofish *Gambusia affinis*, and threadfin shad *Dorosoma petenense* were primarily herbivores and insectivores. Bluegill *Lepomis macrochirus*, rainbow trout *Oncorhynchus mykiss*, and green sunfish *L. cyanellus*, were primarily insectivores and their diets consisted of less than four percent of fish. Largemouth bass *Micropterus salmoides*, flathead catfish *Pylodictis olivaris*, channel catfish *Ictalurus punctatus*, smallmouth bass *M. dolomieui*, and yellow bullhead *Ameriurus natalis* contained the highest percentage of fish in their diets. Native fish were found in the diets of largemouth bass, flathead catfish, channel catfish and yellow bullhead only below Bartlett Dam and in the diet of smallmouth bass in the headwaters of the Verde River. The percentage of native fish in the diets of piscivores was highest in spring and summer in pools and riffles. Sonora and desert suckers primarily occurred in the diet of primary piscivores in pools, and longfin dace occurred in their diets in riffles. Overall, largemouth bass had the highest percentage of fish and native fish in their diet (16.7%, and 8.3% respectively); four times that of any other piscivore in the Verde River.

Introduction

Native fishes have been rapidly declining across the desert Southwest over the last century (Minckley and Deacon 1991). The desert aquatic environments in which they have evolved have been altered by various chemical, physical, and biological impacts, mostly human caused (Minckley and Deacon 1991; Rinne 1994; Johnson and Hinnes 1999). As a result, many native desert fishes have been listed as threatened or endangered under the Endangered Species Act of 1973 (Minckley and Deacon 1991).

Within Arizona, populations of native fishes have been reduced by construction of dams, alterations in flow regimes, loss of surface water, degradation of riparian vegetation, and the introduction of various nonnative species (Rinne et al. 1998). Over 60 species of fish were introduced into Arizona rivers and streams between 1900 and 1970 (Rinne 1992). These fishes have had detrimental effects on native fishes through competition, hybridization, alteration of habitat, disease transfer, and predation (Rinne and Minckley 1991; Lassuy 1995; Marsh and Douglas 1997).

Predation on native fishes by nonnative fishes in Arizona streams is well documented (Blinn et al. 1993; Marsh and Douglas 1997; Brouder et al. 2000). However, there is little information that identifies which piscivorous nonnative species and size classes are having the largest impact on native fishes or that characterizes the spatial and temporal patterns of this predation. This information would help managers to protect native fishes while maintaining valuable sport fisheries at some locations. Managers would be able to focus removal or management efforts on specific environments and on the most threatening nonnative fishes. Our goals were to identify which species of nonnative fishes (Table 1.1) had the highest percentage of fish in their diets, and characterize changes in the percentage of fish in their diets across the Verde River, by season and environment (i.e., pools, riffles, and runs).

Methods

We divided the Verde River into four sections based on the degree and type of anthropogenic impact (Figure 1.1; Rinne et al. 1998). The first section (Section I), which flowed approximately 69 km from Sullivan Dam to Clarkdale, was largely free of anthropogenic impacts. The second section (Section II), which flowed 49 km from Clarkdale to Beasley Flats, was the most developed section of the river, characterized by many irrigation diversions, sites of ground water pumping and considerably altered riparian vegetation. The third section (Section III), federally designated as "Wild and Scenic" in 1984 under the Wild and Scenic Rivers Act, flowed 90 km from Beasley Flats to Horseshoe Dam. The fourth section (Section IV), flowed 41 km from below Bartlett Dam to the Salt River, had regulated flows and a larger volume of water than all the other sections. We did not sample the area between Horseshoe and Bartlett Dams because this is an isolated section that is not representative of the reset of the Verde River.

Site Selection

We randomly chose three sample sites from available access points within each of the four sections for a total of 12 sites across the river. A randomly chosen pool, riffle, and run were sampled at each site. We used definitions from Arend (1999) to define pools, riffles and runs. Surface area of each sampled pool, riffle, and run was estimated from measures of length and width of each site to allow for across-site comparisons.

Collection of Fish

We sampled fish monthly at each site from March 2002 through January 2003. Block nets measuring 48.8 x 1.8 m with bar mesh size of 3.8 cm were set at each sample site to isolate each pool, riffle, and run. Block nets had float and lead lines; additional weights were added to lead lines when necessary to insure attachment to the stream bed.

We used a combination of raft-mounted and backpack electrofishing to capture fish in each enclosed section. We used a raft-mounted electrofishing unit, equipped with a VVP-15 Coffelt unit, to collect fish from deeper pools and runs. The raft had two anodes, each consisting of a Wisconsin ring and eight cable droppers. Two dropper cable cathode arrays were hung from each side of the raft. We used Smith-Root Model 12 and

15 backpack electrofishing units to collect fish along shallow shorelines where the raft was not able to reach and in riffles and shallow pools and runs. An average setting of 7 amps, 40 Hz, and 60 pulses per second was used to capture fish.

Electrofishing started at approximately 0800 and concluded when each pool, riffle and run had been sufficiently sampled. At least three passes were made in each pool, riffle, and run and the entire area was sampled in each pass. Experimental gill nets, 47.5 m long with six, 7.6 m panels of 1.3 cm, 1.9 cm, 2.5 cm, 3.2 cm, 3.8 cm, and 5.1 cm mesh, were set on two occasions in deep pools to test the capture efficiency of the raft electrofishing unit. Gill nets were set after depletion sampling was complete and we electrofished toward the nets on all sides to herd any remaining fish into the nets.

Seasons

Three seasons were delineated based on observed growth rates of nonnative fishes and fluctuations in water temperature. March through May was designated as spring, June through September as summer, and October through January as winter.

Diet Analysis

Nonnative fishes were collected for diet analysis from each pool, riffle and run. We anesthetized fish, weighed them to the nearest 0.1 g, and measured their total length to the nearest 1 mm. We used the gastric lavage technique (Seaburg 1957), to collect stomach samples from all sizes of fish. We used an agricultural sprayer and various sizes of copper tubing attachments to collect samples from fish with true stomachs. We used forceps to remove prey items, such as crayfish, that could not be flushed from the stomach. These fish were then released back into the river. For fish without true stomachs, (carp *Cyprinus carpio*, mosquitofish *Gambusia affinis*, red shiners *Cyprinella lutrensis*, threadfin shad *Dorosoma petenense*, and tilapia *Tilapia* spp.), we removed the foregut from 10-15 randomly selected individuals from each pool, riffle and run. We did not sample more individuals because we wanted to minimize the effect of sampling mortality on the populations. All stomach contents were preserved in 90% ethanol and transported to the laboratory.

In the laboratory, we examined the contents of each diet sample under a dissecting microscope to separate items into the following categories: fish (by species and developmental stage), insects (by order), plants, crayfish, amphibians, tapeworms, and other nonfood or unidentifiable items. We used the dentary, cleithrum, pharyngeal arch and opercle diagnostic bones (Hansel et al. 1988) to identify fish prey to species. We used methods outlined by Snyder (1979) and Snyder and Muth (1990) to identify larvae and fish eggs. Field guides (Phillips and Comus 1999) were used to attempt to identify amphibians. The U.S. Fish and Wildlife Service (USFWS) Pinetop Fish Health Unit identified parasites found in samples. After identification, all prey items were blotted dry with a paper towel and weighed to the nearest 0.01 g. Parasites and nonfood items were excluded from the diet analysis.

Data Analysis

Diet proportions of each nonnative fish species were averaged across all sites and dates. The top five piscivores were identified based on percentage of fish (native, nonnative, and unknown prey fish) in their diet and the relative abundance of each species (Velez et al. *in prep.*, this issue). For the five top piscivores, we used one-way analysis of variance (ANOVA) and linear combinations to estimate variation in the percent fish (by wet weight) and percent native fish in their diet by section of river, environment, and season. We did not test for interactions between section of river, environment, and season because we did not capture fish in each environment and season within each section. The proportion of fish and native fish consumed was transformed (logit) to account for lack of homogeneity of variance. Untransformed mean proportions were converted to percents for ease of interpretation.

Results

Largemouth bass, flathead catfish, channel catfish, smallmouth bass, and yellow bullhead catfish were the primary piscivores (Table 1.2). Tilapia, common carp, red shiners, mosquitofish, and threadfin shad primarily fed upon insects and plant material (Table 1.2). Less than 1% (wet weight) of their diets consisted of fish, all of which were nonnative fishes. Bluegill, green sunfish, and rainbow trout fed primarily on insects; the diets of these fishes consisted of a small percentage (< 5%) of both native and nonnative fishes (Table 1.2).

Largemouth Bass

Largemouth bass ate primarily insects (Tricoptera, Ephemeroptera, and Odonata; Table 1.2). Of all nonnative fishes, largemouth bass contained the highest percentage of fish in their diet (16.8%, SE = 1.05). Their diet also contained the highest percentage of native fish (8.3%, SE = 0.80), which consisted of longfin dace, desert sucker, and Sonora sucker.

Largemouth bass ate the highest percentage of fish in Section IV (Figure 1.2); 18.68% (SE = 2.16) higher than in both Sections II and III (Table 1.3; linear combinations, $F_{1,1106} = 74.45$, $P < 0.01$). We never found largemouth bass in Section I. Fish composed the highest percentage of their diet in spring and summer (Figure 1.3); 6.6% (SE = 2.47) higher than in winter (Table 1.3; linear combinations, $F_{1,1106} = 7.24$, $P = 0.01$). The percentage of fish in their diet was also highest in pools (Figure 1.4); 5.3% (SE = 2.44) higher than in riffles and runs (Table 1.3; linear combinations, $F_{1,1106} = 4.80$, $P = 0.03$).

Native fish were only observed in the diet of largemouth bass in Section IV (Figure 1.2) and they composed the highest percentage of the diet in pools (Figure 1.4); 5.3% (SE = 1.84) higher than in riffles and runs (Table 1.3; linear combinations, $F_{1,1106} = 8.22$, $P < 0.01$).

Longfin dace were only found in the diet of largemouth bass in riffles. Sonora suckers and unidentified suckers were primarily found in the diet of largemouth bass in pools (Table 1.4). Desert suckers were primarily found in the diet of largemouth bass in riffles.

Flathead Catfish

The diet of flathead catfish consisted primarily of insects (Ephemeroptera and Trichoptera; Table 1.2). Fish composed 6.8% of the diet, less than half of which were native fish, desert and Sonora suckers. The highest percentage of fish in the diet occurred in Section IV (Table 1.3; linear combinations, $F_{1,150} = 4.75$, $P = 0.03$). Native fish were only found in the diet of flathead catfish in runs in Section IV during the spring and summer (Figure 1.2, 1.3 and 1.4).

Channel Catfish

The diet of channel catfish consisted primarily of plant material and insects (Trichoptera, Ephemeroptera, and Diptera; Table 1.2). Fish composed less than 5% of the diet, over half of which were native fish (Sonora sucker and desert sucker).

Fish and native fish composed the highest percentage of the diet during the spring (Figure 1.3); 7.37% (SE = 2.52) and 5.10% (SE = 2.01) higher, respectively, than in summer and winter (Table 1.3; linear combinations, $F_{1,245} = 8.54$, $P < 0.01$; $F_{1,245} = 6.42$, $P = 0.01$, respectively). Native fish were observed only in the diet of channel catfish in pools in Section IV (Figure 1.2 and 1.4).

Smallmouth Bass

The diet of smallmouth bass consisted primarily of insects (Trichoptera, Coleoptera, Diptera, and Hemiptera), and crayfish (Table 1.2). Native fish composed less than 0.1% of the fish consumed (Table 1.2).

Smallmouth bass had the highest percentage of fish in their diet during the summer (Figure 1.2); 2.17% (SE = 0.89) higher than in the spring and winter combined (Table 1.3; linear combinations, $F_{1,1438} = 5.99$, $P = 0.01$). Native fish (Sonora sucker) were only observed in the diet in Section I during the spring and summer in runs and riffles (Table 1.4). Smallmouth bass were also never captured in Section IV.

Yellow Bullhead

The diet of yellow bullhead consisted primarily of plant material, insects (Ephemeroptera, Diptera, and Coleoptera) and crayfish. Native fish (Sonora sucker and unidentified sucker) composed less than 1% of the fish consumed (Table 1.2).

The percentage of fish in the diet was not significantly different by section of river, season or environment (Table 1.3; Figure 1.2). Native fish (longfin dace, desert sucker, and Sonora sucker) were found in the diet only in Section IV (Figure 1.2).

Discussion

Largemouth bass, smallmouth bass, channel catfish, flathead catfish, and yellow bullhead are the primary piscivores in the Verde River. Tilapia, common carp, red shiners, mosquitofish, and threadfin shad were primarily herbivores and insectivores and probably are not having a predatory impact on the abundance and distribution of native fishes. Green sunfish, bluegill, and rainbow trout were primarily insectivores with a small percentage of fish (< 5%) in their diet; the impact of predation by these species on native fishes would only be significant if their consumption rates or population numbers were high.

These results are consistent with dietary studies on these species (Odum 1971; Marsden 1996; Garcia-Berthou 2001). Marsden (1996) and Garcia-Berthou (2001) found carp to be primarily herbivores and insectivores however they did find evidence of carp consuming a small percentage of fish eggs; we found no evidence of fish eggs in the diet of carp. Ruppert et al. (1993) found fish larvae in the diet of red shiners in Colorado; however we found no evidence of larval fish or fish eggs in the diet of red shiners. We believe eggs and larvae would have been detected if they were in the diets of these species because we were able to detect eggs and larvae in the diets of other species. Eggs of native fish in the Verde River may not be easily accessible to carp and red shiners (Marsden 1996), or there may be higher concentrations of their preferred prey items (aquatic plants and insects) in the Verde River than there were in areas studied by Marsden (1996) and Garcia-Berthou (2001), for carp and red shiners to consume.

Only a small percentage of fish, including native fish (Sonora sucker and unidentified sucker), were found in the diets of green sunfish, bluegill, and rainbow trout. Other studies indicate that bluegill and green sunfish may cause decreased recruitment of razorback suckers in Lake Mohave by preying upon eggs and larvae (Minckley and Deacon 1991). Predation by and competition with green sunfish are also believed to be the reason for the decline in Gila chub *Gila intermedia,* in Sabino Canyon, Arizona (Dudley and Matter 2000). In the Verde River, abundance of green sunfish is low (Velez et al. *in prep.*), and the percentage of their diet consisting of fish is low so they probably are not having a significant impact on the abundance and distribution of native fishes.

Rainbow trout occurred in our sampling areas in very low numbers; however, they are stocked into the Verde River each year. In 2002, approximately 27,525 trout were stocked in the Camp Verde area (Section II) and 4,500 were stocked below Bartlett Dam (Section IV) to provide angling opportunities and to supplement the diet of bald eagles, *Haliaeetus leucocephalus,* on Native American reservation lands (Scott Bryan, personal communication). The percentage of fish consumed by rainbow trout could be as high as 9.3% (upper 95% C.I.). With high stocking densities, this species has the potential to impact native fish populations though predation, especially with spring stockings that coincide with the spawning time of many native fishes (Sublett et al. 1990).

Largemouth Bass

Of all nonnative fishes, largemouth bass contained the highest percentage of fish and native fish in their diet, four times the amount of any other piscivore in the Verde River. These results are not surprising given that largemouth bass are primary piscivores (Keast 1985) and become piscivorous when they reach 51 mm (Becker 1983).

The percentage of fish (native and nonnative) in the diet was the highest below Bartlett Dam. The area below Bartlett Dam also contained the highest density of native fishes, especially young of the year Sonora and desert suckers (Velez et al. *in prep.*). The high percentage of native fish in the diet in the spring coincides with spring spawning of Sonora and desert suckers, and reflects the sites where bass were most frequently caught.

Roundtail chub were never observed in the diet of any nonnative fishes. Longfin dace were observed in the diets of largemouth bass only in riffles, which reflects the primary habitat of longfin dace (Sublette et al. 1990). The pharyngeal arch of longfin dace was indistinguishable from that of red shiners, so it is possible that the percent of longfin dace in the diet was underestimated. Only four longfin dace were identified in stomach samples, all of which were in early stages of digestion and could be easily identified.

Flathead Catfish

Predation by flathead catfish is thought to be the primary reason for decline of many native fishes in the Lower Colorado River and the Salt River (Marsh and Brooks 1989; Arizona Game and Fish Department 1995). The differences in size structure between flathead catfish in the Verde and Salt Rivers may be the primary reason for this discrepancy. The average size of flathead catfish we collected was 142 mm TL and 85% were less than 250 mm. Flathead catfish are secondary piscivores, becoming piscivorous later in life (Keast 1985), when they reach 250 mm (Sublette et al. 1990). We also set gill nets in pools after completing our depletion sampling to test the effectiveness of our sampling methods; we never captured any fish in the gills nets.

Channel Catfish

A small percentage of the diet of channel catfish consisted of desert sucker and Sonora suckers. Fish (native and nonnative) were most common in the diet of fish below Bartlett Dam, especially in pools. The majority of channel catfish were captured below Bartlett Dam, and these fish were significantly larger than those above Bartlett Dam. This difference in size structure between sections and the abundance of sucker below the dam may account for the commonness of fish in the diet of catfish below Bartlett Dam.

Marsh and Brooks (1989) found recently stocked razorback suckers in high densities in the diet of channel and flathead catfish in the Gila River, Arizona. Channel catfish have the potential to have a predation impact on the abundance and distribution of native fishes; they are opportunists and are also secondary piscivores (Keast 1985).

Smallmouth Bass

Fish were most common in the diet of smallmouth bass in the relatively pristine headwaters of the Verde River (Section I) during spring and summer, however fish composed less that 5% of the diet. Previous studies have found native fish and fish in general to compose a higher percentage of the diet of smallmouth bass than we documented (Brouder et al. 2000; Robertson and Winemiller 2001). We observed native fish in very low densities in the upper Verde River and this may account for their rarity in the diets of smallmouth bass. However, fish of similar sizes, such as red shiners, were found in the diet in higher numbers. Smallmouth bass have the potential to have a predation impact on the abundance and distribution of native fish.

YellowBullhead

The diet of yellow bullhead primarily consisted of insects, plants and crayfish. The percent of crayfish in the diet of yellow bullheads was greater than in other nonnative fishes; overall crayfish composed a small percentage of the diet of all nonnative fishes (< 14%). Fish composed less than 3% of the diet, one-third of which were native fish (longfin dace and unidentified sucker). Fish were most common in the diet of yellow bullhead below Bartlett Dam in riffles in spring and summer. Seaburg and Moyle (1964) also found bullheads to eat primarily crustaceans and only a few fish. Even though yellow bullhead ate only a small percentage of fish, one-third were native fishes, so yellow bullhead have the potential to have an impact on the abundance and distribution of native fishes.

Conclusions

Based on diet alone, largemouth bass were the primary piscivore in the Verde River both for native and nonnative prey fishes. Native fish composed the highest percentage of the diet of all nonnative fishes below Bartlett Dam, which coincides with the highest abundances of native fishes. Fish, including native fish composed the highest percentage of the diet of all nonnative fishes during the spring and summer, which coincides with the spawning of native fishes. These trends suggest that these nonnative fishes, especially largemouth bass, could be negatively impacting the abundance and distribution of native fishes through predation. To determine if predation by nonnative fishes is significantly impacting native fish populations, the consumption rates and abundances of nonnative and native species are required.

Prey fish (native and nonnative) in the diet of nonnative fishes could be viewed as the highest percent of native fish these species could have in their diet. Piscivores are opportunistic (Hodgson and Kitchell 1987); they are not seeking out specific species of native fish to feed upon. If native fishes were in higher density above Bartlett Dam we might see the same predation patterns occurring. The low densities of native fish above

Bartlett Dam may be caused by continual predation since the early 1900s, Velez et al. (Chapter 4) discusses this topic in more detail.

Arizona's nonnative sport fishery is a major funding source for the Arizona Game and Fish Department and it generates more revenue for Arizona than any other recreational source. If native fish are going to be conserved, and with the least effect on sport fisheries, the impact of predation by nonnative fishes needs to be well understood. The three companion papers, which follow in this report, further define the impact these nonnative fishes are having on native fishes in the Verde River.

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Table 1.1 - Native and nonnative fishes found during our study (March 2002-2003) and historically in the Verde River, Arizona.

Common Name	Scientific Name
Native Fishes	
Colorado Pikeminnow*+	*Ptychocheilus lucius*
Desert Sucker*	*Catastomus clarki*
Gila Topminnow+	*Poeciliopsis occidentalis*
Loach Minnow+	*Tiaroga cobitis*
Longfin Dace*	*Agosia chrysogaster*
Razorback Sucker*+	*Xyrauchen texanus*
Roundtail Chub*	*Gila robusta*
Sonora Sucker*	*Catastomus insignis*
Speckled Dace	*Rhinichthys osculus*
Spikedace+	*Meda fulgida*
Nonnative Fishes	
Black Crappie	*Pomoxis nigromaculatus*
Bluegill Sunfish*	*Lepomis macrochirus*
Channel Catfish*	*Ictalurus punctatus*
Common Carp*	*Cyprinus carpio*
Fathead Minnow	*Pimephales promelas*
Flathead Catfish*	*Pylodictis olivaris*
Green Sunfish*	*Lepomis cyanellus*
Largemouth Bass*	*Micropterus salmoides*
Mosquitofish*	*Gambusia affinis*
Rainbow Trout*	*Oncorhynchus mykiss*
Red Shiner*	*Cyprinella lutrensis*
Sailfin Molly	*Poecilia latipinna*
Shortfin Molly	*Poecilia mexicana*
Smallmouth Bass*	*Micropterus dolomieui*
Threadfin Shad*	*Dorosoma petenense*
Tilapia spp.*	*Tilapia spp.*
Yellow Bullhead Catfish*	*Ameriurus natalis*
Yellow Bass	*Morone mississippiensis*

* Fish species captured in this study
+ Fish species federally listed as threatened or endangered

Table 1.2.- Percent by weight and standard errors of prey consumed by nonnative fishes in the Verde River, Arizona (all sites and seasons combined), 2002-2003.

Prey group	Bluegill sunfish N = 22 (19-190 mm) % (SE)	Rainbow trout N = 32 (225-356 mm) % (SE)	Tilapia spp. N = 92 (22-317 mm) % (SE)	Green sunfish N = 754 (21-216 mm) % (SE)	Mosquito fish N = 497 (13-56 mm) % (SE)	Common carp N = 316 (39-710 mm) % (SE)	Red shiner N = 1557 (6-89 mm) % (SE)
Total Fish	4.29 (4.25)	3.83 (2.71)	0	0.61 (0.24)	0.17 (0.17)	0.42 (0.30)	0.02 (0.84)
Native Fishes	4.29 (4.25)	0	0	0.48 (0.23)	0	0	0
Longfin dace	0	0	0	0.13 (0.13)	0	0	0
Desert sucker	0	0	0	0	0	0	0
Sonora sucker	0.04 (0.04)	0	0	0	0	0	0
Catastomus spp.	4.25 (4.25)	0	0	0.34 (0.71)	0	0	0
Nonnative Fishes	0	0	0	0.22 (0.14)	0	0.32 (0.32)	0
Yellow bullhead	0	0	0	0	0	0	0
Common carp	0	0	0	0	0	0	0
Red shiner	0	3.83 (2.71)	0	0.18 (0.14)	0	0.05 (0.05)	0
Mosquito fish	0	0	0	0	0.17 (0.17)	0	0
Channel catfish	0	0	0	0.04 (0.04)	0	0	0
Green sunfish	0	0	0	0	0	0.27 (0.27)	0
Micropterus spp.	0	0	0	0	0	0	0
Smallmouth bass	0	0	0	0	0	0	0
Largemouth bass	0	0	0	0	0	0	0
Tilapia spp.	0	0	0	0	0	0	0
Flathead catfish	0	0	0	0	0	0	0
Cypriniformes	0	0	0	0	0	0	0
Centrarchidae	0	0	0	0	0	0	0
Ictalurus spp.	0	0	0	0	0	0	0
Unknown Fishes	0	0	0	0.05 (0.04)	0	0.10 (0.10)	0.02 (0.84)
Invertebrates	75.98 (8.74)	63.98 (7.30)	14.26 (3.65)	78.85 (1.23)	93.50 (1.07)	20.82 (2.14)	96.65 (0.41)
Plants	19.72 (8.12)	32.15 (7.16)	84.67 (3.76)	13.03 (0.99)	6.23 (1.05)	76.39 (2.24)	3.26 (0.41)
Crayfish	0	0.04 (0.04)	1.07 (1.07)	7.09 (0.78)	0.10 (0.10)	2.37 (0.81)	0.06 (0.04)
Amphibians	0	0	0	0.41 (0.21)	0	0	0

Table 1.2 cont.- Percent by weight and standard errors of prey consumed by nonnative fishes in the Verde River, Arizona (all sites and seasons combined), 2002-2003.

Prey group	Threadfin shad N = 1 (51 mm) % (SE)	Largemouth bass N = 1109 (12-515 mm) % (SE)	Flathead catfish N = 154 (27-505 mm) % (SE)	Channel catfish N = 248 (21-573 mm) % (SE)	Smallmouth bass N = 1441 (10-340 mm) % (SE)	Yellow bullhead N = 271 (29-328 mm) % (SE)
Total Fish	0	16.76 (1.05)	6.84 (1.91)	4.11 (1.11)	3.43 (0.43)	2.71 (0.87)
Native Fishes	0	8.30 (0.80)	1.89 (1.05)	2.43 (0.88)	0.07 (0.06)	0.86 (0.53)
Longfin dace	0	0.34 (0.17)	0	0	0	0
Desert sucker	0	2.80 (0.47)	0.79 (0.62)	0.46 (0.36)	0	0
Sonora sucker	0	2.97 (0.49)	1.10 (0.76)	1.38 (0.62)	0.07 (0.06)	0.12 (0.12)
Catastomus spp.	0	2.20 (0.40)	0	0.60 (0.35)	0	0.74 (0.52)
Nonnative Fishes	0	6.17 (0.67)	4.96 (1.63)	0.94 (0.56)	2.79 (0.39)	0.89 (0.49)
Yellow bullhead	0	0	0	0	0.05 (0.03)	0.25 (0.25)
Common carp	0	0.30 (0.14)	0.18 (0.18)	0	0.11 (0.08)	0
Red shiner	0	2.23 (0.41)	3.83 (1.48)	0	1.65 (0.31)	0.34 (0.30)
Mosquito fish	0	1.44 (0.32)	0	0.62 (0.46)	0.57 (0.18)	0
Channel catfish	0	0.08 (0.08)	0	0	0	0
Green sunfish	0	0.20 (0.13)	0	0	0.06 (0.06)	0.29 (0.29)
Micropterus spp.	0	0.18 (0.13)	0	0	0.27 (0.13)	0
Smallmouth bass	0	0.18 (0.13)	0	0	0	0
Largemouth bass	0	0.33 (0.16)	0	0.32 (0.32)	0	0
Tilapia spp.	0	0.75 (0.25)	0	0	0	0
Flathead catfish	0	0.09 (0.09)	1.00 (0.72)	0	0	0
Cypriniformes	0	0	0	0	0.02 (0.02)	0
Centrarchidae	0	0.39 (0.16)	0	0	0.03 (0.03)	0
Ictalurus spp.	0	0	0	0	0.03 (0.03)	0
Unknown Fishes	0	1.97 (0.35)	0.005 (0.057)	0.73 (0.36)	0.66 (0.18)	0.95 (0.47)
Invertebrates	100	56.20 (1.36)	61.85 (3.61)	29.58 (2.74)	71.27 (1.06)	55.05 (2.64)
Plants	0	14.10 (0.92)	20.03 (3.02)	57.73 (2.89)	11.89 (0.81)	26.95 (2.30)
Crayfish	0	1.11 (0.87)	11.01 (2.23)	8.50 (1.66)	12.95 (0.81)	14.43 (1.95)
Amphibians	0	1.84 (0.37)	0	0.08 (0.07)	0.35 (0.14)	0.85 (0.52)

Table 1.3.- Results of one-way analysis of variance testing whether the mean percent of total fish and native fish in the diet of largemouth bass, flathead catfish, channel catfish, smallmouth bass, and yellow bullhead catfish varies by section of river, environment, and season. Separate analyses were done for each species.

	Largemouth bass			Flathead Catfish			Channel Catfish			Smallmouth bass			Yellow bullhead		
Variable	*F*	df	*P*	*F*	df	*P*	*F*	df	*P*	*F*	df	*P*	*F*	df	*P*
Total Fish															
Section	53.01	2, 1106	<0.01	2.51	3, 150	0.06	1.15	3, 244	0.32	1.72	2, 1438	0.18	1.68	3, 267	0.17
Environment	3.36	2, 1106	0.02	0.82	2, 151	0.44	1.54	2, 245	0.22	0.14	2, 1438	0.87	1.32	2, 268	0.27
Season	3.97	2, 1106	0.02	1.22	3, 150	0.30	3.47	2, 245	0.03	4.15	2, 1438	0.02	1.25	2, 268	0.29
Native Fish															
Section	72.11	2, 1106	<0.01	12.79	3, 150	<0.01	0.48	3, 244	0.70	0.44	2, 1438	0.64	2.13	3, 267	0.09
Environment	6.03	2, 1106	<0.01	0.81	2, 151	0.45	1.31	2, 245	0.27	0.75	2, 1438	0.47	0.94	2, 268	0.39
Season	1.06	2, 1106	0.35	0.48	2, 151	0.62	4.41	2, 245	0.01	0.23	2, 1438	0.79	0.72	2, 268	0.48

Table 1.4.- Percent by weight and standard errors of longfin dace, desert sucker, Sonora sucker, and unidentified suckers consumed by largemouth bass by season and environmental below Bartlett Dam (Section IV), Verde River, Arizona.

	Spring	**Summer**	**Winter**
	% (SE)	**% (SE)**	**% (SE)**
		Longfin Dace	
Pool	0	0	0
Riffle	6.18 (6.18)	0	2.11 (2.11)
Run	0	0	0
		Desert Sucker	
Pool	2.15 (1.49)	7.98 (5.01)	3.69 (3.69)
Riffle	16.66 (11.78)	0	0
Run	1.30 (1.29)	1.67 (1.67)	6.54 (4.61)
		Sonora Sucker	
Pool	18.07 (8.35)	9.17 (4.51)	0.73 (0.73)
Riffle	0.71 (0.71)	4.17 (4.17)	0
Run	0	4.09 (2.18)	3.53 (3.15)
		Catastomus spp.	
Pool	6.85 (3.45)	7.62 (3.07)	0
Riffle	4.79 (4.79)	0	0
Run	3.54 (2.43)	3.33 (2.25)	0.07 (0.07)

Figure 1.1.- Verde River location within Arizona and section and sample location on the Verde River, Arizona.

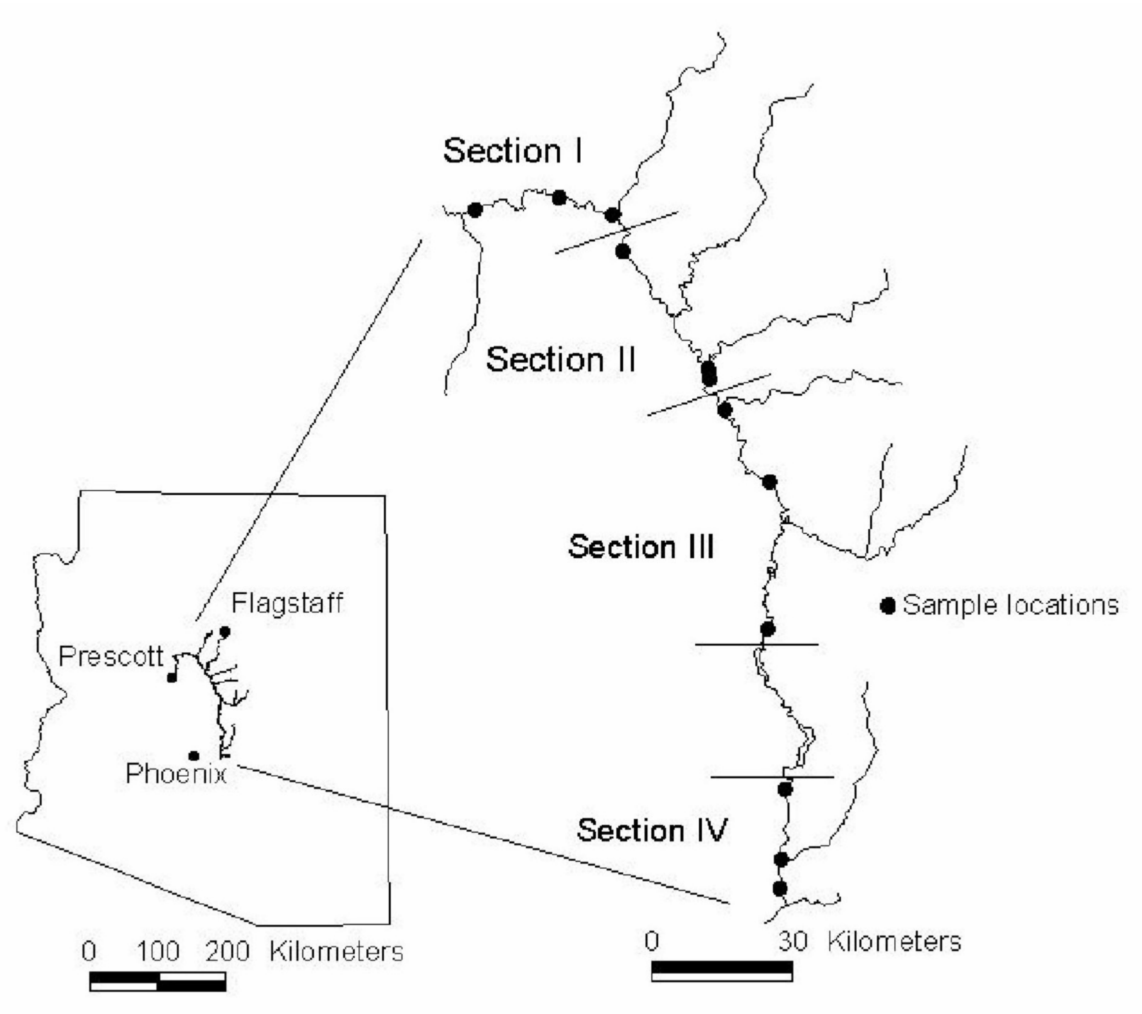


Figure 1.2.-Percent by weight of native and nonnative fish in the diet of largemouth bass (LMB), flathead catfish (FHC), channel catfish (CCF), smallmouth bass (SMB), and yellow bullhead (YBH) by section of river.

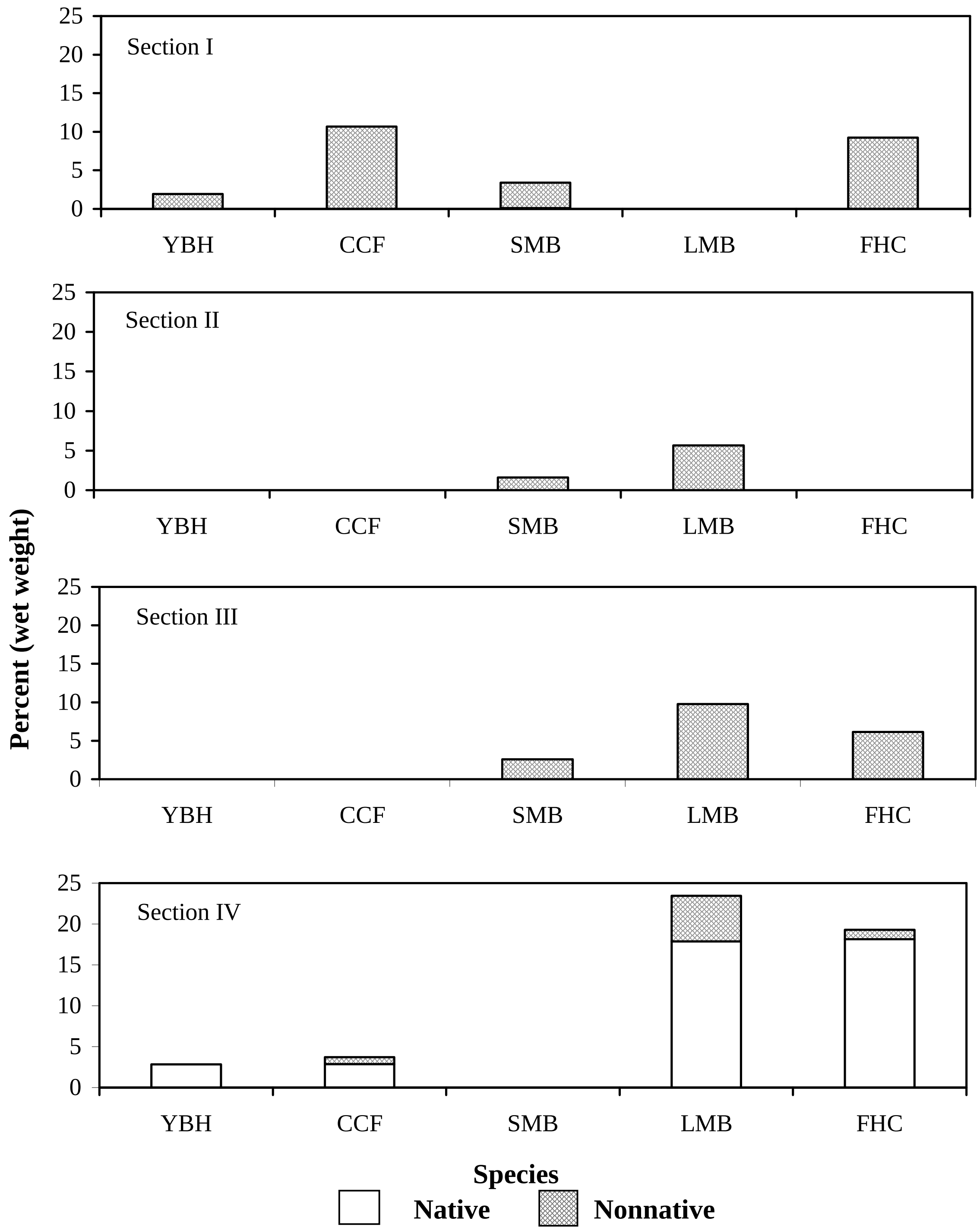


Figure 1.3-Percent by weight of native and nonnative fish in the diet of largemouth bass (LMB), flathead catfish (FHC), channel catfish (CCF), smallmouth bass (SMB), and yellow bullhead (YBH) by season.

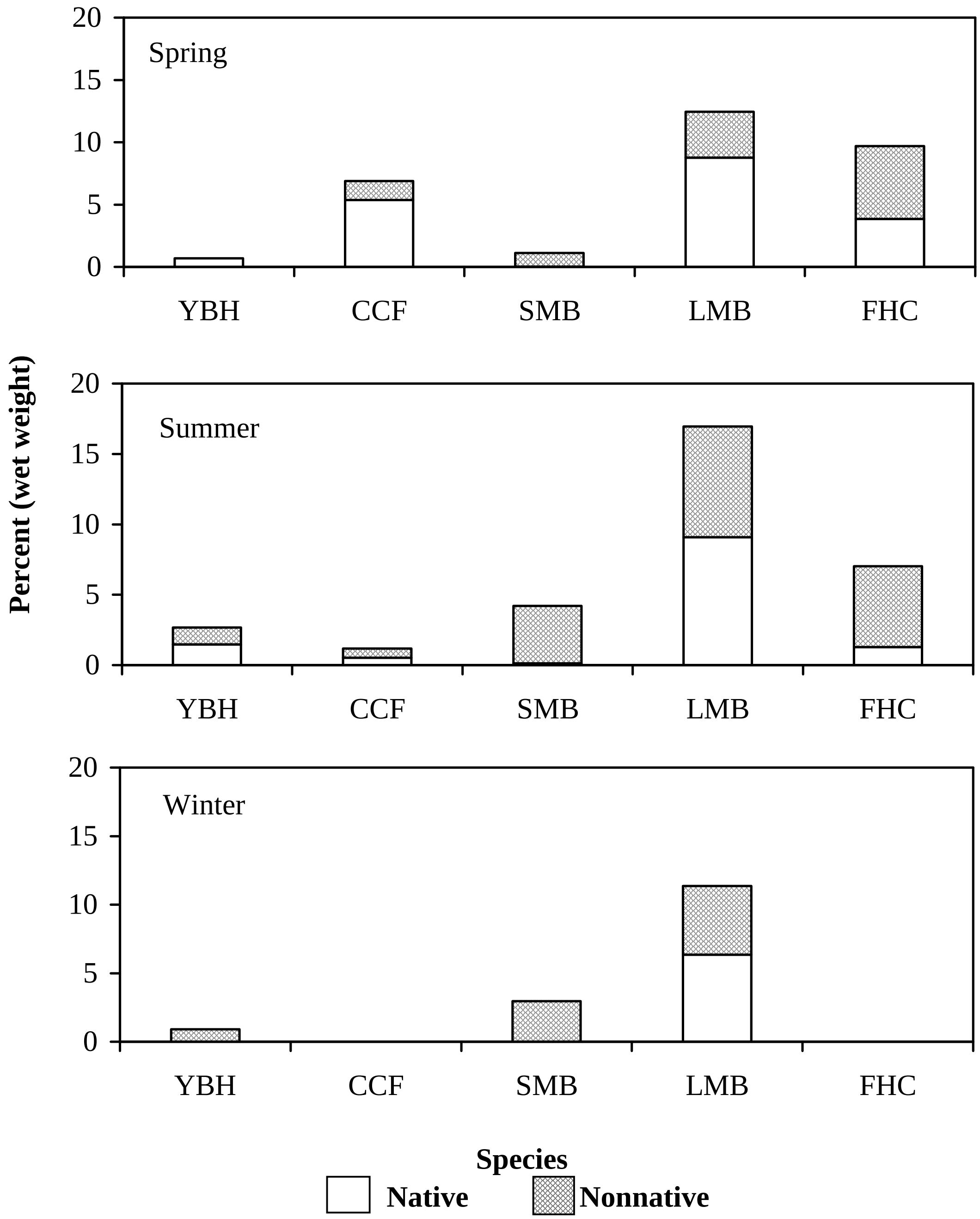
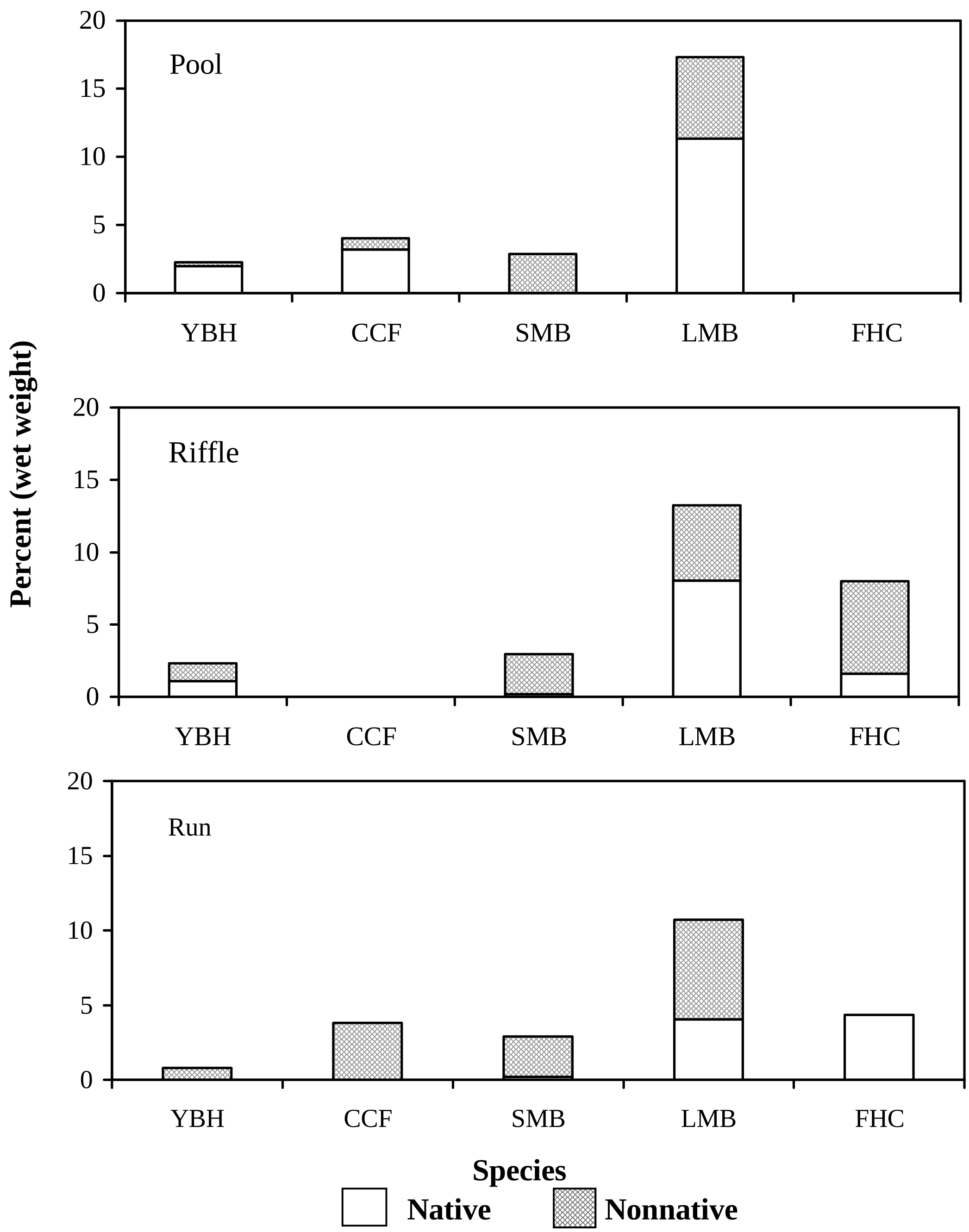


Figure 1.4.-Percent by weight of native and nonnative fish in the diet of largemouth bass (LMB), flathead catfish (FHC), channel catfish (CCF), smallmouth bass (SMB), and yellow bullhead (YBH) by environment.



Chapter 2: Rates of Consumption of Native Fish by Nonnative Fishes in the Verde River, Arizona

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Abstract

Largemouth bass *Micropterus salmoides*, smallmouth bass *M. dolomieui*, channel catfish *Ictalurus punctatus*, flathead catfish *Pylodictis olivaris*, yellow bullhead *Ameiurus natalis*, and rainbow trout *Oncorhynchus mykiss* were sampled throughout the Verde River from March 2002 to January 2003 to examine trends in prey fish consumption. The Wisconsin bioenergetics model (Hanson et al. 1997) was used to quantify variation in daily ration of fish, including native fish consumed by largemouth bass, smallmouth bass, channel catfish, flathead catfish, yellow bullhead, and rainbow trout. Largemouth bass had the highest overall daily ration of fish and native fish, more than twice that of any other species. The daily ration of fish consumed by largemouth bass was highest below Bartlett Dam where native fish densities were the highest and when native fishes were spawning (spring and summer). Daily ration of juvenile largemouth bass (< age 1) was higher than other juvenile nonnative fishes, which corresponds with overlap in use of habitat with age 0 native fishes. Although fish were a small percentage of the diet of rainbow trout, they had the second highest daily ration of fish (exclusively nonnative), while all other species had similar lower daily rations of fish and native fish. Sample sizes of rainbow trout were small (n=32), so further study is required to better evaluate native fish consumption by this species. Knowledge of the distribution and population sizes of these introduced fishes is needed to evaluate the overall impacts to native fishes in the Verde River system.

Introduction

The introduction of nonnative fishes across the desert Southwest have had detrimental effects on native fishes through competition, hybridization, disease transfer, and predation (Rinne and Minckley 1991; Lassuy 1995; Marsh and Douglas 1997). As a result many native fishes are federally listed under provisions of the Endangered Species Act (ESA) of 1973.

Predation from nonnative sport fishes is hypothesized to be one of the primary causes of native fish declines in the Verde River and across the Southwest (Rinne and Minckley 1991; Lassuy 1995; Marsh and Douglas 1997). Within the Verde River, native fish have been documented in the diets of various nonnative fishes (Brouder et al. 2000; Leslie et al. *in prep.*, this issue), however the rate of consumption of native fishes by nonnative fishes has not been quantified. By identifying the consumption rate of native fishes by nonnative fishes managers will be able to evaluate the potential effects of increasing (stocking) or decreasing (mechanical removal) the biomass of nonnative fishes will have on the native fishes in the Verde River.

We estimated the consumption rate of fish and native by largemouth bass *Micropterus salmoides*, smallmouth bass *M. dolomieui*, channel catfish *Ictalurus punctatus*, flathead catfish *Pylodictis olivaris*, rainbow trout *Oncorhynchus mykiss*, and yellow bullhead *Ameiurus natalis,* in the Verde River. These species were chosen for analysis based on the percentage of their diet composed of fish and native fish (Leslie et al. *in prep.*). Rainbow trout were specifically chosen because they are the only nonnative species that is currently being stocked into the Verde River. By quantifying consumption rates of native fishes by nonnative piscivores we will identify (1) which species and age classes of nonnative fishes exhibit the highest daily consumption rates (2) the season when consumption rates of native fishes were the highest and (3) the geographic region in which consumption is primarily occurring.

This information allows managers to assess which species and age classes are having the greatest predatory impact on native fishes and make management decisions accordingly. By focusing control and removal efforts on the specific species and age classes that have the highest consumption rates of native fishes, managers have been able to greatly reduce the potential predation on native fishes and increase the abundance and distribution of native fishes (Foerster and Ricker 1941; Meachum and Clark 1979; Smith and Tibbles 1980; Friesen and Ward 1999; Koonce et al. 1993; Tyus and Saunders III 2000).

Methods

Study design

We used the Wisconsin bioenergetics model (Hanson et al. 1997) to calculate consumption rates of prey fish for primary predators in the Verde River (largemouth bass, smallmouth bass, channel catfish, flathead catfish, yellow bullhead, and rainbow trout; as determined by Leslie et al., *in prep.*) by section of river, season, and age class.

We divided the river into four major sections based on degree and type of anthropogenic impacts (see Figure 1.1). Section I, flowed approximately 69 km from Sullivan Dam to Clarkdale and was largely free of anthropogenic impacts. Section II, flowed 49 km from Clarkdale to Beasley Flats, and was the most developed section of the river, characterized by many irrigation diversions, sites of ground water pumping and considerably altered riparian vegetation. Section III, federally designated as “Wild and Scenic” in 1984 under the Wild and Scenic Rivers Act, flowed 90 km from Beasley Flats to Horseshoe Dam. Section IV, flowed 41 km from below Bartlett Dam to the Salt River, and had regulated flow and a larger volume than other sections.

We delineated three seasons based on observed growth rates of nonnative fishes and fluctuations in water temperature. Spring was designated as March through May (simulation day 1 to 94), summer was June through September (day 95 to 220), and winter was October through February (day 221 to 365). Days of simulation for age 0 fish started on the first day we captured them. Our sampling ended in January 2003; however, we ran our simulations from March 2002 to March 2003 to represent consumption rates of fish across the entire year. For purposes of our simulations, diet composition, temperature, and growth rate estimates were assumed to be constant for each species from January 2003 through February 2003

We delineated three age classes for largemouth bass, smallmouth bass, channel catfish, flathead catfish and yellow bullhead based on length frequencies for each species. Consumption rates were not determined by age class for rainbow trout because age 1 fish were stocked into the Verde River and they are assumed to not be reproducing or surviving through the summer (Roger Sorensen, Arizona Game and Fish Department, personal communication).

Bioenergetics Model Simulations

The Wisconsin bioenergetics model estimates the daily consumption rates of each prey species by each predator through balanced energy equations that take into account each predator's specific physiological parameters, energy densities (Joules/gram) of prey, proportion of the diet made of different prey, growth rates of the predator, timing of and energy spent on reproduction by each species, and the temperature regimes in which they occur.

Physiological parameters.--We used physiological parameters for consumption, respiration, waste loss, and predator energy density that were included in the bioenergetics model for largemouth bass, smallmouth bass, and rainbow trout (Shuter and Post 1990; Rand et al. 1993; Rice et al. 1993, respectively). We used physiological parameters described by Blanc and Margraf (2002) for channel catfish. We used channel catfish as a surrogate species for flathead catfish and yellow bullhead because physiological parameters were not available for these species. We borrowed energy densities for prey species from the literature (Table 2.1).

Diet composition.--We used diet information collected by Leslie et al. (*in prep.*) for diet composition inputs into the model. We used section- and species-specific length frequencies to separate diet composition data into age classes at each sample site. We pooled diet composition across each pool, riffle and run at each sample site to increase sample size and because we were unable to determine in which environment the prey items were consumed.

Diet data were pooled for all rainbow trout and the bioenergetics model was run for the spring stocking season (January through May). We used Diet data from April and May 2002 and January 2003 for the spring simulation using the bioenergetics model. We collected only one trout during the summer season so we only analyzed consumption rates for the spring.

Growth rates.--Growth rates for age 0 and age 1 fish were calculated from length frequency data (Devries & Frie 1996) for all fishes except rainbow trout. Length frequency data were not reliable for age 2+ fish so the average size of age 2+ fish was calculated using length frequency data and used as the average length of age 2+ at the beginning of our study. We did not use a weighted average because the data was normally distributed with no obvious outliers. We calculated the average growth per day of age 2+ fish using mark-recapture data from tagged age 2+ fish. We multiplied growth per day by the number of days during each season to calculate the average length of each species at the beginning and end of each subsequent season (Table 2.2). The winter growth rate of age 1 channel catfish in Section IV was used to calculate winter growth for age 2+ channel catfish because no age 2+ channel catfish were marked or recaptured during winter. We developed length-weight regressions for each species to convert growth in length to growth in weight for input into the bioenergetics model.

We assumed no growth for rainbow trout during our simulation because water temperature was above optimal temperature for growth (25°C; Sublette et al. 1990), and rainbow trout generally do not survive in the Verde River long enough to experience growth (Roger Sorensen, Arizona Game and Fish Department, personal communication). Also the average weights of all rainbow trout captured were very similar to average weights of stocked fish (215 g) so we assumed they were not gaining or loosing a significant amount of weight while residing in the Verde River.

Reproduction.--We accounted for energy costs associated with spawning for age 2+ largemouth bass, smallmouth bass, flathead catfish, channel catfish and yellow bullheads. The bioenergetics model requires inputs on the day of spawning and the proportion of fish mass that is lost on that day (gonado somatic index (GSI)). We calculated the spawning day for each species based on the water temperature at which they spawn (Table 3: Sublette et al. 1990) and the GSI for each species was borrowed from the literature (Timmons et al. 1980; Davis 1986; Davis 2000).

Temperature regime.--The temperature regimes for each section were calculated (Figure 2.1) from water temperature measurements taken from each pool, riffle, and run. Water temperatures were measured mid-morning at median depth of the water column. While water temperatures can fluctuate throughout the day we assumed we were capturing the median water temperature because temperatures tend to peak in the late afternoon and are generally coldest in the early morning. We calculated average water temperature for each month (Figure 2.1) by averaging site-specific water temperatures within each section. Temperature profiles were the same for all age classes and species within a section.

The model interpolated values of diet composition, thermal experience, and growth between sample dates. The model was run only for age classes of nonnative fishes where prey fish were found in the diet; otherwise daily ration was entered as zero.

Analysis

We used one-way analysis of variance (ANOVA) and linear combinations to test for and quantify differences in mean daily ration of fish and native fish by species and age class of nonnative fish, section of river, and season. We did not test for interactions between section of river, environment, and season because we did not capture fish in each environment and season within each section.

Piscivores are opportunistic (Hodgson and Kitchell 1987); they are not seeking out specific species of native fish to feed upon. We viewed the daily ration of fish (native and nonnative) consumed by nonnative fishes as the highest possible predation rate that could occur on native fishes (longfin dace, Sonora sucker and desert sucker) if they were readily available as prey. The daily ration of native fishes is the actual daily consumption of native fishes we observed.

Results

Daily Ration

Largemouth bass had the highest average daily ration of fish and native fish (Figure 2.2: ANOVA, $F_{5,106}$ = 5.49, P < 0.01; $F_{5,106}$ = 5.95, P < 0.01, respectively). The average daily ration of fish by largemouth bass was 5.2 mg/g (SE = 1.44) greater than the daily ration of fish by all other species (linear combinations, $F_{1,106}$ =12.73, P < 0.01). Their daily ration of native fish was 2.9 mg/g (SE = 1.04) greater than the daily ration of native fish consumed by any other species (linear combinations, $F_{1,106}$ =7.83, P < 0.01).

Rainbow trout had the second highest daily ration of fish, all of which were nonnative prey fish (Figure 2.2). Flathead catfish had the second highest daily ration of native fishes, followed by yellow bullhead, channel catfish, and smallmouth bass (Figure 2.2). Flathead catfish, yellow bullhead, channel catfish, and smallmouth bass had similar low consumption rates of fish.

Spatial Trends

The highest daily rations of fish and native fish consumed by piscivores occurred below Bartlett Dam, in Section IV (Figure 2.3; ANOVA, $F_{3,107}$ = 4.03, P = 0.01; $F_{3,107}$ = 8.02, P < 0.01, respectively). The daily ration of fish by nonnative fishes was 3.4 mg/g (SE = 1.09) higher in Section IV than in any other sections of the river (linear combinations, $F_{1,107}$ = 11.27, P < 0.01). The daily ration of native fish by nonnative fishes was 3.5 mg/g (SE = 0.71) higher in Section IV than in any other section (linear combinations, $F_{1,107}$ = 23.89, P < 0.01).

Within Section IV, largemouth bass had the highest daily ration of fish and native than other species; within other sections the daily ration of fish was not significantly different by species (Figure 2.3; ANOVA, $F_{3,28}$ = 6.58, P < 0.01; $F_{3,28}$ = 5.86, P < 0.01). The daily ration of fish consumed by largemouth bass was 12.1 mg/g (SE = 2.75) higher than the daily ration of other species in Section IV (linear combinations, $F_{1,28}$ = 19.41, P <0.01). Likewise, the daily ration of native fish consumed by largemouth bass was 8.3 mg/g (SE = 2.03) higher than the daily ration by other species in Section IV (linear combinations, $F_{1,28}$ = 16.71, P <0.01).

Seasonal Variation

The average daily ration of fish consumed by nonnative fishes was lowest during winter (Figure 2.4; ANOVA, $F_{2,108}$ = 4.64, P < 0.01). During the winter, the average daily ration of fish was 3.1 mg/g (SE = 1.05) lower than the daily ration of fish consumed by nonnative fishes during spring and summer (linear combinations, $F_{1,108}$ = 8.58, P < 0.01). The average daily ration of native fishes was not significantly different by season

(ANOVA, $F_{2,108}$ = 2.18, P < 0.12), the daily ration was 1.4 mg/g (SE = 0.73) lower in winter than in spring and summer (linear combinations, $F_{1,108}$ = 3.75, P = 0.05). The daily ration of native fish was the highest for all piscivores during the spring (Figure 2.4).

Largemouth bass had the highest daily ration of fish and native fish during summer and winter than any other species (Figure 2.4; ANOVA, $F_{4,37}$ = 10.31, P < 0.01; $F_{4,37}$ = 3.77, P = 0.01; $F_{4,37}$ = 2.28, P = 0.07; $F_{4,37}$ = 2.59, P = 0.05, respectively). The daily ration of fish consumed by largemouth bass was 10.5 mg/g (SE = 1.69) greater than the daily ration of fish consumed by other species during the summer, and 0.8 mg/g (SE = 0.21) greater during the winter (linear combinations, $F_{1,37}$ = 38.75, P < 0.01; $F_{1,33}$ = 14.31, P < 0.01, respectively). The daily ration of native fish consumed by largemouth bass was 4.3 mg/g (SE = 1.45) greater than the daily ration of fish consumed by other species during the summer, and 0.5 mg/g (SE = 0.15) greater during the winter (linear combinations, $F_{1,37}$ = 8.62, P < 0.01; $F_{1,33}$ = 9.81, P < 0.01, respectively).

Age Relations

There were no statistical significant differences in daily ration of fish or native fish consumed by various age classes of largemouth bass (Figure 2.5; ANOVA, $F_{2,24}$ = 0.97, P = 0.39; $F_{2,24}$ = 0.44, P = 0.65, respectively), smallmouth bass ($F_{2,24}$ = 0.42, P = 0.89; $F_{2,24}$ = 1.04, P = 0.37), channel catfish ($F_{2,24}$ = 2.09, P = 0.22; $F_{2,24}$ = 0.78, P = 0.51), yellow bullhead ($F_{2,24}$ = 0.42, P = 0.66; $F_{2,24}$ = 1.27, P = 0.30), or flathead catfish ($F_{2,24}$ = 0.37, P = 0.69; $F_{2,24}$ = 0.59, P = 0.56).

Within each age class, largemouth bass had the highest daily ration of fish and native fish compared to other species (Figure 2.5; linear combinations, $F_{1,25}$ = 8.69, P < 0.01; $F_{1,34}$ = 10.86, P < 0.01; $F_{1,37}$ = 4.47, P = 0.04, respectively). Age 0 and 1 largemouth bass also had the highest daily ration of native fishes of all other species (Figure 2.5; linear combinations, $F_{1,25}$ = 4.00, P = 0.05; $F_{1,34}$ = 5.62, P = 0.02, respectively). The difference in daily ration among piscivores was greatest within age 0 fish; the daily ration of fish by age 0 largemouth bass was 8.51 mg/g (SE = 2.89) greater than the daily ration of fish consumed by other age 0 fish. Additionally they were the only species to consume native fishes.

Discussion

By focusing management and research efforts on the species and age classes of predators that have the highest consumption rates of native fishes, managers have been able to increase the abundance and distribution of native fishes. Salmon *Oncorhynchus* spp., populations have benefited from control efforts on northern pikeminnow *Ptychocheilus oregonensis*, (Foerster and Ricker 1941; Friesen and Ward 1999; Tyus and Saunders III 2000), and artic char *Salvelinus alpinus* (Meachum and Clark 1979), while many native fishes have benefited from control efforts on lamprey *Petromyzon marinus*, in the Great Lakes (Smith and Tibbles 1980; Koonce et al. 1993).

Data on consumption rates of native fishes alone suggest that the abundance and distribution of native fishes in the Verde River might be increased if future management efforts reduce the abundance of largemouth bass and rainbow trout. Predation by other species is also important; however, their daily ration of prey fish is less than half of that by largemouth bass and rainbow trout. If the average size of the other piscivores were to increase or if they are at high densities, they could also have a large predatory impact on the abundance and distribution of native fishes. Consumption rates alone are not enough to determine the impact of predation by nonnative fishes; the abundance of native and nonnative fishes must also be considered. This topic will be further discussed by C. Velez (*in prep.*).

Current data indicate that management and research efforts could have the greatest impact on the abundance and distribution of native fishes by focusing on largemouth bass below Bartlett Dam. Largemouth bass had the highest consumption rate of fish (native and nonnative) below Bartlett Dam where densities of native fish were highest (Velez et al. *in prep.*); the highest consumption rate of fish in spring and summer when native fishes are spawning; and of all age 0 and 1 piscivores, they had the highest daily ration of fish at ages 0 and 1 when habitat use overlaps with young of the year native fishes.

A more extensive study focusing on rainbow trout may be warranted before stocking practices are changed in the Verde River. Our consumption rate estimates are based on the diet of only 32 rainbow trout, and we found no evidence of them consuming native fishes. However, rainbow trout are opportunistic feeders (Hodgson and Kitchell 1987), and they had the second highest consumption rate of fish. Consumption rates of rainbow trout were high, likely because of their high metabolism in the warm Verde River. They have the potential to impact the abundance and distribution of native fishes if they are stocked in areas where native fishes are in high densities or are spawning.

Limitations of Data

To make inference about the spatial, seasonal and age variation in consumption rates of fish by predators in the Verde River we made several assumptions. The primary assumption in determining predator demand for prey is that food is not limiting, thus consumption is equivalent to demand (Ney 1990). While food can often be limiting in closed systems (Ney 1990), we feel that if prey availability was a limiting factor in our study, then prey would be equally limiting to all species and the trends in consumption rates would not be affected.

The Wisconsin bioenergetics model requires numerous physiological input parameters that are often difficult to measure accurately. The validity of consumption estimates depends on the accuracy of the input parameters. We assumed that values of physiological parameters we borrowed from the literature were representative of fishes in the Verde River. Parameter estimates are routinely borrowed from the literature and used in the bioenergetics model. While the parameter estimates may not be the exact values experienced in the field, they are useful for showing trends in predator consumption (Ney 1990; Hanson et al. 1996).

We also made several assumptions to be able to draw inference to the Verde River from our sample data. We assumed that: the diet and growth rates of fishes and the temperature regimes at our sampling sites (which were randomly chosen from available access points) were representative of the Verde River; electrofishing provided a representative sample of species and age class of piscivores; three consecutive sampling days at three sites were representative of a month within a given section; and there was no diel variation in the proportions of prey consumed by these piscivores. We feel that our estimates were representative of the general trends in consumption rates of fish and native fish that are occurring in the Verde River. While there are fluctuations in data across sites and years, the bioenergetics model is widely used and allows the evaluation of trends in consumption rates (Kitchell et al. 1977; Stewart et al. 1981; Ney 1993; Schindler et al. 1993).

Management Implications

Because of the small number of rainbow trout captured and analyzed (n=32), we recommend a more extensive study focusing on the predation impact of rainbow trout on native fishes and the stocking practices of rainbow trout before changing stocking practices. Based on current stocking records, 5,031 kg of rainbow trout were stocked into the Verde River in 2002. If every trout survived to feed for one day, they could consume 18 kg of prey fish (based on daily ration of 3.57 mg prey fish/g/day). Survival of stocked fish varies; angling records indicate that approximately 80% of rainbow trout are killed within the first week of being stocked into the Verde River (Andy Clark, Arizona Game and Fish Department, personal communication). We observed rainbow trout in the Verde River in August; these fish lived for at least four months because the last date of stocking was in April. Rainbow trout have the potential to impact the abundance and distribution of native fishes because their stocking overlaps with the peak of spawning activities by native fishes. Further research is needed to better evaluate the impact of rainbow trout and if their effects are significant, to determine the best stocking locations, dates, and sizes of fish to stock into the Verde River to reduce any predation impact they could have on native fishes.

Future research is also needed to determine what methods will be most effective in reducing densities of largemouth bass in the Verde River and if these efforts are effective in increasing the abundance and distribution of native fishes. Complete removal of largemouth bass from the Verde River may be impossible or undesirable. Researchers have been successful in increasing prey abundances by altering age structure and density of predators by increasing harvest through reward programs (bounties), changing fishing regulations and by physical removal efforts (Ney 1990; Beamesderfer 1996; Tyus and Saunders III 2000). These management actions may be useful in decreasing the demand for prey fish and increasing native fish abundance and distribution.

Increased stocking of native fishes combined with removal efforts of largemouth bass may increase the abundance and distribution of native fishes in the Verde River (Ney 1990). Currently razorback suckers (*Xyrauchen texanus*) and Colorado pikeminnow (*Ptychocheilus lucius*) greater than 300 mm are currently being reintroduced into the Verde River. These larger fish are assumed to be large enough to escape predation by nonnative fishes (Jahrke & Clark 1999); during our study the average size of prey fish consumed was 32 mm long, and 99% of the prey fish consumed were less than 100 mm. Brouder et al. (2000) also found the majority of native fishes preyed upon ranged in length from 34-90 mm. If the size of razorback suckers and Colorado pikeminnow stocked was reduced, it may be possible to increase the number of fishes that can be stocked into the Verde River. Stocking of other native species may also help increase their abundances and distributions throughout the Verde River.

Researchers are currently conducting nonnative removal studies on the upper Verde River (Section I) and appear to be getting increased abundance of young suckers (John Rinne, personal communication). Continued research is needed to test the effect of removing the primary piscivores from the Verde River on the abundance and distribution of native fishes. Research is also needed to determine the annual exploitation rate of largemouth bass that will provide the greatest reduction in predation while not resulting in increased predation, growth or reproduction in surviving largemouth bass or other predators.

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Table 2.1.- Prey energy densities (J/g wet weight) used in the bioenergetics models.

Species	**Closest Surrogate**	**Energy Density (J/g)**	**Source**
Longfin dace	Fathead minnow	4488	Bryan et al. (1996)
Sonora sucker	White sucker	3696	Bryan et al. (1996)
Desert sucker	White sucker	3696	Bryan et al. (1996)
Unknown sucker	White sucker	3696	Bryan et al. (1996)
Nonnative fish	Average of species	4543	Cummings & Wuycheck (1971); Miranda & Muncy (1989); Bryan et al. (1996)
Unknown fish		4605	Miranda & Muncy (1989)
Insects		3140	Hewett & Johnson (1992)
Plants	Algae	992	Kitchell & Windell (1970)
Crayfish		3140	Cummins & Wuycheck (1971)
Amphibians	Larval fish	4000	Hanson & Johnson (1997)

Table 2.2.- Seasonal growth used in bioenergetics simulations, in terms of initial and final weights for each season, for each age-group of largemouth bass (LMB), smallmouth bass (SMB), channel catfish (CCF), yellow bullhead (YBH), and flathead catfish (FHC), March 2002-2003.

		Initial weight (g) for:				
Age	Day	LMB	SMB	CCF	YBH	FHC
				Section I		
0	94	*	2.50	*	-	-
	220	*	8.02	-	6.68	-
	365	*	10.74	-	11.37	-
1	1	*	13.95	-	-	-
	94	*	19.72	*	14.21	-
	220	*	48.23	-	28.96	-
	365	*	59.83	-	-	-
2+	1	*	80.38	-	-	-
	94	*	88.96	*	-	125.50
	220	*	114.46	-	68.29	126.57
	365	*	-	-	75.35	-
				Section II		
0	94	2.46	1.44	-	-	-
	220	15.31	12.28	-	-	-
1	1	11.59	13.95	-	-	-
	94	22.13	26.71	-	-	-
	220	37.19	51.93	-	-	-
	365	44.62	59.83	-	-	*
2+	1	159.10	31.30	-	-	-
	94	182.47	36.28	-	-	-
	220	218.87	51.72	-	-	-
	365	266.28	-	-	-	*
				Section III		
0	94	2.46	2.50	-	-	3.47
	220	11.59	10.74	-	-	12.85
	365	17.41	-	-	-	-
1	1	13.37	26.71	-	*	-
	94	33.79	44.69	-	-	19.15
	220	62.08	59.83	-	-	41.08
2+	1	239.60	88.79	-	*	-
	94	271.58	97.92	-	-	102.21
	220	317.80	-	-	-	103.17
	365	377.77	-	-	-	-
				Section IV		
0	1	3.64	*	*	*	*
	94	3.98	*	-	4.82	5.88
	220	22.13	*	-	17.39	10.20
	365	24.76	*	-	-	-
1	1	24.76	*	5.65	11.37	10.20
	94	37.19	*	13.62	24.76	15.83
	220	67.02	*	32.83	33.51	-
	365	83.26	*	39.52	-	-
2+	1	292.82	*	215.41	-	178.07
	94	326.80	*	317.39	68.29	179.04
	220	380.71	*	506.03	82.78	180.34
	365	446.35	*	583.36	-	-

* No diet data   - Simulation not run

Table 2.3.- Water temperature (°C) when spawning begins and the calculated first day of spawning used in bioenergetics simulations for age 2+ largemouth bass, smallmouth bass, channel catfish, yellow bullhead and flathead catfish by section of river from March 2002 to March 2003.

	Largemouth bass		Smallmouth bass		Channel catfish		Yellow bullhead		Flathead catfish	
Section	°C	Day	°C	Day	°C	Day	°C	Day	°C	Day
I	18	-	15	68	21	-	20	80	24	158
II	18	64	15	50	21	-	20	-	24	-
III	18	31	15	31	21	-	20	-	24	107
IV	18	18	15	-	21	174	20	37	24	100

- Simulation not run

Figure 2.1. - Thermal experience for largemouth bass, smallmouth bass, channel catfish, flathead catfish, yellow bullhead, and rainbow trout used in bioenergetics modeling for March 2002 to February 2003. Model simulations began on March 1, 2002 (day 1) and ran through March 1, 2003 (day 365).

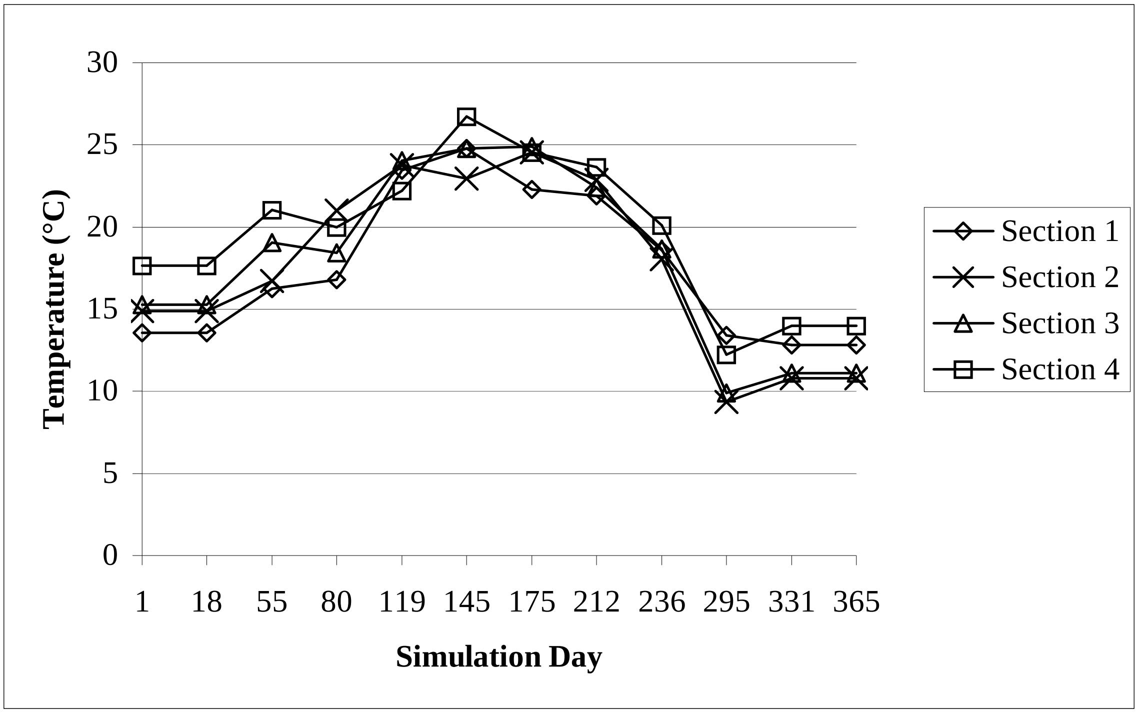


Figure 2.2. – Average daily ration (mg of prey per gram of predator per day) of yellow bullhead (YBH), channel catfish (CCF), smallmouth bass (SMB), largemouth bass (LMB), flathead catfish (FHC), and rainbow trout (RBT) feeding on native and nonnative prey fish in the Verde River, Arizona, March 2002-2003.

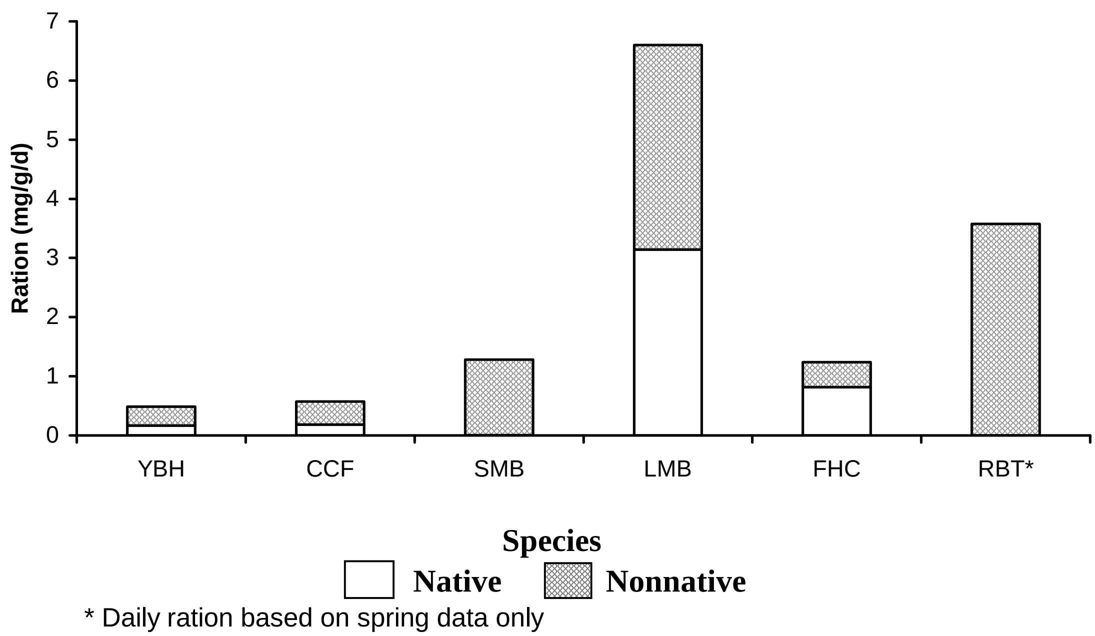


Figure 2.3.- Average daily ration of native and nonnative fish (mg of prey per gram of predator per day) by section of river, of largemouth bass (LMB), smallmouth bass (SMB), channel catfish (CCF), flathead catfish (FHC), and yellow bullhead (YBH) in the Verde River, March 2002-2003.

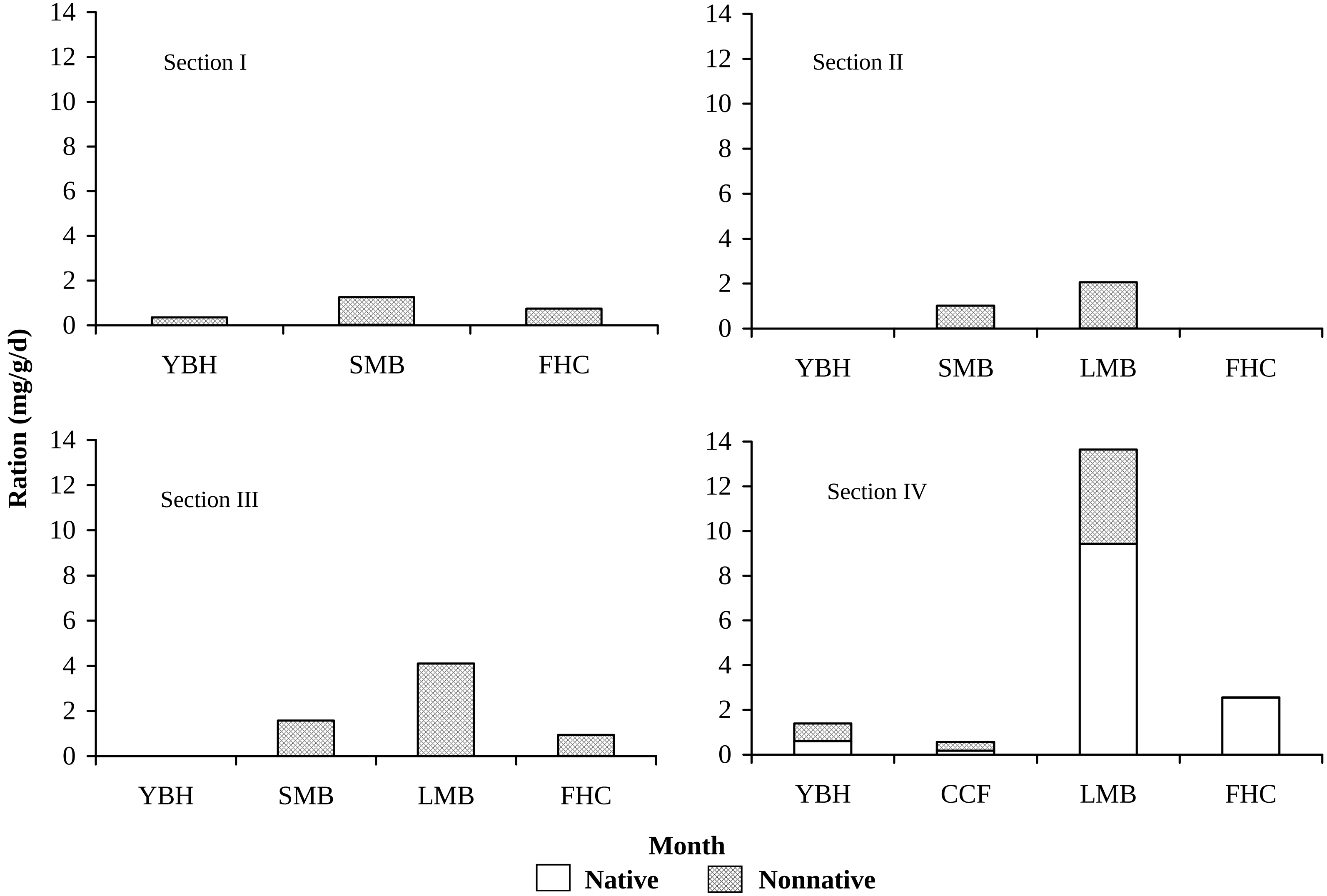


Figure 2.4.- Average daily ration (mg of prey per gram of predator per day) by season, of largemouth bass (LMB), smallmouth bass (SMB), channel catfish (CCF), flathead catfish (FHC), and yellow bullhead (YBH) feeding on native and nonnative prey fish in the Verde River, Arizona, March 2002-2003.

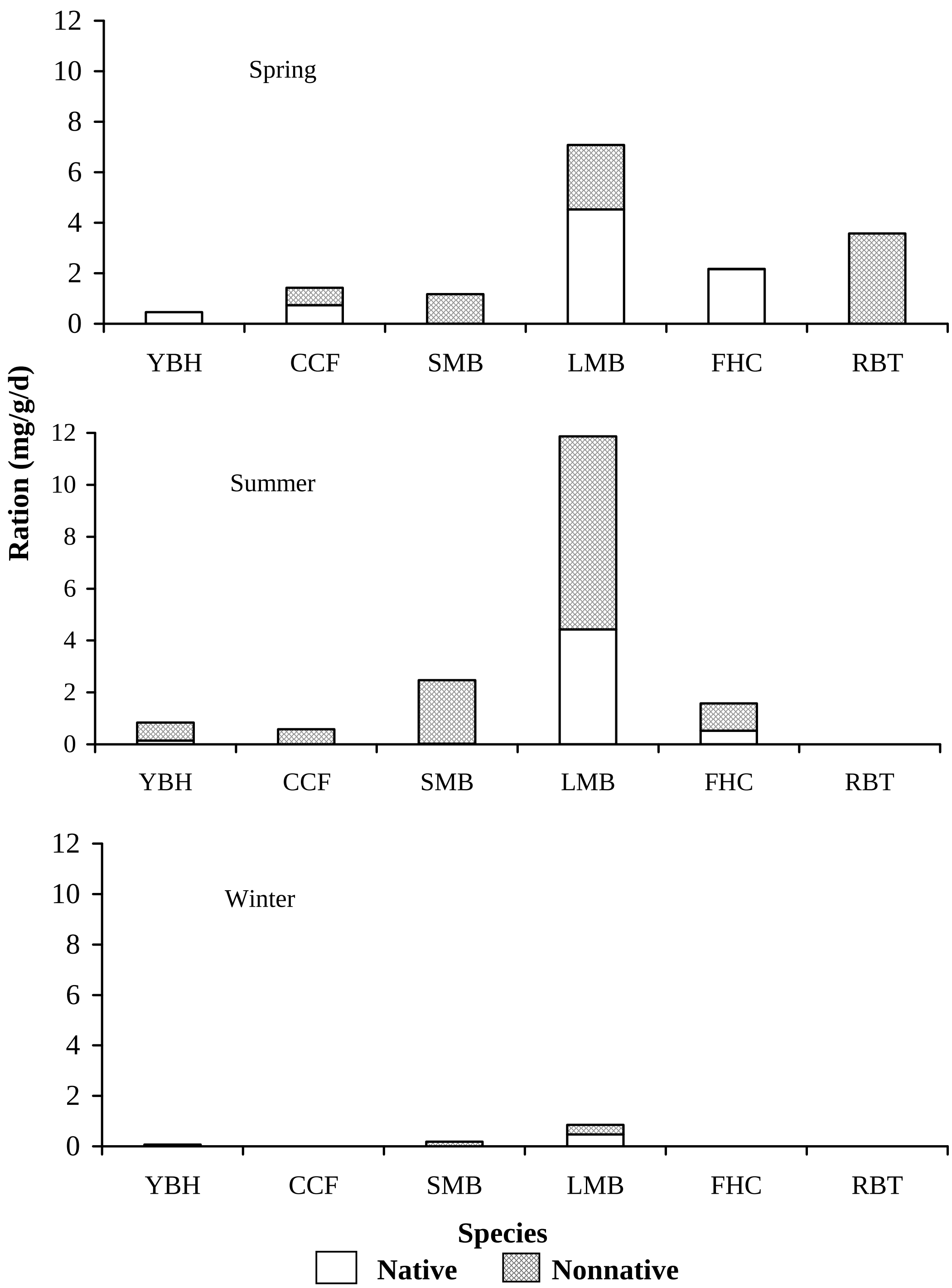


Figure 2.5.- Average daily ration (mg of prey per gram of predator per day) by age class, of largemouth bass, smallmouth bass, channel catfish, flathead catfish, and yellow bullhead feeding on native and nonnative prey fish in the Verde River, Arizona, March 2002-2003.

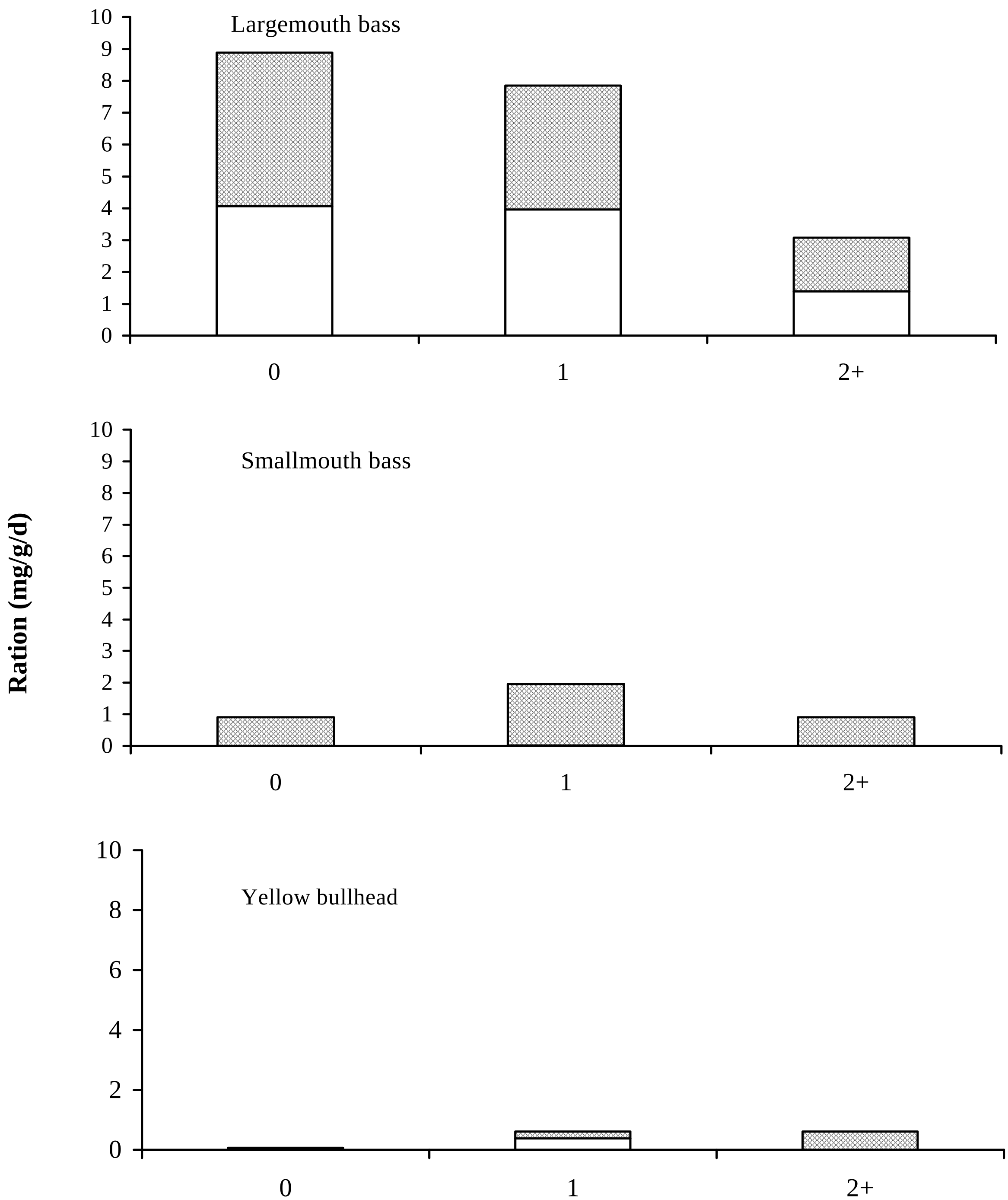
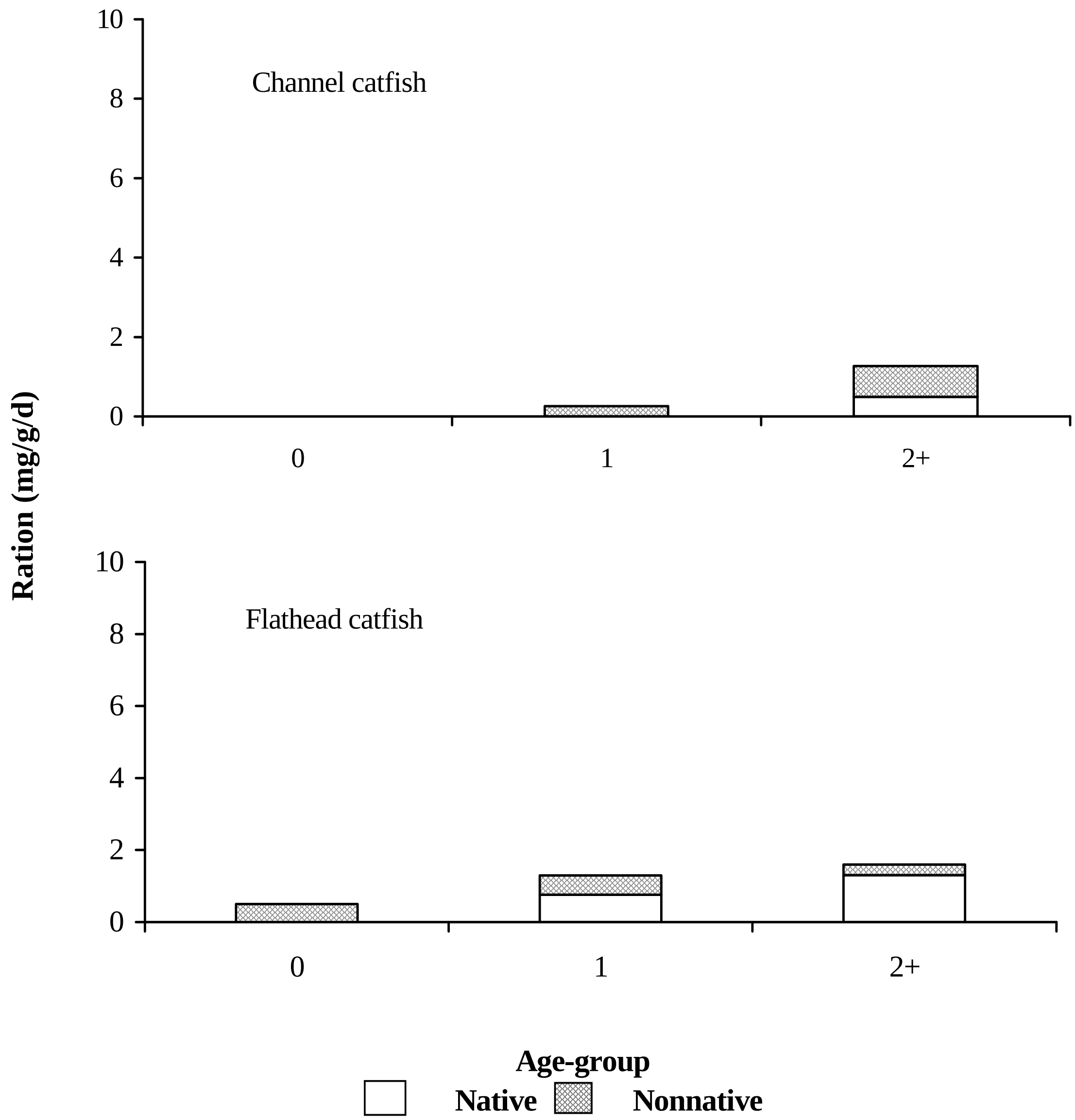


Figure 2.5 cont.- Average daily ration (mg of prey per gram of predator per day) by age group, of largemouth bass, smallmouth bass, channel catfish, flathead catfish, and yellow bullhead feeding on native and nonnative prey fish in the Verde River, Arizona.



Chapter 3: 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) denser 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.

Methods

Study Design

Following the designations of Rinne et al. (1998), we divided the river into four sections (Figure 3.1) based on the degree of human impact (Table 3.2). 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 (Figure 3.1), for a total of 12 sample sites (Table 3.3). 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 Cofflet 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 3.4), 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 3.4 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 3.4). 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 3.4). 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 dolomieui* 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%) (Figure 3.2). 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 (Figure 3.3, multiple regression and linear contrasts, $F_{1,693}$ = 112.86, P<0.001; $F_{1,693}$ = 32.97, P<0.001, respectively).

Section

Tables 3.6 and 3.7 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 3.8 and 3.9 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 3.8) and standing crops (Table 3.9) 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 3.5; 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 3.10 and 3.11 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 3.4). 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 3.4).

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 3.4). 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 3.12. Surprisingly, each section in the Verde River has a similar standing crop to various temperate and tropical rivers across the world (Table 3.12). 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 (Figure 3.4). 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 3.5), 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. Smaller fishes, such as mosquitofish and red shiners could swim through the mesh of the block nets. Therefore, the assumption of a closed population for these species may have been violated, and their densities 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 (Dave 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 4). 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 3.1. 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 3.2. 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 3.3. Site name, number, and coordinates of sample sites along the Verde River.

Site Name	Site #	Latitude	Longitude
Game and Fish Property	1	34.8683	-112.401
Perkinsville Bridge	2	34.8946	-112.208
Aston Property	3	34.8648	-112.085
Perkins Property	4	34.7955	-112.059
Black Bridge	5	34.5733	-111.856
White Bridge	6	34.5528	-111.851
Kovacavich Property	7	34.4938	-111.816
Childs	8	34.3582	-111.711
Sheeps Bridge	9	34.0769	-111.708
Needle Rock	10	33.7714	-111.665
Ft. McDowell	11	33.6379	-111.669
Beeline Hwy	12	33.5818	-111.672

Table 3.4. 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 3.5. 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 3. 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 3 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 3.7. 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 3.7. 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 3.8. Estimated densities of fishes (# individuals/ $100m^2$) 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 3.9. 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 3.10. 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 3.11. 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 3.12. 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

Figure 3.1. 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.

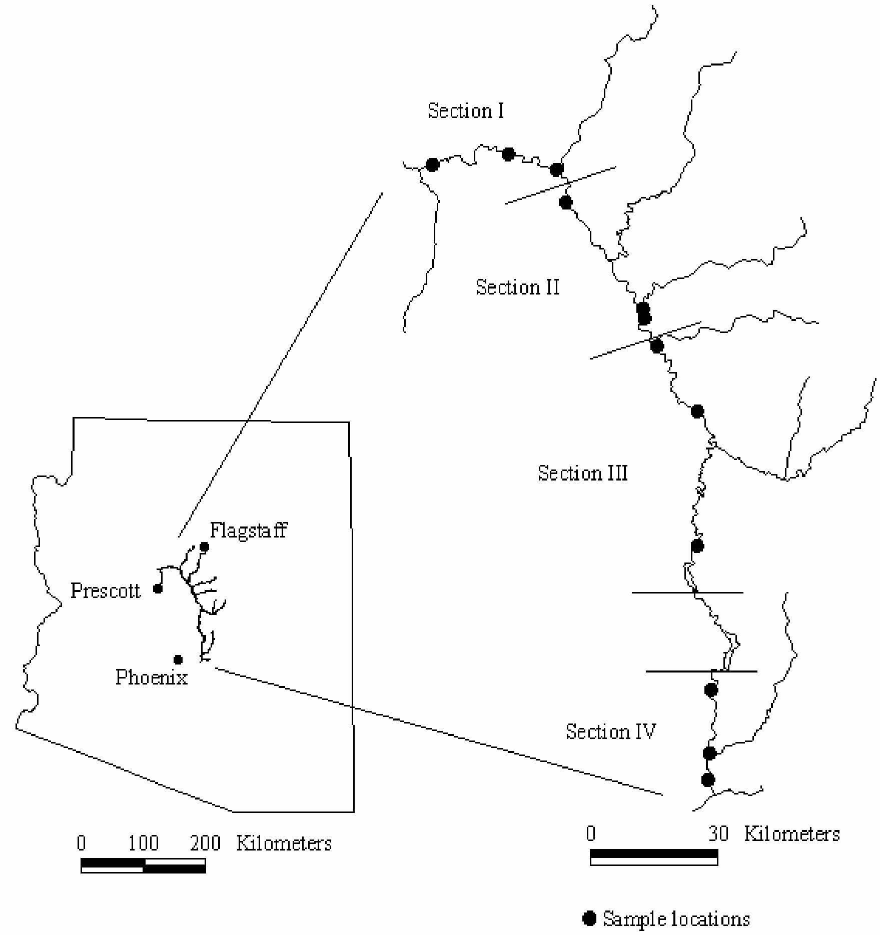


Figure 3.2. The percent relative abundances of native and nonnative fishes in the Verde River by section and environment type, from March - January 2003.

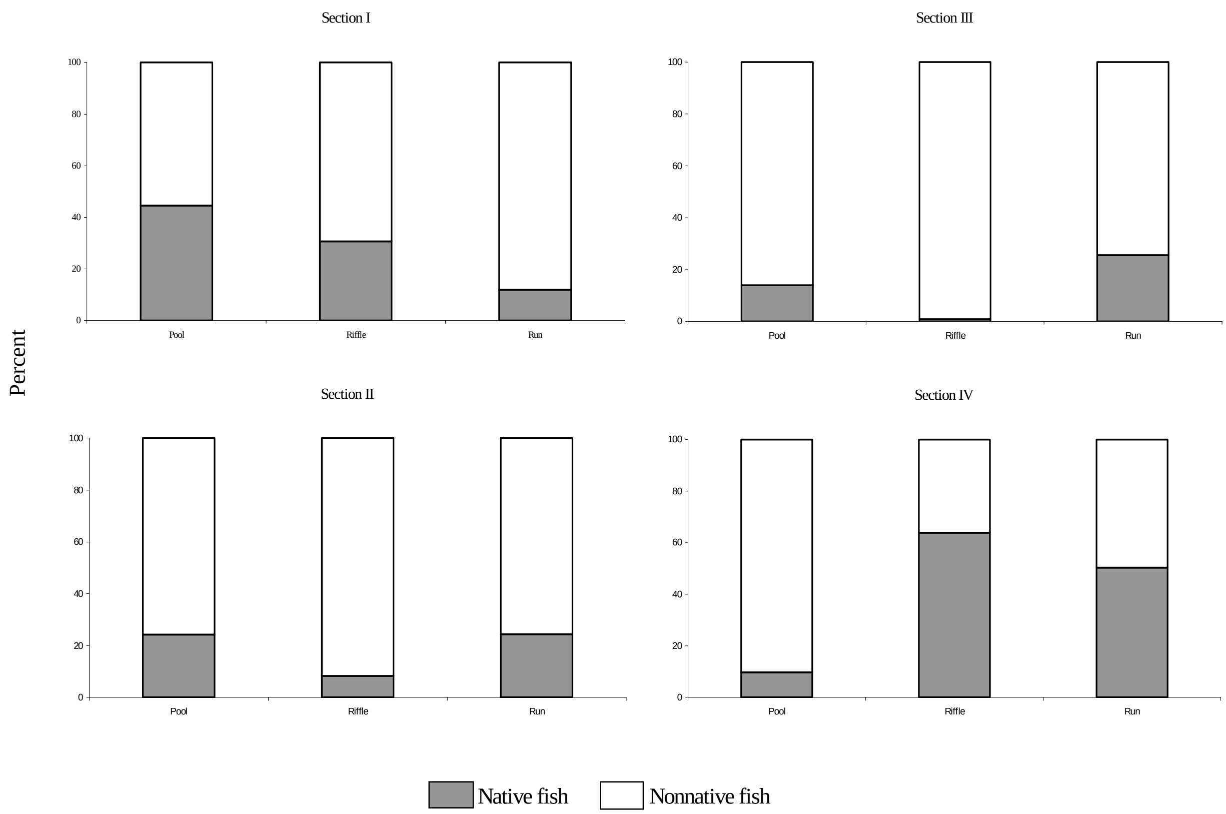


Figure 3.3. Average [log transformed scale] density (# fish/ 100m2) and standing crop (g fish/ 100m2) of native and nonnative fishes in pools, riffles, and runs across the Verde River from March 2002- January 2003.

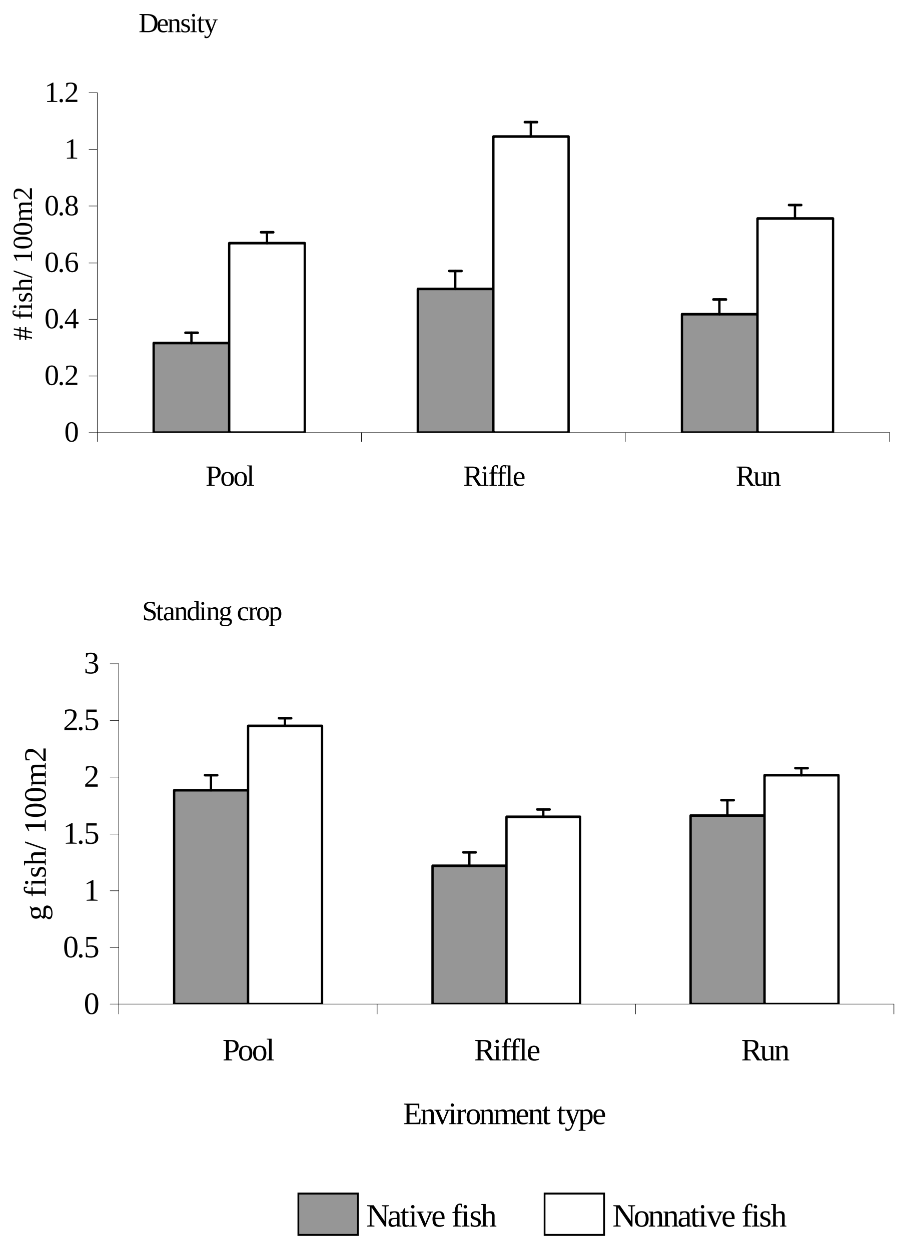
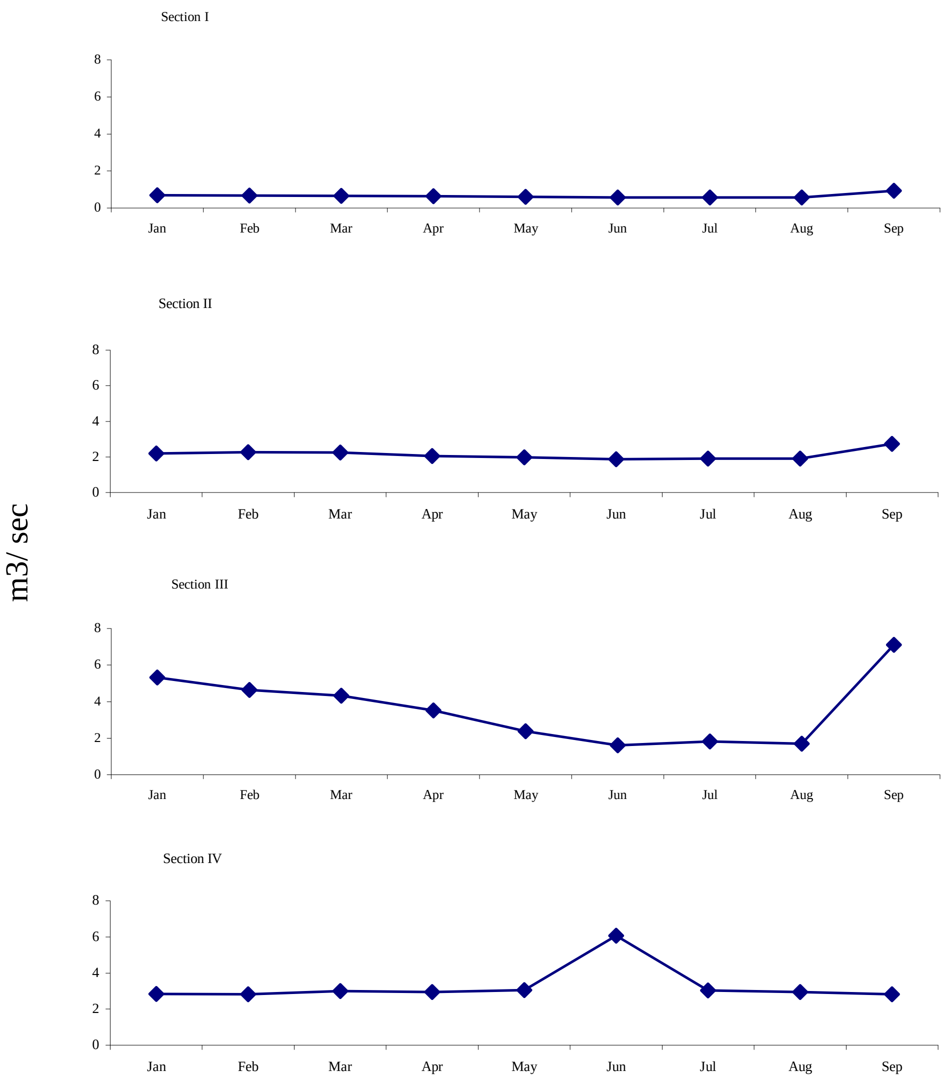


Figure 3.4. Average monthly flows (USGS 2002b) in each section of the Verde River from   Jan - Sep 2002.



Chapter 4: 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.

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 3) 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 3), 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 (Figure 4.1; 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 4.1; Figure 4.3), and on native prey fish in Section IV (Table 4.2, Figure 4.4; 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 4.1, Figure 4.5; 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 4.2, Figure 4.6; 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 4.1), and the greatest amount of native prey fish during the spring and summer (Table 4.2; 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 (Table 4.1), and age 2+ channel catfish consumed the greatest amount of native prey fish (Table 4.2; 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 (Figure 4.3).

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 (Figure 4.4), which coincided with the highest estimated densities of native fishes (Chapter 3). 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 3).

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 3). 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 (Figure 4.3), 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 3).

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 (Figure 4.3). However, over 27,000 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 piscivory 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 upstream of Horseshoe Reservoir and nonnative populations are still thriving, so a bounty program may be necessary to increase harvest of nonnative fishes. Below Horseshoe Reservoir, general statewide regulations are in effect. 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 4.1. 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 4.2. 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		

Figure 4.1. 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

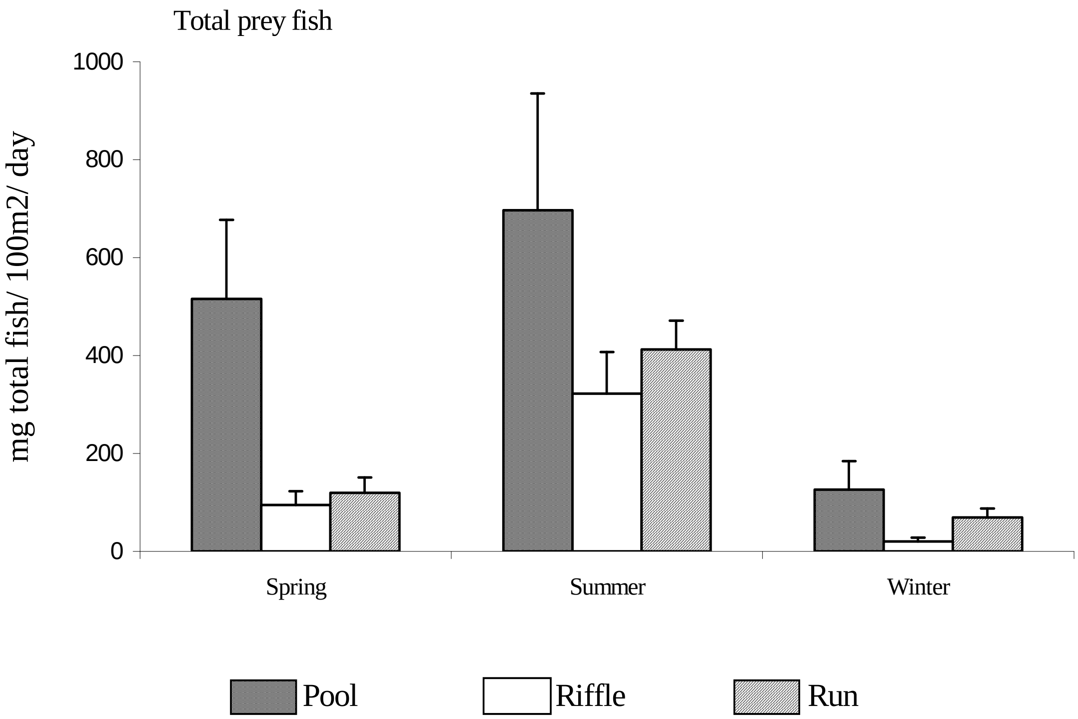

Figure 4.2. Estimated loss of native prey fish (mg native fish/ 100m2/ day) consumed in each environment type by all six predators combined during the spring, summer, and winter seasons between March 2002- January 2003.

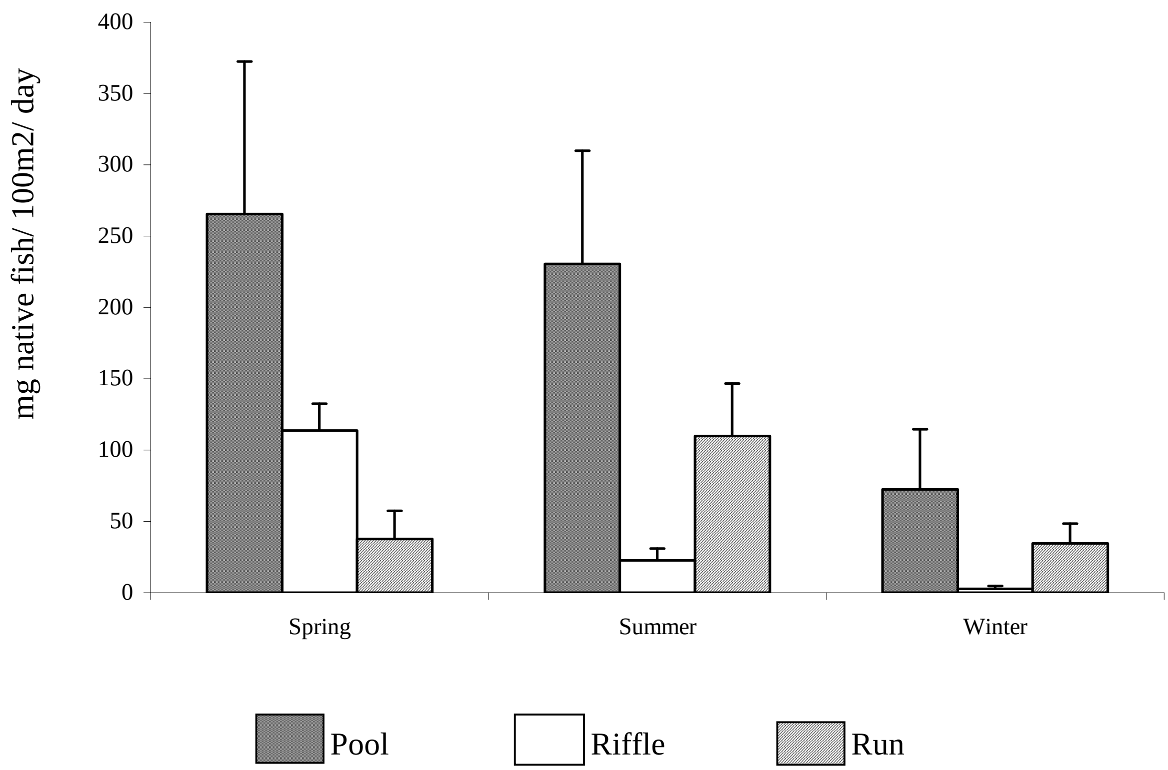

Figure 4.3. Estimated loss of total prey fish (mg total fish/ 100m2/ day) to channel catfish (CCF), flathead catfish (FHC), largemouth bass (LMB), rainbow trout (RBT), smallmouth bass (SMB), and yellow bullhead (YBH) in the Verde River from March 2002- January 2003.

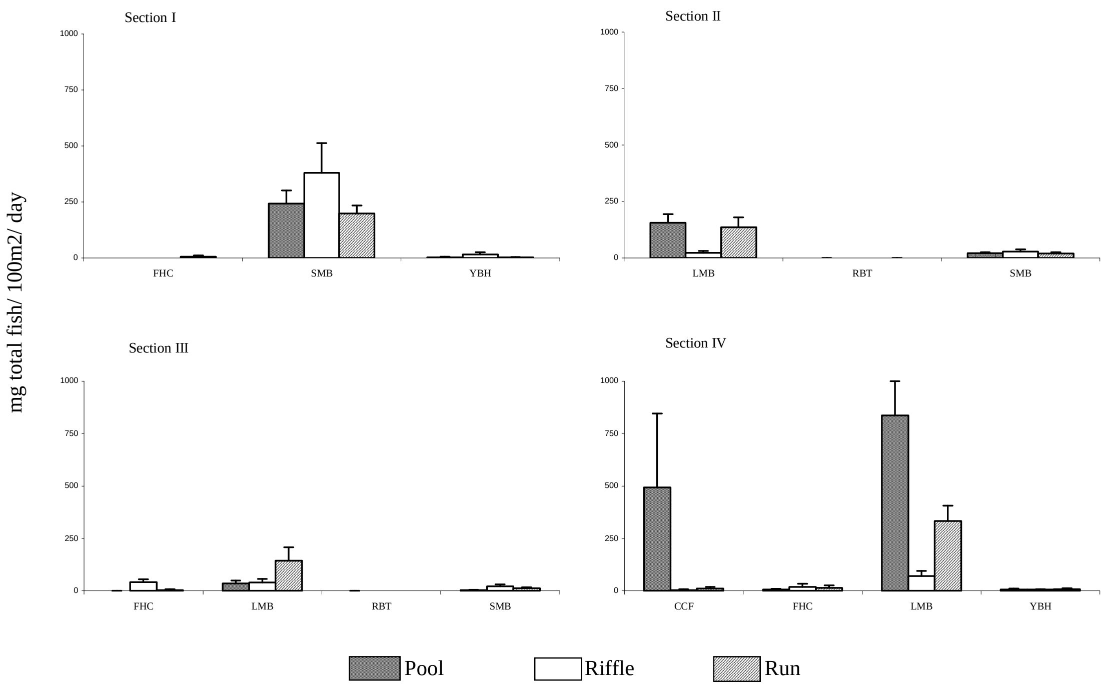

Figure 4.4. Estimated loss of native prey fish (mg native fish/ 100m2/ day) to channel catfish (CCF), flathead catfish (FHC), largemouth bass (LMB), smallmouth bass (SMB), and yellow bullhead (YBH) in the Verde River from March 2002- Januray 2003.

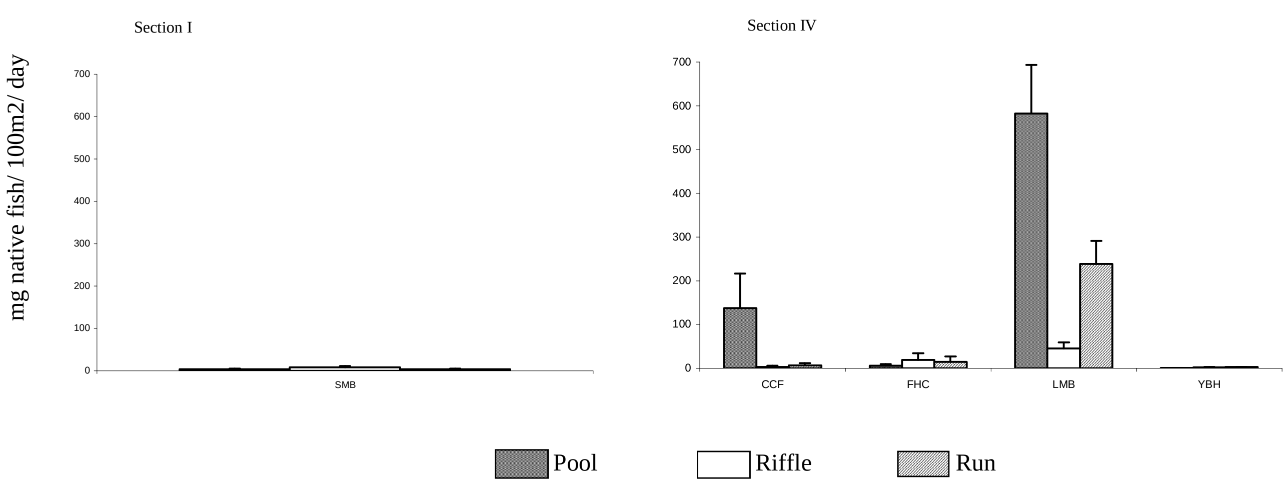

Figure 4.5. The estimated loss of total prey fish (mg total fish/ 100m2/ day) to channel catfish (CCF), flathead catfish (FHC), largemouth bass (LMB), smallmouth bass (SMB), and yellow bullhead (YBH) by environment type and age class in the Verde River from March 2002- January 2003.

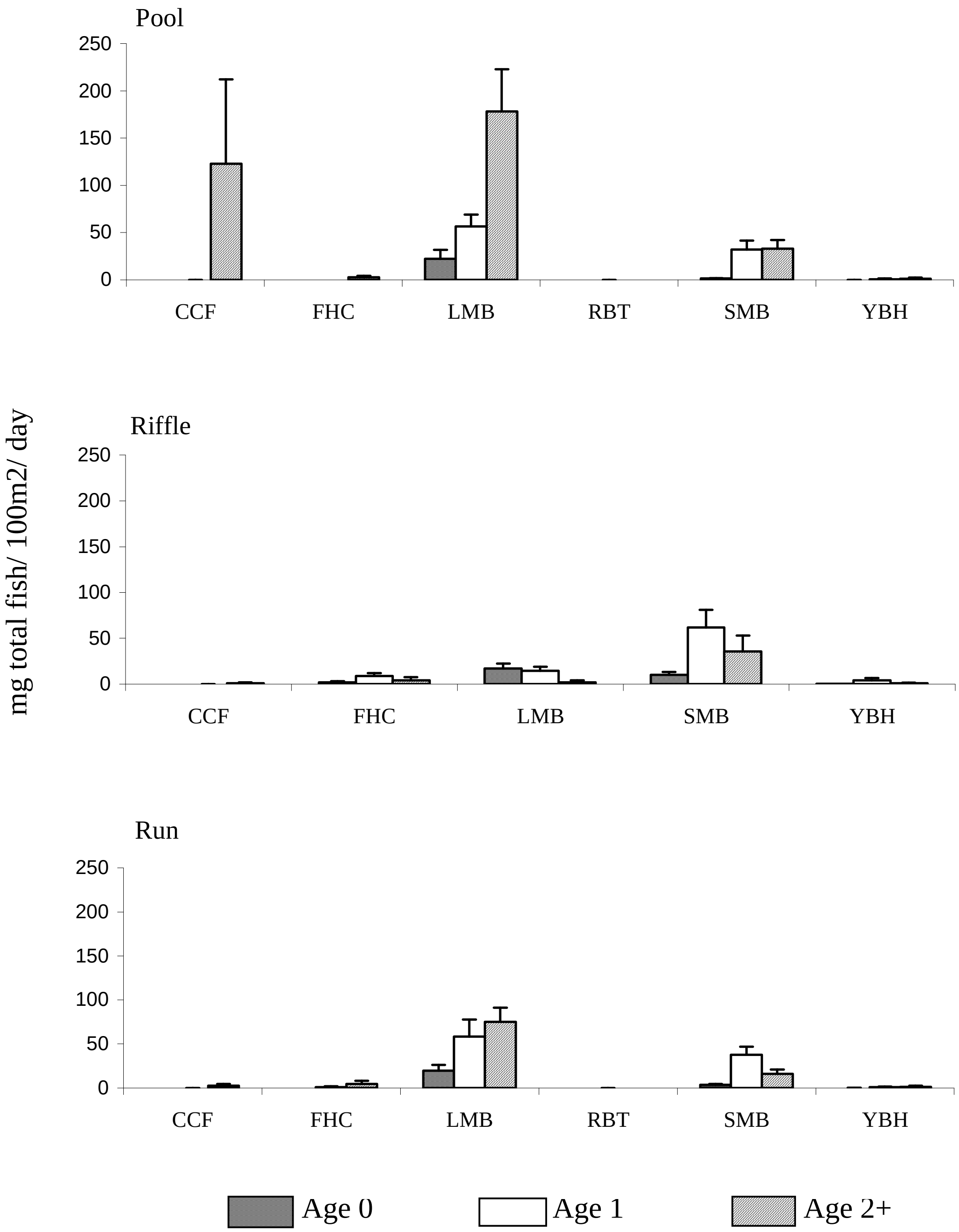

Figure 4.6. The estimated loss of native prey fish (mg native fish/ 100m2/ day) to channel catfish (CCF), flathead catfish (FHC), largemouth bass (LMB), smallmouth bass (SMB), and yellow bullhead (YBH) by environment type and age class in the Verde River from March 2002- January 2003.