THE EFFECTS OF GREEN SUNFISH ON THE DISTRIBUTION, ABUNDANCE AND HABITAT USE OF GILA CHUB IN SABINO CREEK, ARIZONA

Final Report to Arizona Game and Fish Department

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by

Robert Kenneth Dudley

and

William J. Matter

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LOTTERY DOLLARS WORKING FOR WILDLIFE

DISCLAIMER

STATEMENT BY AUTHORS

Most of this report was written by R. K. Dudley as a thesis in partial fulfillment of requirements for a Master of Science degree at the University of Arizona, under the direction of W. J. Matter. The thesis is deposited in the University Library to be made available to borrowers under rules of the library.

This report retains the style and format of the thesis, in which Chapters 1-3 are written as individual manuscripts to be submitted for publication. However, the report has been modified in response to technical and scientific comments by reviewers within Arizona Game and Fish Department. Also, figures and tables occur at the end of the appropriate chapters.

ACKNOWLEDGEMENTS

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INTRODUCTION

Gila chub (*Gila intermedia*) may be extirpated in Mexico and New Mexico (Minckley 1991) and are presently listed as "threatened" by the Arizona Game and Fish Department. Gila chub are now abundant at fewer than 10 sites below the central Arizona highlands and Mogollon Rim (Minckley 1969, 1985) and are often restricted to the uppermost pools or springs within these areas (Rinne 1975, Minckley 1991).

The presence of green sunfish (*Lepomis cyanellus*) has been correlated with declines of Gila chub in Arizona (Minckley et al. 1977). There is concern about declines of Gila chub throughout their historical range. My goal was to determine the effects of green sunfish on the distribution, abundance and habitat use of Gila chub in Sabino Creek.

I used a combination of field observations and experimental manipulations to address specific research objectives. Although all of the objectives relate to understanding the effects of green sunfish on Gila chub, I have grouped them into logical study units and presented them in chapters, each in the format of a scientific article. I am senior author on all 3 articles. Dr. William J. Matter assisted in all aspects of this project, and is a co-author on all articles.

The objectives for the work reported in Chapter 1 were to determine: 1) the distribution of Gila chub and green sunfish, 2) differences in the abundance and size-class structure of Gila chub in areas with and without sunfish, and 3) changes in the distribution or abundance of Gila chub or green sunfish following a flood in the winter of 1992-1993.

The objectives for the work reported in Chapter 2 were to determine: 1) if successful recruitment of Gila chub would occur in areas where densities of green sunfish were experimentally reduced, 2) the microhabitat use of YOY chub and small (< 7.5 cm, TL) green sunfish, and 3) if small green sunfish are predaceous on YOY chub.

The objectives for the work reported in Chapter 3 were to determine: 1) microhabitat used by sub-adult and adult Gila chub, 2) seasonal changes in microhabitat used by sub-adult and adult chub in areas without sunfish, and 3) whether Gila chub use different habitat conditions in areas with sunfish than in areas without sunfish.

STUDY AREA

Sabino Creek, Pima County, Arizona is part of the Gila River Basin and drains an area of 91.9 km^2 (35.5 mi^2) (USGS 1992). The creek originates near Mt. Lemmon (elevation 2790 m) and has an average gradient of 34 m/km (180 ft/mi) (Miller, J. 1961). My study area was located in the lowermost reaches of Sabino Creek (elevation < 1088 m) (Figure 1) where green sunfish and Gila chub are the only fish present. The substrate ranged from sand to boulder-bedrock, with virtually no vascular aquatic vegetation. The discharge is erratic because of seasonal patterns of heavy rainfall, snow melt and drought (Miller, J. 1961). Discharge averages 0.37 m^3/s (12.9 cfs) (based on 52 years of records) and ranges from 0 to 218.9 m^3/s (0 to 7,730 cfs) (USGS 1992). During the summer (May through September), much of the study reach became a series of isolated pools (not connected by surface flow). Nine stone bridges cross Sabino Creek and act as temporary barriers to natural upstream movement by fish. Only sunfish are present downstream of a point 0.5 km below bridge 1; both chub and sunfish occur upstream from this point to a rock barrier (about 0.5 km above bridge 8); and only chub occur above this barrier (Figure 2). Chub occur upstream to a point below a large rock waterfall (about 1.6 km above bridge 9).

Figure 1. Location of Sabino Creek, Arizona

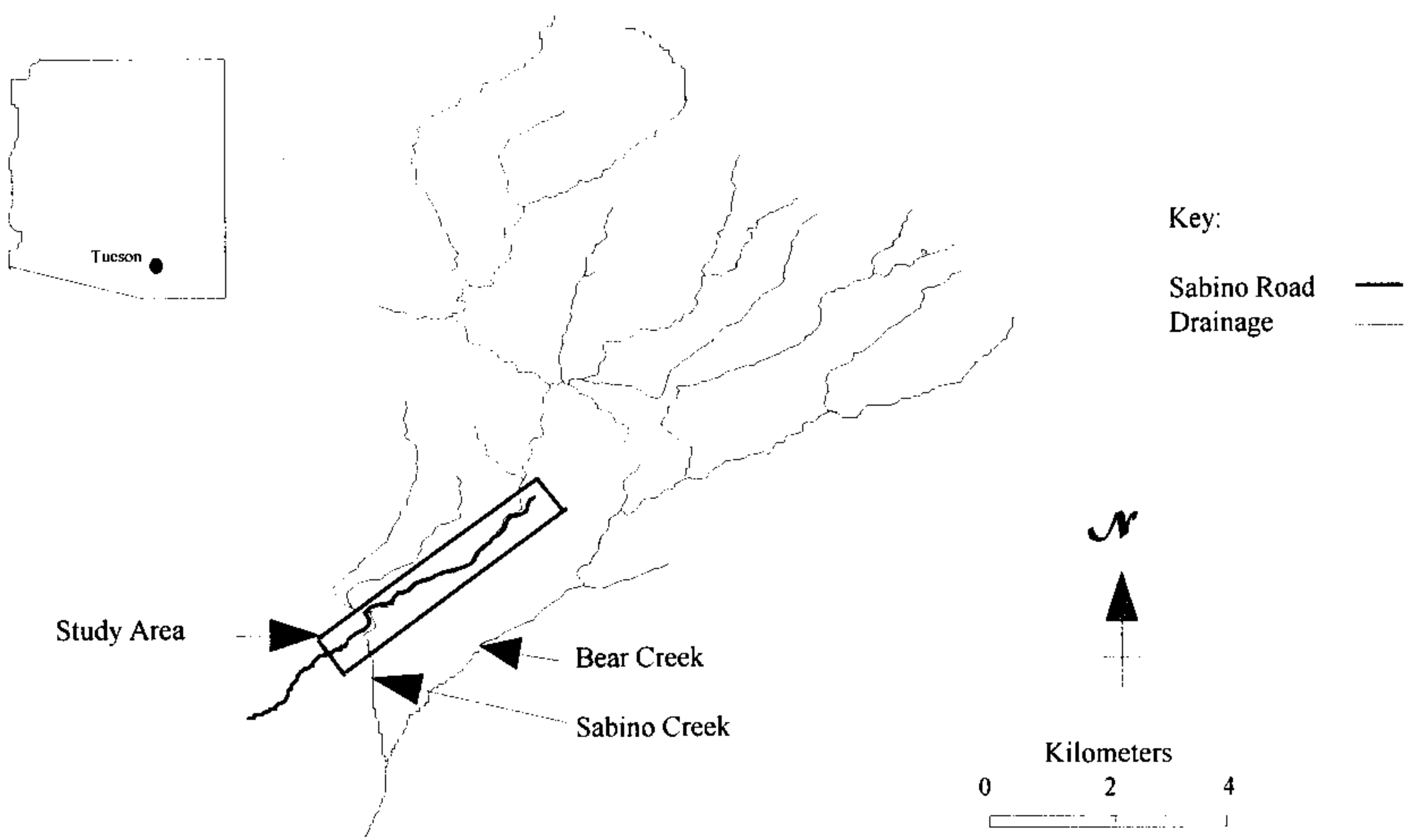
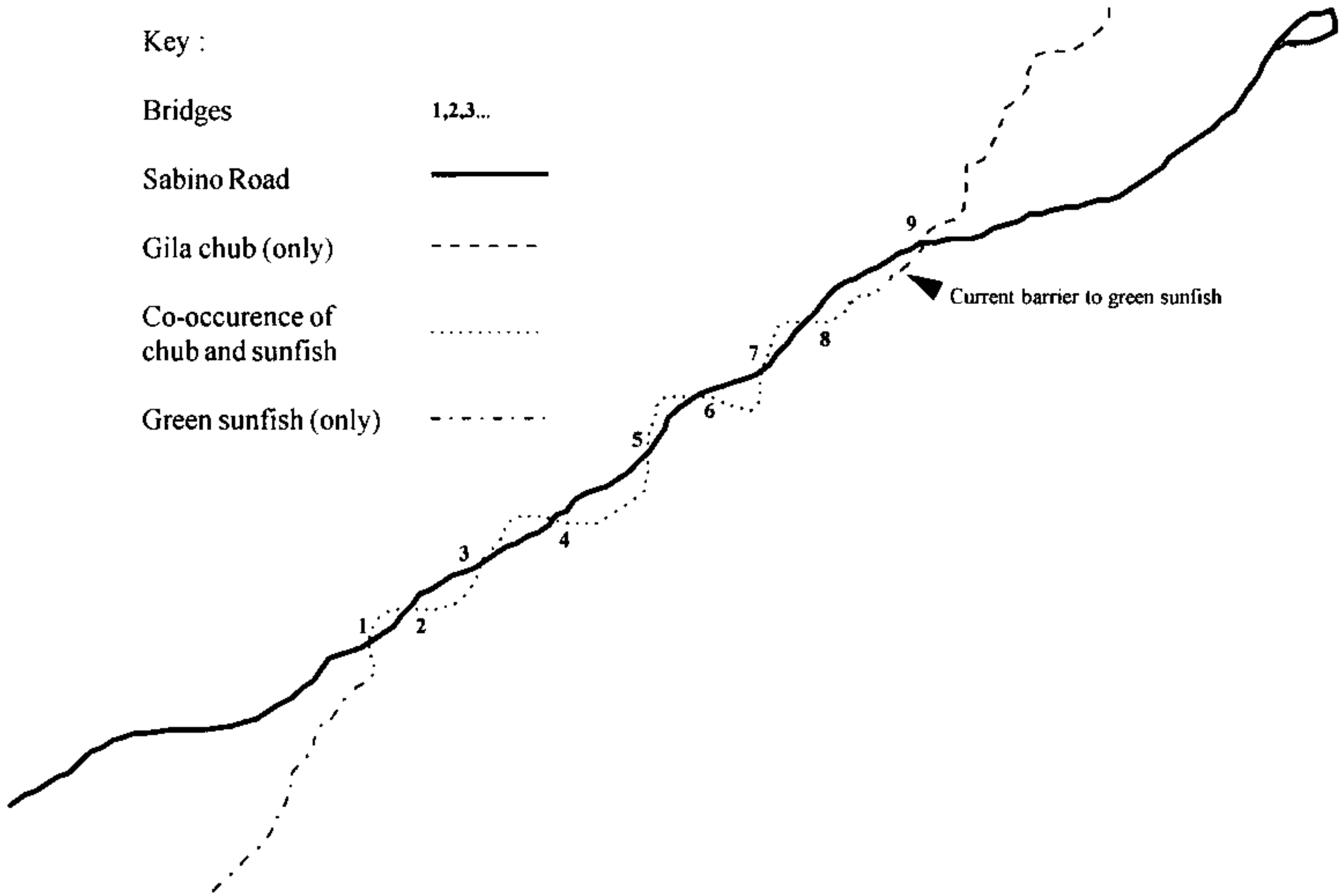


Figure 2. Distributions of Gila chub and green sunfish in Sabino Creek, Arizona (map not to scale)



CHAPTER 1. DISTRIBUTION AND ABUNDANCE OF GILA CHUB AND GREEN SUNFISH IN SABINO CREEK, ARIZONA

ABSTRACT

Green sunfish (*Lepomis cyanellus*) have been found progressively farther upstream in Sabino Creek over the past 12 years. However, the distributions of Gila chub (*Gila intermedia*) and green sunfish remained relatively constant from fall 1993 through fall 1994. A rock barrier has temporarily prevented further upstream movement by sunfish. Many fish were lost as pools dried up during low flow in summer 1994, but losses of Gila chub were minimal because most chub occupied upstream pools that did not dry completely.

Densities of Gila chub were about 90% lower in Sabino Creek below bridge 8 where they co-occurred with green sunfish than in upstream reaches without sunfish. Chub < 24.0 cm, TL were absent in areas with sunfish. The majority of chub in areas with sunfish were > 7.5 cm, TL. Densities of chub, especially fish < 7.5 cm, may be lower in downstream areas because of interactions with green sunfish.

Green sunfish were found farther upstream in Sabino Creek following a winter flood than prior to the flood. The density of green sunfish was similar in the upper and lower parts of their distribution in the creek following the flood. A few chub, all > 7.5 cm, TL, were found farther downstream following the flood than before it. These results do not support the hypothesis that floods in the desert Southwest displace introduced fish downstream thereby aiding the persistence of native fish in canyon-bound streams.

INTRODUCTION

Much of the aquatic habitat required by native fish of the desert Southwest has been lost or altered over the past 100 years (Minckley and Deacon 1968, Hendrickson and Minckley 1984). Perennial flows in many spring-fed streams and surrounding wet meadows (cienegas) have been lost to agricultural and municipal uses (Miller, R. 1961, Minckley 1969, 1991, Williams and Sada 1985). The small size of existing springs and streams makes fish populations susceptible to extirpation following minor habitat alterations (Williams and Sada 1985) or the effects of introduced fish (Naiman and Soltz 1981). Gila chub (*Gila intermedia*) are endemic to streams and marshes of the upper Gila River basin including areas of Arizona, New Mexico and Sonora, Mexico (Rinne 1976). They have been reported to be most abundant in deep pools with extensive cover (Minckley 1973, Griffith and Tiersch 1989), and the loss of these conditions is correlated with decreases in their distribution and abundance (Hendrickson and Minckley 1984). They may be extirpated in Mexico and New Mexico (Minckley 1991) and are presently listed as "threatened" by the Arizona Game and Fish Department. Gila chub are now abundant at fewer than 10 sites below the central Arizona highlands and Mogollon Rim (Minckley 1969, 1985) and are often restricted to the uppermost pools or springs within these areas (Rinne 1975, Minckley 1991).

Species Interactions

Declines in the distribution and abundance of many native fish of the desert Southwest are correlated with the increased distribution of introduced fish (Williams and Sada 1985, Bestgen and Platania 1991, Minckley and Deacon 1991). Non-native species may impact native fish through predation, competition for resources, or harassment in small closed areas. Native fish may be rapidly eliminated because they evolved with different or few natural competitors and predators (Miller, R. 1961, Meffe 1985, Miller 1989). When native fish are restricted to isolated pools (Meffe 1985, Minckley 1991), interactions with introduced species may be accentuated (Naiman and Soltz 1981, Meffe 1985).

Green sunfish (*Lepomis cyanellus*) have successfully colonized areas far outside their native range (Werner 1977), often out-competing or preying on native species (Williams and Sada 1985). Green sunfish are habitat generalists (Layher and Maughan 1987), able to exploit and switch between a variety of conditions and food resources (Werner and Hall 1979). They are the most piscivorous of the lepomids (Werner 1977, Sigler and Sigler 1987) and have been associated with the decline of many native cyprinids (Moyle and Nichols 1973, Lemly 1985), especially in the desert Southwest (Marsh and Langhorst 1988, Fausch and Bramblett 1991). Predation by green sunfish may explain the absence of Gila chub from downstream reaches of Sycamore Creek, Arizona (John Rinne, Rocky Mtn. Forest and Exp. Range Station, personal communication) and in the Santa Cruz River, Arizona (Minckley et al. 1977). Declines of Gila chub in Sabino Creek have been associated with the presence of green sunfish (Deborah Bieber, U.S. Forest Service, personal communication). My first objective was to determine the distributions of Gila chub and green sunfish in Sabino Creek. My second objective was to quantify differences in the abundance and size-class structure of Gila chub in areas with and without sunfish.

Effects of Flooding on Native and Introduced Fish

Native fish of the desert Southwest are often adapted morphologically and behaviorally to survival in streams that periodically flood (Williams and Sada 1985;

Minckley and Deacon 1991), and can rapidly recolonize areas after flooding (Minckley and Barber 1971; Collins et al. 1981, Meffe 1984). Minckley (1973) has suggested that many introduced fish may not be adapted to periodic floods and may be displaced during floods. Although green sunfish are adapted to headwater streams (Moyle and Cech 1988), they are often displaced during high-volume summer floods in southwestern streams (Harrel 1978, Minckley and Meffe 1987). Sabino Creek experienced a record flood during the winter of 1992-1993. The Nongame Branch of the Arizona Game and Fish Department in conjunction with the Coronado National Forest collected data on the distribution of Gila chub and green sunfish before the flood. My third objective was to determine if the distribution or abundance of Gila chub or green sunfish changed following the flood.

METHODS

Estimates of the distribution and abundance of Gila chub and green sunfish were made in fall (September to November) of 1993 and 1994. Gila chub and green sunfish tend to select pools and, during much of the year, Sabino Creek is reduced to a series of pools not connected by surface flow. Capture of fish in these pools by seine or electrofishing was difficult due to the rock and boulder substrate. I located fish primarily through underwater observations (in 16 pools in 1993 and 43 pools in 1994). I moved upstream through the center of each pool and recorded numbers of each species seen, as an index of relative abundance. I estimated fish length to the nearest 2.5 cm by reference to an underwater measuring rod. Density estimates for both species were calculated by dividing their abundance by the surface area (m^2) of a particular site.

The distribution of Gila chub and green sunfish before the winter flood of 1992-1993 was noted by the Coronado National Forest and Arizona Game and Fish Department during annual "fall fish counts." Electrofishing was the primary technique used in these surveys. I noted the distribution, but not abundance, of both species along Sabino Creek during numerous visits for other aspects of my study.

RESULTS

The distributions of Gila chub and green sunfish remained relatively constant throughout my study. Gila chub were found slightly farther downstream in 1993 (0.5 km below bridge 1) than in 1994 (0.2 km below bridge 1), but the upper distributions of chub and sunfish did not change.

Many fish were lost as pools below bridge 8 dried up during periods of low flow in summer 1994. Over 70% of the wetted area below bridge 8 in May was dry by July. However, losses of Gila chub were minimal because most chub occupied pools upstream of bridge 9 that did not dry up.

Green sunfish comprised the majority of fish below bridge 8 in 1993 and 1994 (Figures 1 and 2). The density of Gila chub was about 90% lower below bridge 8, where they co-occurred with sunfish, than in upstream reaches without sunfish (Figure 3). A higher percentage of chub were > 7.5 cm, TL in areas with sunfish (about 50 %) than in areas without sunfish (about 20 %) in 1993 and 1994 (Figures 4 and 5). Chub < 4.0 cm, TL were absent from areas with sunfish in 1993 and 1994.

<u>Flooding</u>

Prior to 1993, the highest daily mean discharge in Sabino Creek was 60.3 m/s^3 (2,130 cfs) and the maximum discharge was 218.9 m/s^3 (7,730 cfs) (based on 52 years of data, USGS 1992). In 1993 the highest daily mean discharge was 90.1 m/s^3 (3,180 cfs) and the maximum discharge was 365.3 m/s^3 (12,900 cfs) (USGS 1993), the highest values ever recorded in Sabino Creek.

The Arizona Game and Fish Department reported the upper distribution of green sunfish in Sabino Creek as below bridge 8 in 1992. I found green sunfish below a boulder barrier between bridges 8 and 9 in the fall of 1993 following the flood of 1992-1993. I found little difference in the density of sunfish between the upper and lower parts of their distribution following the flood (Figure 6). The Arizona Game and Fish Department reported the lower distribution of Gila chub to be between bridges 7 and 8 in 1992. I found Gila chub below bridge 1 in the fall of 1993.

DISCUSSION

Green sunfish have been found progressively farther upstream in Sabino Creek over the past 12 years (Figure 7); (David Lazaroff, former Environmental Education Specialist, Coronado National Forest, unpublished data). Bridges appear to only act as temporary barriers to upstream movement by sunfish. Stream-wide distributions of Gila chub and green sunfish were relatively static during my study. I found Gila chub farther downstream in 1993 (0.5 km below bridge 1) than in 1994 (0.2 km below bridge 1), but only three adult chub were seen below bridge 1 during the 1993 survey. Low densities of chub in downstream areas with sunfish made it difficult to determine the lowermost distribution of chub. Therefore, any differences in the lower distribution of chub between years are approximate. Also, seasonal variability in the extent of surface water alters the lowermost distribution of chub and sunfish.

Large numbers of fish, especially juveniles, can be lost in southwestern streams when areas dry up during summer (Carpenter 1992). All riffles in my study area dried up during summer. Fish retreated to pools, but most of these pools dried in subsequent weeks, killing fish trapped in them. I estimated that at least 70% of the wetted area below bridge 8 was lost at the summer minimum, and thus a comparable proportion of fish probably died. Pools that persisted through summer had bedrock substrates or were upstream of bridge 8. Recolonization of de-watered sites was rapid (within days) for both species once continuous surface water flow resumed in late summer to fall. Thus, dramatic seasonal changes in the local distribution of fish are driven, in part, by changes in quantity of surface water.

Gila chub were at much lower densities or absent in areas with sunfish than in areas without sunfish. A much higher percentage of chub were > 7.5 cm in areas with sunfish than in areas without sunfish. I observed no YOY chub in areas with sunfish. However, YOY chub were observed in these areas before the upstream advance of sunfish (David Lazaroff, unpublished data), and I observed YOY chub in upstream areas lacking sunfish. The absence of YOY chub, lower densities of chub and predominance of large chub in areas with sunfish suggest that negative interactions occur between sunfish and chub where their distributions overlap.

Flooding

Fish native to the desert Southwest are thought to have evolved behaviors and morphologies to withstand floods, but introduced fish may lack similar adaptations, making them susceptible to downstream displacement during floods (Minckley 1973). During the winter of 1992-1993, the highest discharge recorded in 53 years occurred over a period of several weeks. However, green sunfish were not displaced from areas they occupied before the flood. I found sunfish further upstream following the flood than before it. Sunfish may have moved upstream of bridge 8 during the flood when surface flow connected areas above and below the bridge. However, it is also possible that sunfish were moved upstream by humans or were already present above bridge 8, but were missed during pre-flood surveys by Arizona Game and Fish Department. Also, the density of sunfish was similar in upstream and downstream areas following the flood, not indicative of downstream displacement. Green sunfish may be more resistant to flooding than other non-natives because they evolved in mesic streams that periodically flooded (Minckley and Meffe 1987). The tolerance of green sunfish to high flow (Carlander 1977) may be one reason this species has invaded and persisted in low elevation streams in the desert Southwest (Minckley 1973).

Nearly all previous studies on the effects of flooding on native and non-native fish have been based on floods that occurred during summer (Minckley and Meffe 1987). Many fish of low elevation desert streams are more active and farther from cover in summer than in winter, making them more susceptible to displacement during floods. They are reclusive in winter, using areas in or close to cover. Fausch and Bramblett (1991) suggested that fish occupying areas with extensive cover and little velocity are immune to displacement by floods. Most sunfish I located during winter in Sabino Creek were relatively inactive and occupied interstitial spaces between rocks and boulders in areas with no measurable water velocity (see Chapt. 3). The inactivity and selected habitat of sunfish during winter may be major reasons they were not displaced during the winter flood in Sabino Creek. The results for green sunfish do not support the hypothesis of

Minckley and Meffe (1987) on the impacts of flooding on non-native fish, and suggest that the seasonal timing of floods may greatly alter their impact on fish. However, another introduced species, mosquito fish (*Gambusia affinis*) were recorded in the lower reaches of Sabino Creek in 1992 by the Arizona Game and Fish Department, but have not been found since the flood of 1992-1993. Apparently mosquito fish were displaced, as predicted by the hypothesis of Minckley and Meffe (1987).

I found Gila chub about 2 km farther downstream following the flood than they had been reported prior to it. However, this difference cannot be attributed unequivocally to the effects of flooding because only low densities of chub were found in downstream areas. The few chub that I found by sampling many sites in downstream areas over several months could easily have been missed during previous 1-day surveys of a limited number of sites by the Arizona Game and Fish Department.

The downstream movement of some native fish during floods is common in the desert Southwest (John 1964, Minckley and Meffe 1987). Small chub (< 4.0 cm, TL), abundant in upstream areas without sunfish, could have moved or been swept downstream by floods, but no small chub were observed in areas with sunfish over the 2 years of my study. Either small chub were not displaced downstream or were quickly eliminated by sunfish (see Chapt. 2).

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Figure 1. Relative abundance of Gila chub and green sunfish in four areas of Sabino Creek, Arizona in September to November of 1993. (n=number of pools sampled within each area)

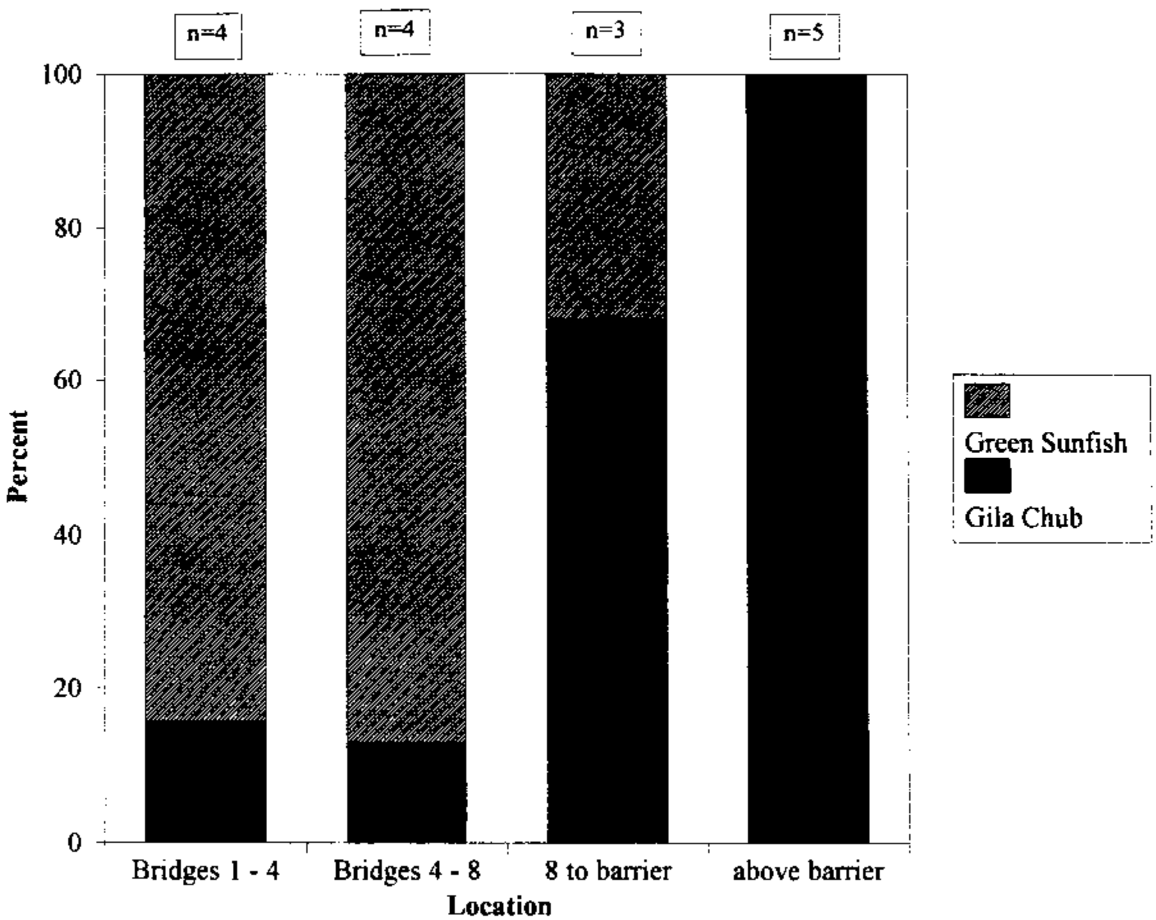


Figure 2. Relative abundance of Gila chub and green sunfish in four areas of Sabino Creek, Arizona in September to October of 1994. (n=number of pools sampled within each area)

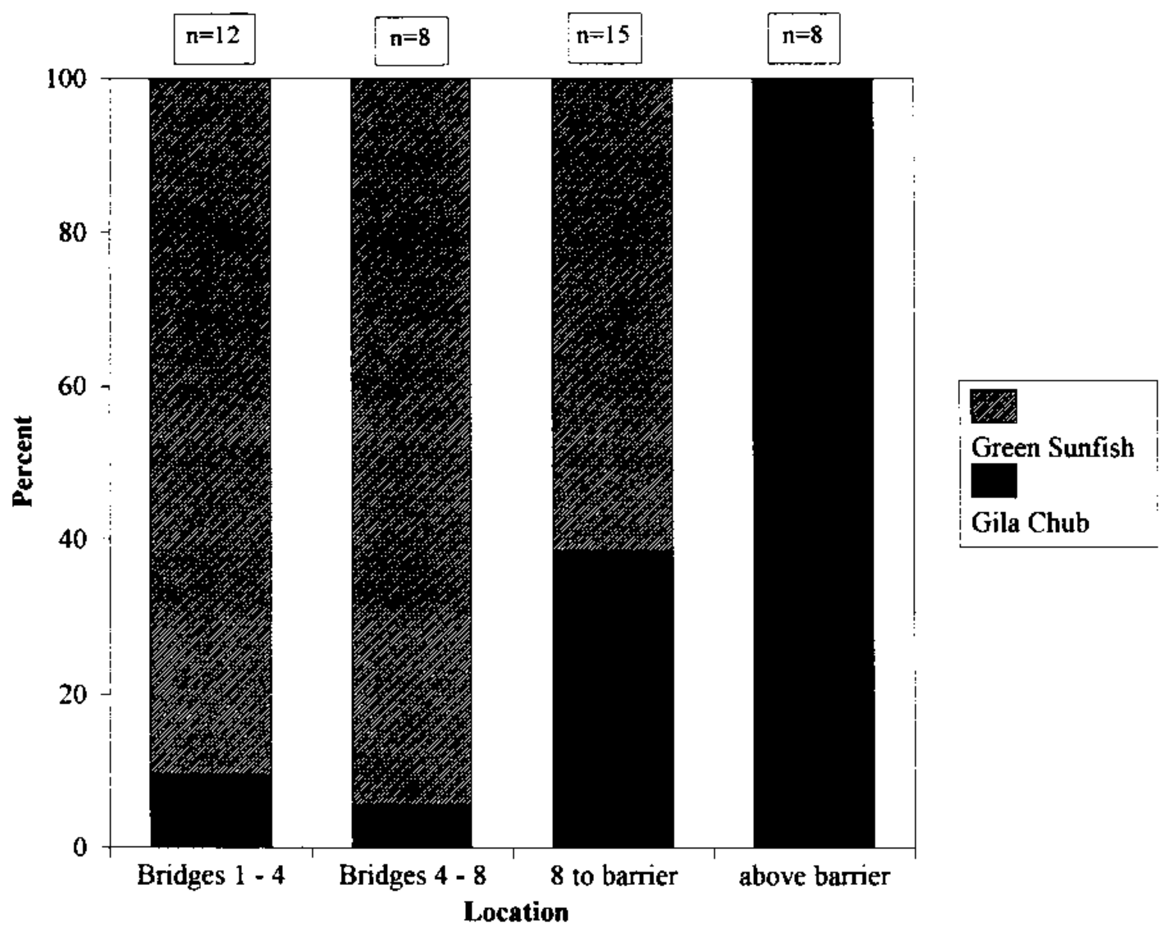


Figure 3. Density (#/m^2) of Gila chub in four areas of Sabino Creek, Arizona in fall of 1993 and 1994. (n=number of pools sampled within each area)

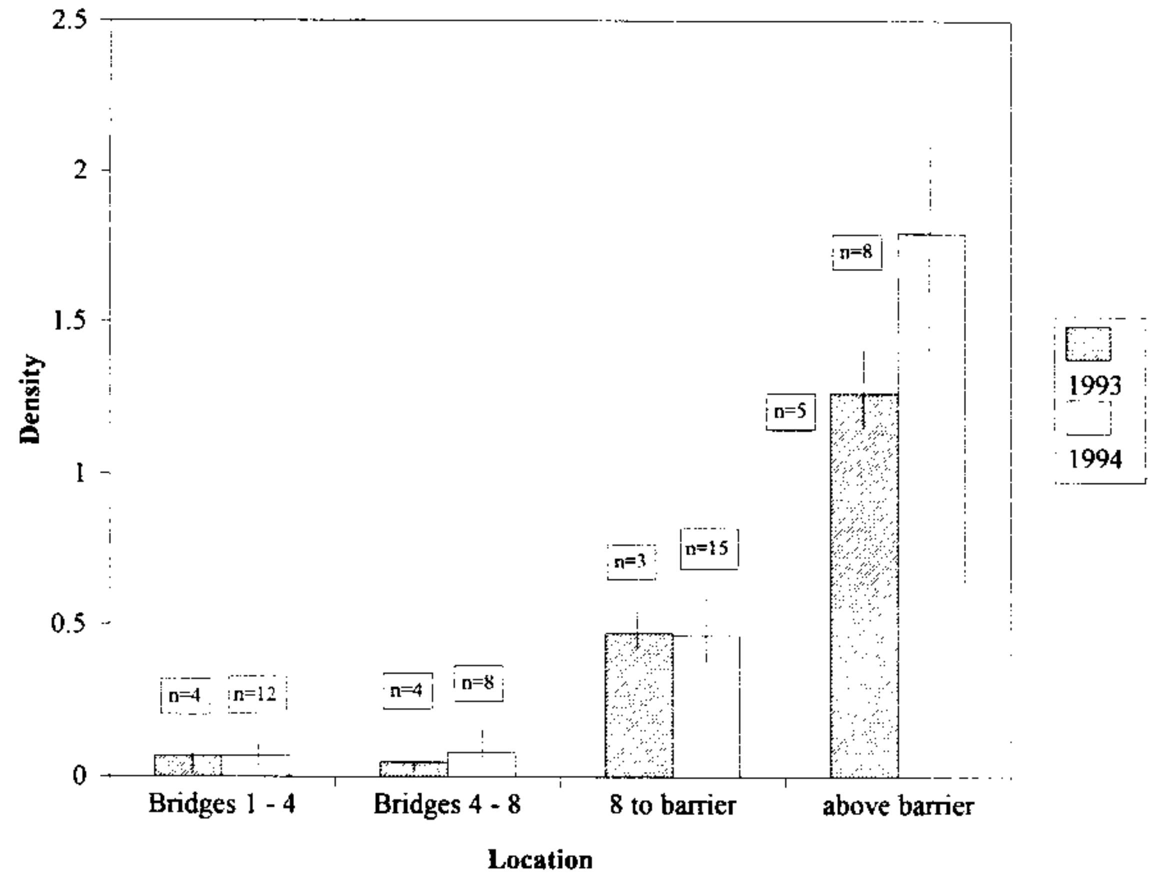


Figure 4. Relative abundance of four size-classes of Gila chub in three different areas of Sabino Creek, Arizona in September to November of 1993. (n=number of pools sampled within each area)

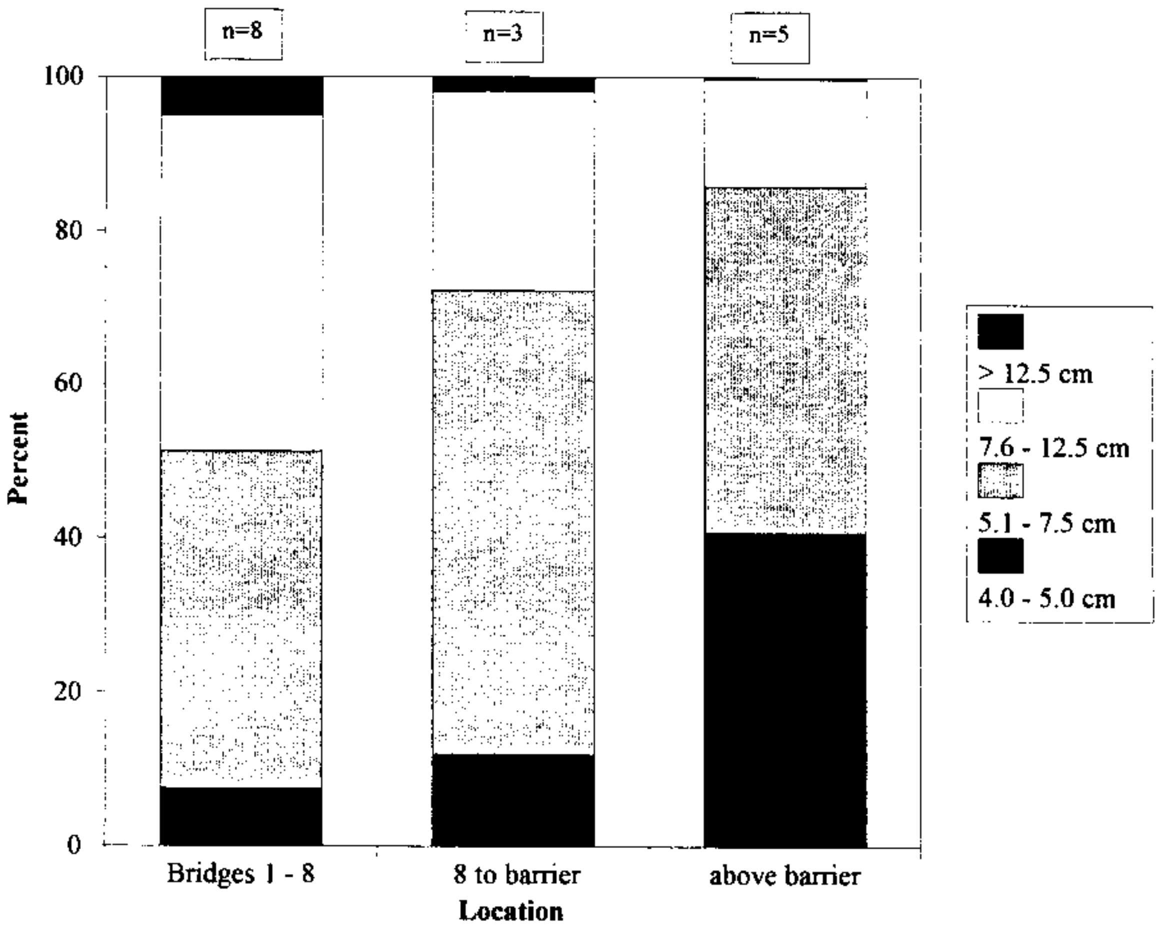


Figure 5. Relative abundance of five size-classes of Gila chub in three different areas of Sabino Creek, Arizona in September to October of 1994. (n=number of pools sampled within each area)

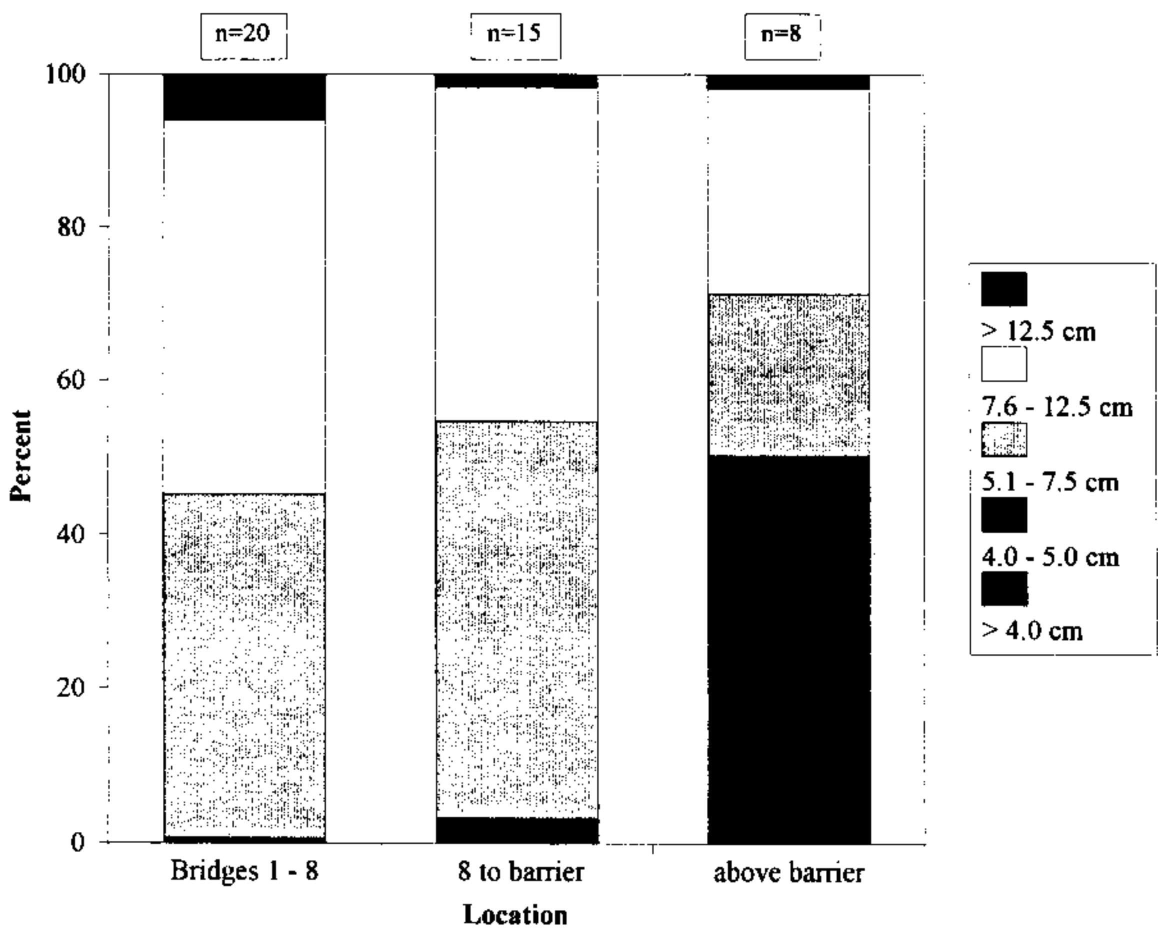


Figure 6. Density (#/m^2) of green sunfish in three different areas of Sabino Creek, Arizona in September to November of 1993. (n=number of pools sampled within each area)

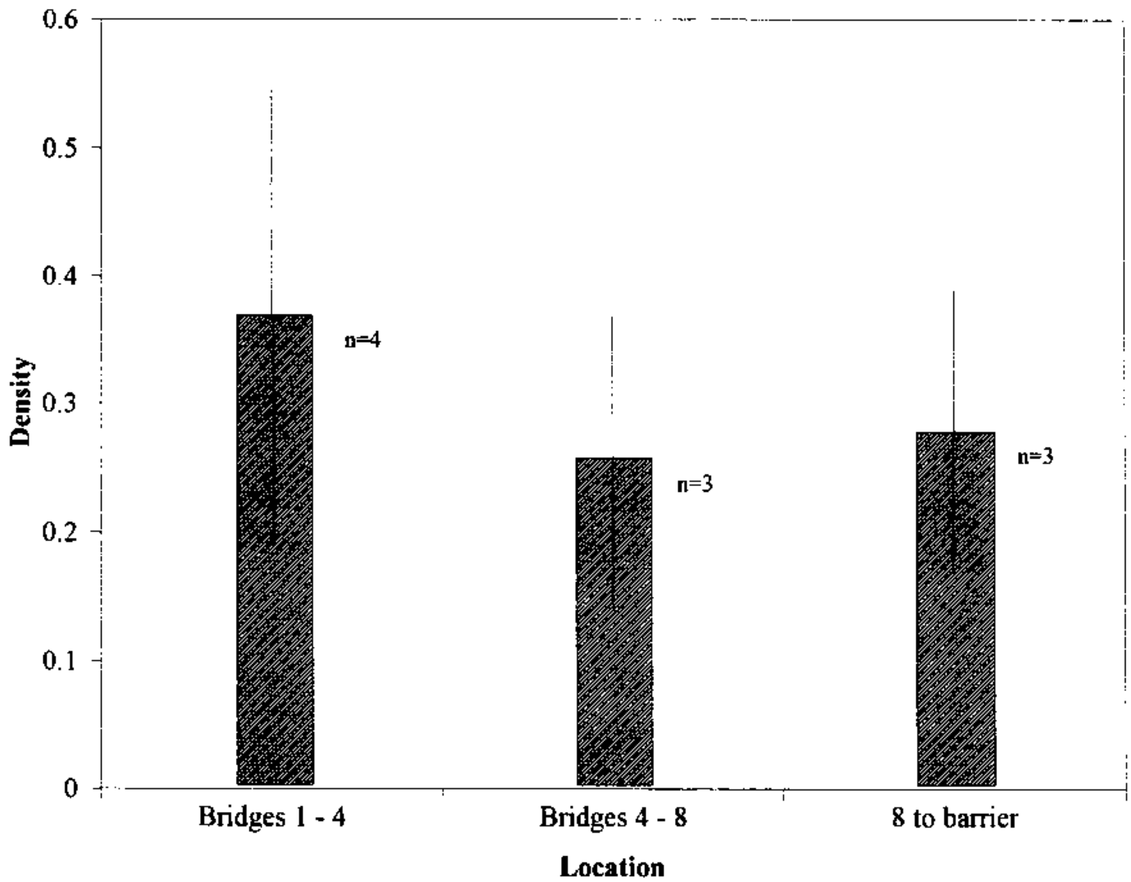
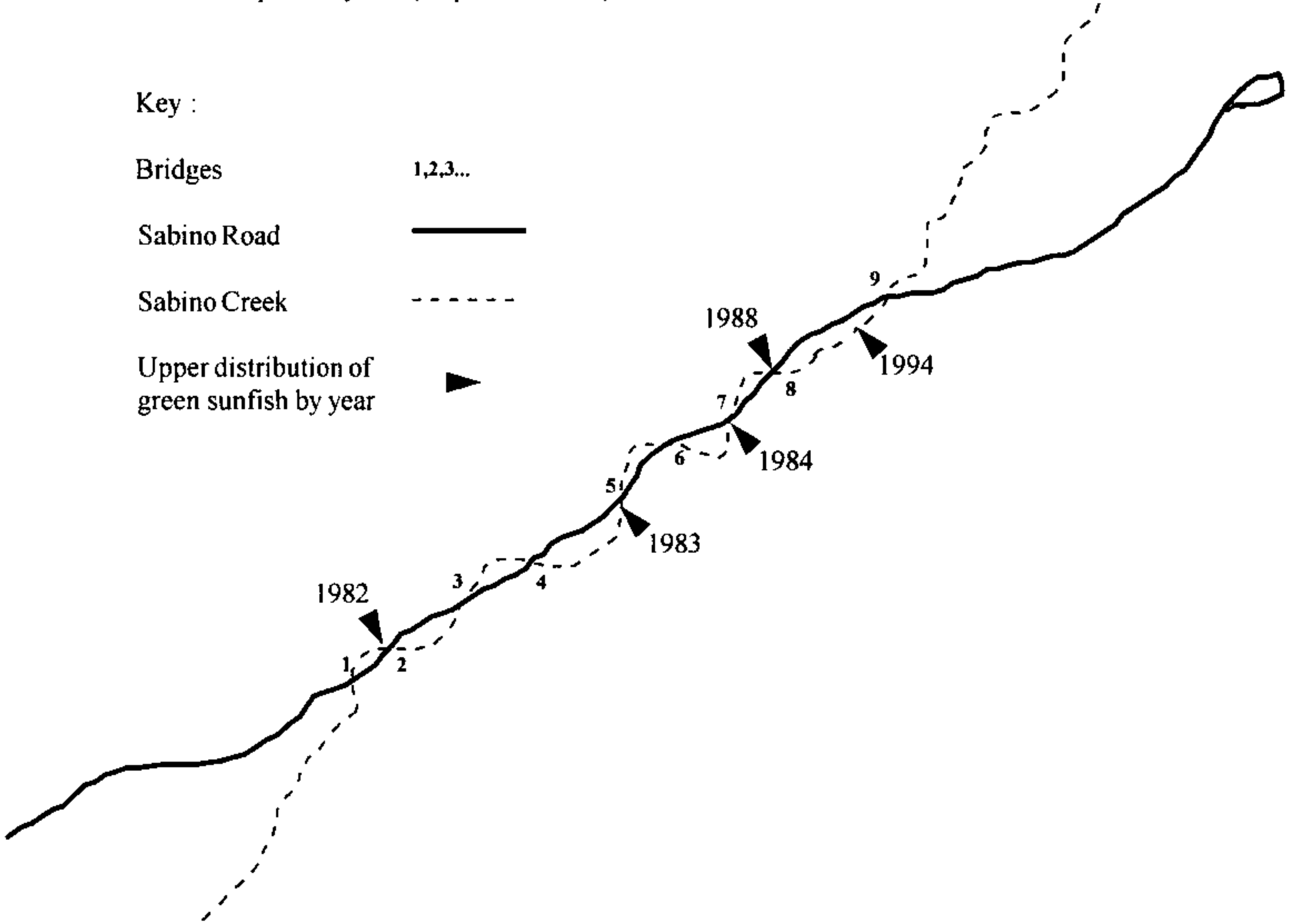


Figure 7. Progressive upstream movement by green sunfish in Sabino Creek, Arizona over the past 12 years (map not to scale)



CHAPTER 2. THE EFFECTS OF GREEN SUNFISH ON RECRUITMENT OF GILA CHUB IN SABINO CREEK, ARIZONA

ABSTRACT

Small size-classes of Gila chub (*Gila intermedia*) were less abundant in reaches of Sabino Creek where they co-occurred with green sunfish (*Lepomis cyanellus*) than in areas without sunfish. Small sunfish (< 7.5 cm, TL) occupied sites with shallow (≤ 20 cm) water, small substrates (< 2 mm in diameter) and no measurable water velocity. Young-of-year (YOY) chub occupied nearly identical conditions. Shallow areas act as refugia for YOY chub, but may be ineffective in areas with small sunfish.

I studied the impact of sunfish on recruitment of Gila chub by reducing numbers of sunfish by about 90% in three pools, and then comparing abundance of YOY Gila chub in these pools to abundance of YOY in three control pools (sunfish not removed). A few sunfish < 7.5 cm, TL remained in removal pools. I observed no YOY chub in control pools or removal pools, but during this same time, I found abundant YOY chub in upstream areas without sunfish.

In predation experiments, relatively small green sunfish in three size-classes (5.1, 6.4 and 8.0 cm, TL) readily consumed YOY Gila chub in two size-classes (< 2.0 and 2.0-2.5 cm, TL). These results suggest that the absence of YOY Gila chub in reaches of Sabino Creek containing green sunfish is due to predation by sunfish.

Although sunfish seem to prevent recruitment of YOY chub, larger chub still co-occur at low densities with sunfish. However, the continued presence of Gila chub in areas with sunfish may be dependent on periodic downstream movement of chub from

sunfish-free refugia upstream. Thus, the present co-occurrence of Gila chub and green sunfish may not indicate that these species are able to co-exist in the same area over time.

INTRODUCTION

Much of the aquatic habitat required by native fish of the desert Southwest has been lost or altered over the past 100 years (Minckley and Deacon 1968, Hendrickson and Minckley 1984). The small size of existing springs and streams make fish populations susceptible to extirpation following minor habitat alterations (Williams and Sada 1985) or the effects of introduced fish (Naiman and Soltz 1981). Gila chub (*Gila intermedia*) are endemic to streams of the upper Gila River basin including areas of Arizona, New Mexico and Sonora, Mexico (Rinne 1976). The species may be extirpated in Mexico and New Mexico (Minckley 1991) and is presently listed as "threatened" by the Arizona Game and Fish Department. Gila chub are often restricted to the uppermost pools or springs in a drainage (Rinne 1975, Minckley 1991).

Species Interactions

Increased distribution of non-native fish in streams of the desert Southwest has been correlated with extinction or declines in the distribution of many native fish (Williams and Sada 1985, Bestgen and Platania 1991, Minckley and Deacon 1991). The presence of non-natives also has been correlated with dramatic declines in the growth and recruitment of some native fish (Meffe 1985, Tippie and Deacon 1991). Introduced species may impact native fish through predation (especially on early life stages), competition for resources, or harassment. Native fish may be rapidly eliminated because they evolved with different or few natural competitors and predators (Miller 1961, Meffe 1985, Miller 1989). Losses of aquatic habitat in Arizona have restricted many native fish, including Gila chub, to isolated pools (Meffe 1985, Minckley 1991) where interactions with introduced species may be accentuated (Naiman and Soltz 1981, Meffe 1985).

Green sunfish (*Lepomis cyanellus*) have successfully colonized areas far outside of their native range (Werner 1977), often out-competing or preying on native species (Williams and Sada 1985). They are habitat generalists (Layher and Maughan 1987), able to exploit and switch between a variety of conditions and foods (Werner and Hall 1979). Green sunfish are the most piscivorous of the lepomids (Werner 1977, Sigler and Sigler 1987) and have been associated with the decline of many native cyprinids (Moyle and Nichols 1973, Lemly 1985), especially in the Southwest (Marsh and Langhorst 1988, Fausch and Bramblett 1991). Predation by green sunfish may explain the absence of Gila chub from downstream reaches of Sycamore Creek, Arizona (John Rinne, Rocky Mtn. Forest and Experimental Range Station, personal communication) and in the Santa Cruz River, Arizona (Minckley et al. 1977).

The presence of green sunfish in Sabino Creek also has been associated with declines of Gila chub (Deborah Bieber, U.S. Forest Service, personal communication). While studying the distribution and abundance of Gila chub in Sabino Creek (Chapter 1), I found that a higher percentage of chub were > 7.5 cm, TL in areas with sunfish (about 50 %) than in areas without sunfish (about 20%). Also, Gila chub < 4.0 cm, TL were absent from areas with sunfish. My objective was to study potential causes of these patterns through an experimental approach.

METHODS

Removal Experiments

Lemly (1985) found an increase in the abundance and biomass of several native fish occupying first-order streams in the Piedmont province of North Carolina after reducing densities of green sunfish, thus demonstrating the causal role of sunfish, presumably through predation on young-of-year (YOY) native fish. I used a similar approach to determine whether the density of green sunfish affects recruitment of YOY chub in Sabino Creek.

I chose six pools between bridges 3 and 9 that were similar in area and depth, likely to persist throughout the summer and contained green sunfish and Gila chub. Green sunfish were removed from three pools (r1,r2,r3) but were not removed from the other three (c1,c2,c3) (Figure 1). I began removing sunfish on April 28, 1994, about 1 month before the peak of appearance of YOY Gila chub in upstream areas without sunfish. Sunfish were captured in minnow traps and by electrofishing. Power output from the electrofisher rarely exceeded 300 volts (about 1 amp) and was periodically adjusted to minimize fish injuries or mortalities. Sunfish were released below bridge 1. Sunfish were periodically removed from pools until less than 10 individuals could be seen from the bank. Removal of sunfish was repeated (Table 1) through electrofishing and trapping.

I estimated densities of each species in all six pools twice in the week before removals started by counting all fish seen in underwater observations, moving upstream through the center of each pool. Fish length was estimated to the nearest 2.5 cm by reference to an underwater measuring rod. I used underwater and bank observations to search for YOY Gila chub during and after the spawning season (May to July 1994) to determine if recruitment differed between removal and control pools.

Microhabitat Use

I measured several abiotic variables (depth, velocity and substrate) in areas occupied by YOY Gila chub and small green sunfish (< 7.5 cm, TL), to quantify overlap in conditions selected by the two species.

I estimated microhabitat availability by measuring abiotic conditions immediately after measures of microhabitat use were taken in a particular site. Depth, velocity (with a Marsh-McBirney flow meter) and substrate size (visual estimation) were noted every 50 cm along at least four equally spaced transects perpendicular to flow and no more than 4 m apart.

Predation Experiments

Ruppert et al. (1993) concluded that a lack of control has plagued field studies of predation on YOY fish. They found it was nearly impossible to locate, identify or measure the remains of YOY fish in the guts of predators, even soon after prey were consumed. Therefore, I used instream enclosures to determine both the size at which sunfish become piscivorous on different sizes of YOY Gila chub, and the rates at which different sizes of sunfish consumed YOY chub.

Although large green sunfish (≥ 15 cm, TL) are known to be highly piscivorous (Carlander 1977, Werner 1977), little is known about the piscivory of smaller individuals. About 85% of the sunfish in Sabino Creek were ≤ 7.5 cm, TL (Figure 2) and these small individuals were the focus of predation experiments.

I conducted predation experiments from June 7 to 16, 1994, in plastic enclosures (62 x 34 x 31 cm) with lids to prevent fish escape. Two panels (24 x 17 cm) were cut out of each enclosure and the openings covered with 0.83-mm mesh aluminum screen that allowed free flow of water through the enclosure but blocked escape of fish. Enclosures were placed in the creek at a depth of 15 to 20 cm. The lid was weighted with rocks to prevent movement of enclosures or lids.

A single sunfish and 10 YOY chub of similar size were held together in each trial. I tested three "small" size-classes (mean=5.1 [range=4.5-5.5], 6.4 [range=6.2-6.5] and 8.0 [range=7.6-8.4] cm, TL) of sunfish and two size-classes (< 2.0 cm, TL and 2.0-2.5 cm, TL) of YOY chub. The smallest sunfish used in these experiments (mean=5.1 cm, TL) represented the smallest individuals present during the trials. Fish were held together for 15 to 18 hrs which included a dusk and dawn period. At the end of each trial, I recorded the number of Gila chub remaining. All trials were replicated at least twice; most were replicated three times. All trials were conducted in the same location of the creek (between bridge 8 and r2) (Figure 1) to ensure that conditions for each trial were nearly identical. A newly captured sunfish was used for each trial and all YOY chub remaining after the termination of the experiments were returned to their site of capture. I ran three trials with only YOY chub present in the enclosure to ensure that YOY chub were not escaping or dying and decomposing overnight.

<u>Data Analysis</u>

A two-sample Mann-Whitney-Wilcoxon procedure was used to test for differences between the median depth and velocity used by chub or sunfish and the median depth and velocity along habitat availability transects. A chi-square goodness-of-fit procedure was used to test for differences between the distribution of substrate sizes used by chub or sunfish and the distribution of substrate sizes along availability transects.

A one-way ANOVA was used to determine overall differences in the mean number of YOY chub consumed in predation experiments by the three different size-classes of sunfish. The Scheffé multiple comparison procedure (SPSS Inc., 1990) was used to determine specific pair-wise differences in the mean number of YOY chub consumed by the three different size-classes of sunfish. Two-sample t-tests were used to determine differences in the mean number of small vs. large YOY chub (< 2.0 cm, TL vs. 2.0-2.5 cm, TL) consumed by a particular size-class of sunfish.

RESULTS

Microhabitat Use

In pools without sunfish, median depth at sites used by YOY Gila chub was less ($p < 0.001$) than the median depth along habitat availability transects; the majority of YOY chub used depths ≤ 20 cm (Figure 3). Median depth at sites used by small sunfish (< 7.5 cm, TL) also was less ($p < 0.001$) than the median depth along habitat availability transects; all small sunfish used depths ≤ 20 cm (Figure 3). The distribution of substrate sizes over which YOY chub and small sunfish were found differed ($p < 0.001$) from the distribution of substrate sizes along habitat availability transects; the majority of YOY chub and small sunfish were found over small substrates (Figure 4). All small sunfish and YOY chub used areas with no measurable water velocity.

Removal Experiments

Pools were connected by surface water for the first 3 weeks of removal experiments, but falling water levels isolated pools through the rest of the summer (June through August 1994), preventing re-invasion by green sunfish. The depth and area of each pool was greatly reduced by the end of removal efforts. I removed 1,624 sunfish from the three removal pools (Table 1). The abundance of sunfish was reduced by about 90% in removal pools based on estimates of their original abundance (range=100-300 sunfish/pool) and visual estimates of < 10 sunfish/pool at the end of removal efforts. All sunfish remaining in removal pools were < 7.5 cm, TL. I found YOY sunfish (< 2.5 cm, TL) in removal pools 1 and 3. Removal pool 2 dried up at the time YOY sunfish were being produced. Despite reductions in sunfish densities, I observed no YOY chub in removal pools. However, YOY chub were observed throughout the summer in upstream areas without sunfish. No YOY chub or YOY sunfish were found in control pools during the summer.

Predation Experiments

No chub escaped from enclosures in trials containing only chub. One YOY chub died, but it was not decomposed and was still easily recognizable.

All three size-classes of small green sunfish were capable of consuming both size-classes of Gila chub (Figure 5). In 3 of 8 trails, however, the smallest sunfish consumed no YOY chub. The two larger sizes of sunfish consumed from 60 to 100% of the YOY chub added. The mean number of YOY chub consumed by the 3 sizes of sunfish differed ($p < 0.05$) (Figure 5). The 8.0-cm, TL sunfish consumed more ($p < 0.05$) small YOY chub (< 2.0 cm, TL) than did 5.1-cm, TL sunfish. The 8.0-cm and 6.4-cm, TL sunfish consumed more ($p < 0.05$) large YOY chub (2.0-2.5 cm, TL) than did 5.1-cm, TL sunfish. There were no differences in the number of small vs. large YOY chub consumed by a particular size-class of sunfish. I examined the gut contents of green sunfish immediately after three trials; remains of chub were almost unrecognizable and only visible within the foregut.

DISCUSSION

Introduced fish have been widely implicated in declines in abundance and reduced distributions of native fish throughout the Southwest (Williams and Sada 1985, Williams et al. 1985, Bestgen and Platania 1991, Minckley 1991). However, possible mechanisms causing these changes often have not been demonstrated.

Microhabitat Use

YOY fish naturally are subject to predation by adults of their own and other species, but predation normally does not jeopardize the persistence of the population because YOY occupy areas where they are relatively invulnerable to predation (Werner et al. 1983, Foster et al. 1988). Prior to the introduction of non-native fishes, YOY native fish occupied shallow, low velocity areas which were co-occupied only by non-piscivorous juveniles of cyprinids and catastomids (Minckley 1983). Under these conditions, YOY would have been relatively safe from predation (Meffe 1984, Ruppert et al. 1993).

However, small size-classes of introduced predaceous fish may eliminate recruitment of YOY native fish through their ability to forage efficiently in shallow areas (Ruppert et al. 1993). Small sunfish (< 7.5 cm, TL) occupied shallow water near the margins of pools in Sabino Creek throughout the summer; these same conditions were selected by YOY Gila chub. Green sunfish have been cited as predators of YOY native fish occupying shallow areas (Lemly 1985, Marsh and Langhorst 1988) and may have caused declines in the distribution and abundance of Gila chub due to predation on small size-classes (Minckley et al. 1977).

Shallow water areas in Sabino Creek were characterized by small substrates, a lack of cover and no measurable water velocity. The lack of cover or refugia might have combined to enhance the predatory abilities of small sunfish in shallow isolated pools in Sabino Creek.

Removal Experiments

More sunfish were captured in removal pools than originally had been estimated to reside there, probably because all fish were not seen during underwater observation and because of immigration of sunfish to removal pools before water levels dropped and pools became isolated. Lemly (1985) suggested that reducing the density of exotic fish had a positive impact on recruitment of YOY native fish, but recruitment of Gila chub was not improved by reducing numbers of green sunfish in Sabino Creek. No YOY Gila chub were found in pools where numbers of sunfish were reduced by about 90%. This suggests that either sunfish were not a major cause for the absence of YOY chub in experimental pools or that low densities of small sunfish in removal pools blocked recruitment of YOY chub.

Several factors other than direct predation by sunfish may have contributed to the absence of YOY chub in removal pools and in all areas of Sabino Creek with sunfish. Differences in microhabitat conditions in areas with and without sunfish could affect the number of YOY chub produced. However, a similar range of microhabitat conditions was present in both areas and YOY chub have been found in the past decade (prior to the upstream colonization of sunfish) in areas currently containing sunfish (David Lazaroff, former Environmental Education Specialist, USFS, Coronado National Forest, unpublished data). Also, the density of adult chub was about 90% lower in areas with sunfish than in areas without sunfish (see Chapter 1), including removal pools, and this could have led to production of few or no YOY chub. However, YOY comprised about 30% of the Gila chub in upstream areas without sunfish and I found many YOY chub in the margins of pools even in areas that had comparably low densities of adult Gila chub. Also, spawning could be inhibited by agonistic behaviors of non-natives (Meffe 1985, Tippie and Deacon 1991), especially in isolated pools. I observed agonistic behaviors between chub and sunfish and found that microhabitat use by chub was significantly different in areas with and without sunfish (see Chapter 3). Although adult Gila chub exhibited spawning colors and behaviors in both removal and control pools, I do not know whether spawning actually occurred.

By June 1994, chub and sunfish were forced together into isolated pools throughout much of the study area. Because reduced flows and subsequent habitat constriction coincided with the peak of appearance of YOY Gila chub, the efficiency of predation on YOY chub by the few sunfish remaining in removal pools may have been enhanced. I observed YOY chub only in pools above a temporary barrier that currently marks the upper distribution of green sunfish. This suggests that sunfish may be contributing to the absence of YOY chub, despite the "negative results" from the removal experiments.

In removal pools, I observed high densities of YOY sunfish despite the fact that I had removed all but a few small (< 7.5 cm, TL) individuals. Green sunfish normally do not become reproductively capable until they reach 7.5-10.0 cm, TL (Sigler and Sigler 1987), but dissection of green sunfish from Sabino Creek revealed that they become reproductively capable at about 6.0 cm, TL. I did not find YOY sunfish in the three control pools.

Predation Experiments

The majority of sunfish in Sabino Creek were < 7.5 cm, TL. The small size of sunfish may be due to the loss of large numbers of fish as much of the stream dries up (loss of about 80 to 90% of the wetted area) during summer so that the majority of the population is newly recruited fish. Although large green sunfish (≥ 10.0 cm, TL) are known to be highly piscivorous (Carlander 1977, Werner 1977), little is known about the level of piscivory of smaller individuals.

My experimental evidence demonstrated that even small green sunfish are potential predators of YOY chub. However, the lack of cover and shallow protected areas in experimental instream enclosures, and the forced proximity of predator and prey, probably made YOY chub more vulnerable to predation by sunfish in my experiments than they would normally be in Sabino Creek. However, I conducted predation experiments primarily to determine whether small sunfish would consume YOY chub if they became vulnerable, not to mimic conditions in Sabino Creek.

Conclusions

The absence of YOY chub from areas of Sabino Creek containing sunfish may, in part, be explained by a synthesis of data on microhabitat use and piscivory of green sunfish. The microhabitat selected by YOY chub was nearly identical to that selected by small green sunfish, and small green sunfish were highly predaceous on YOY chub. Thus, it appears probable that predation by green sunfish is responsible for the absence of YOY

Gila chub in areas of co-occurrence in Sabino Creek. Even low densities of small sunfish, as occurred in my removal experiments, may be able to block recruitment of YOY chub.

If green sunfish are blocking recruitment of YOY Gila chub, chub should not persist over time with sunfish. However, sub-adult and adult chub have continued to co-occur at low densities with sunfish in downstream areas of Sabino Creek. These chub probably are relatively invulnerable to predation because of their larger size, but may not be self-sustaining. Co-occurrence of chub and sunfish probably is maintained by periodic downstream movement of chub from upstream areas without sunfish. Thus, co-occurrence of chub and sunfish probably should not be interpreted as a sign that these species are able to co-exist. Introduction of green sunfish into upstream refugia, through transport by humans or natural passage above current temporary barriers, might cause the gradual loss of Gila chub throughout Sabino Creek.

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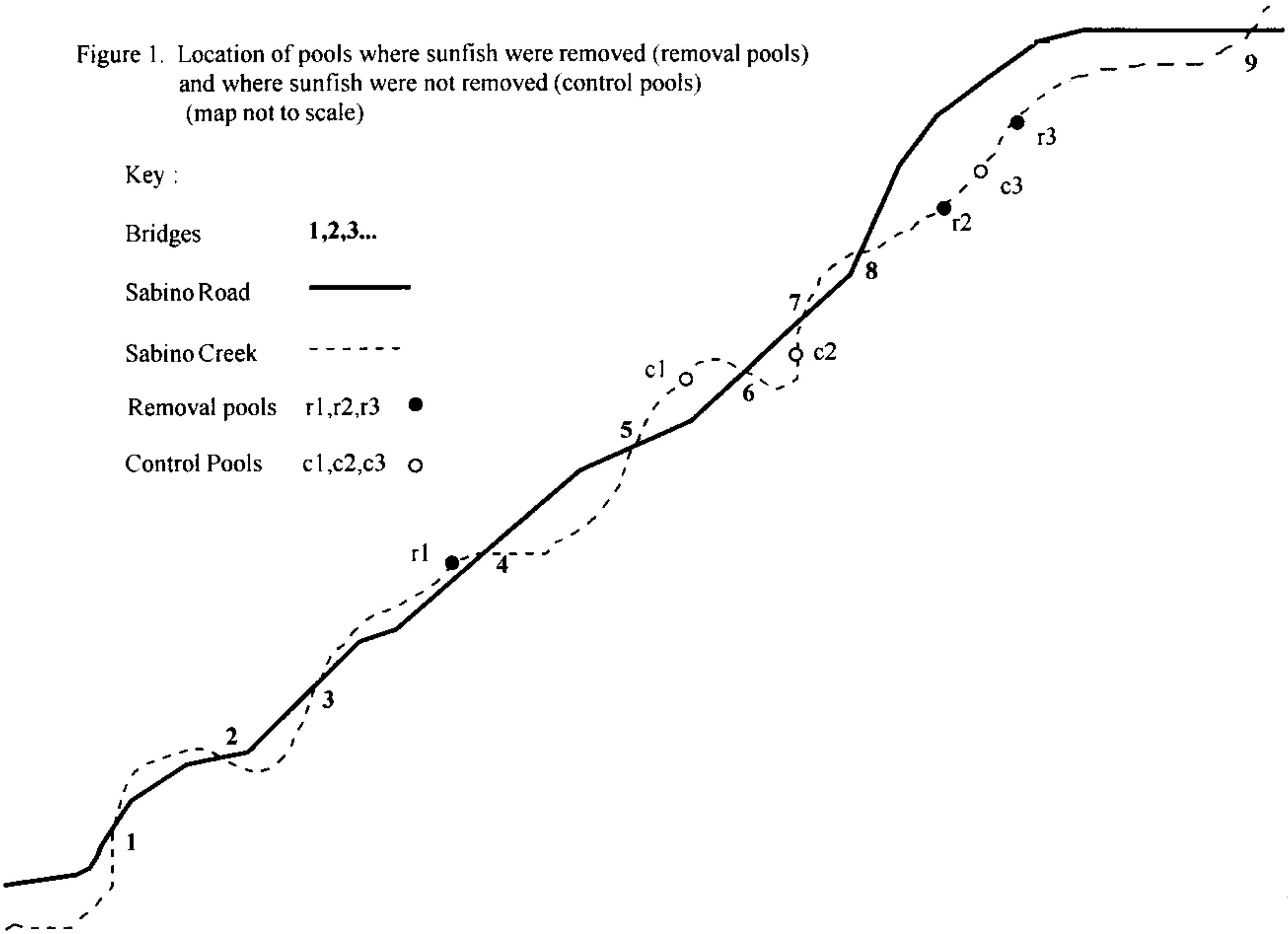


Figure 1. Location of pools where sunfish were removed (removal pools) and where sunfish were not removed (control pools) (map not to scale)

Figure 2. Size-class structure of green sunfish removed from three pools in Sabino Creek, Arizona (June and July 1994). (n=number of fish)

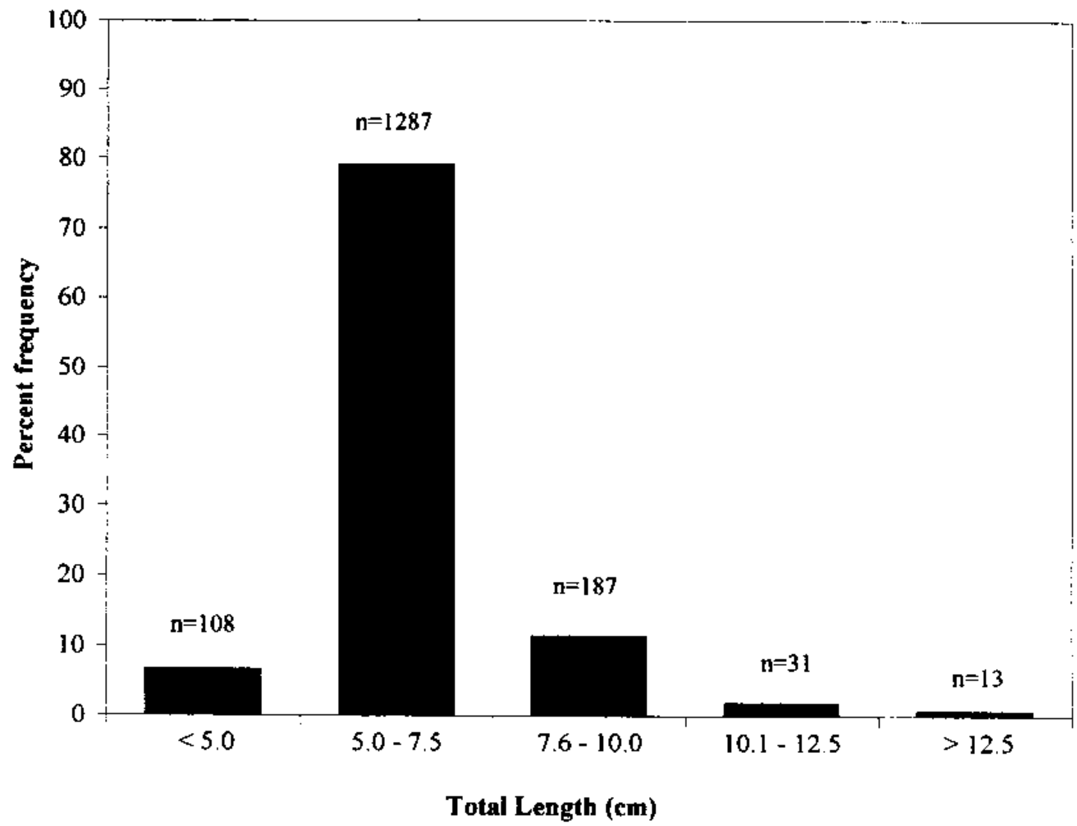
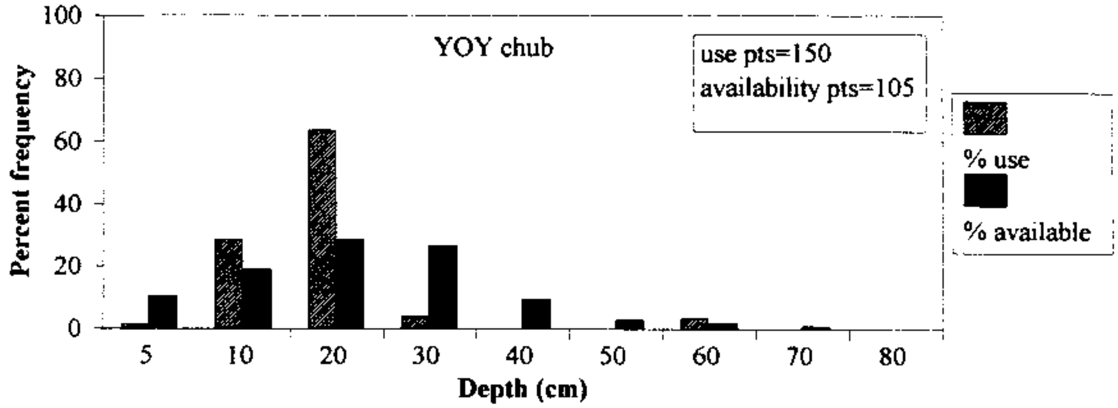


Figure 3. Depth at sites used by YOY Gila chub and small green sunfish (< 7.5 cm, TL) compared to the availability of depths along transects in Sabino Creek, Arizona in June 1994.



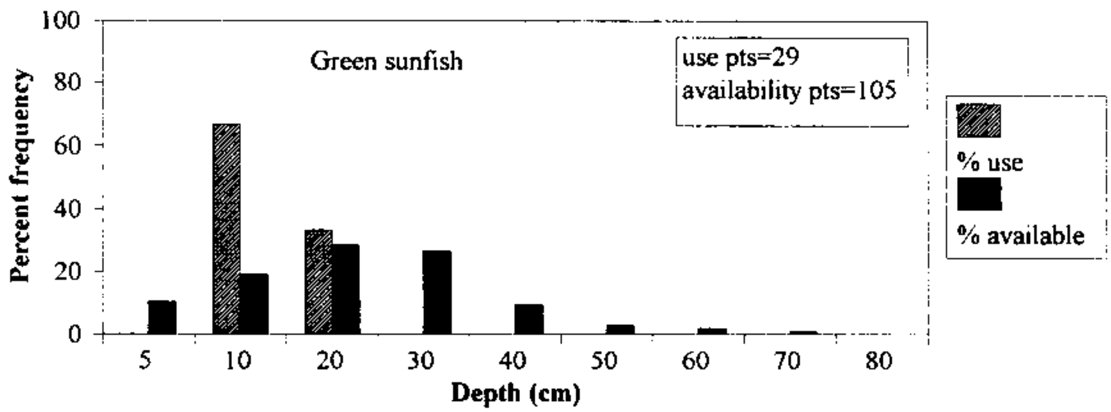
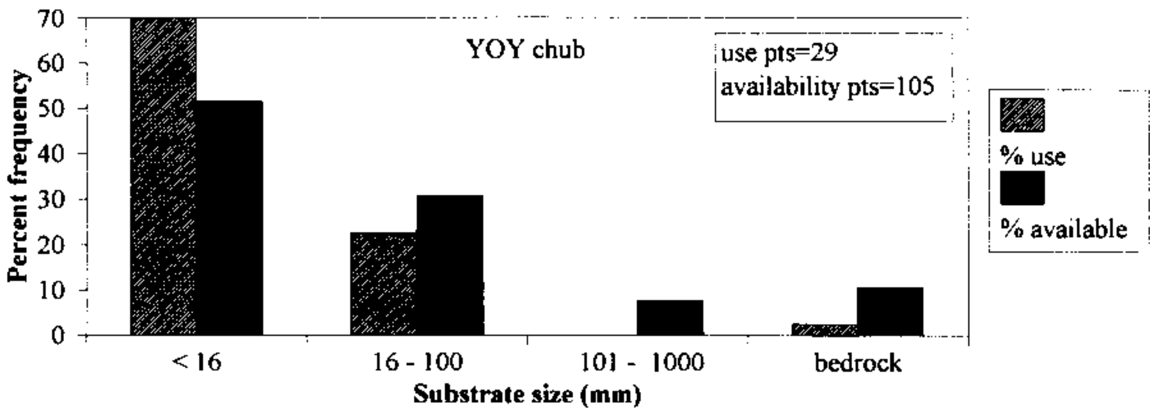


Figure 4. Substrate at sites used by YOY chub and green sunfish (< 7.5 cm, TL) compared to availability of substrates along transects in Sabino Creek, Arizona in June 1994.



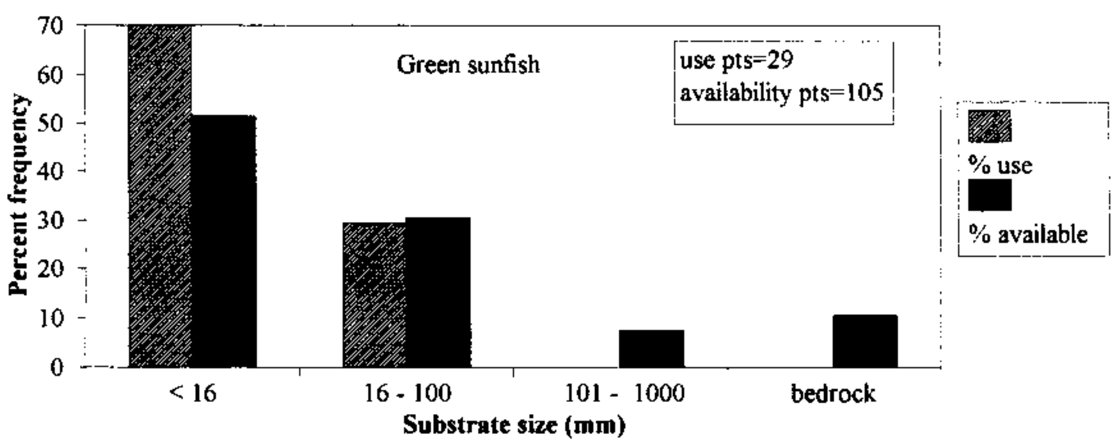


Figure 5. Number of YOY Gila chub, out of 10, eaten by green sunfish in instream enclosures over 15 to 18 hours in Sabino Creek, Arizona. (n=number of trials)

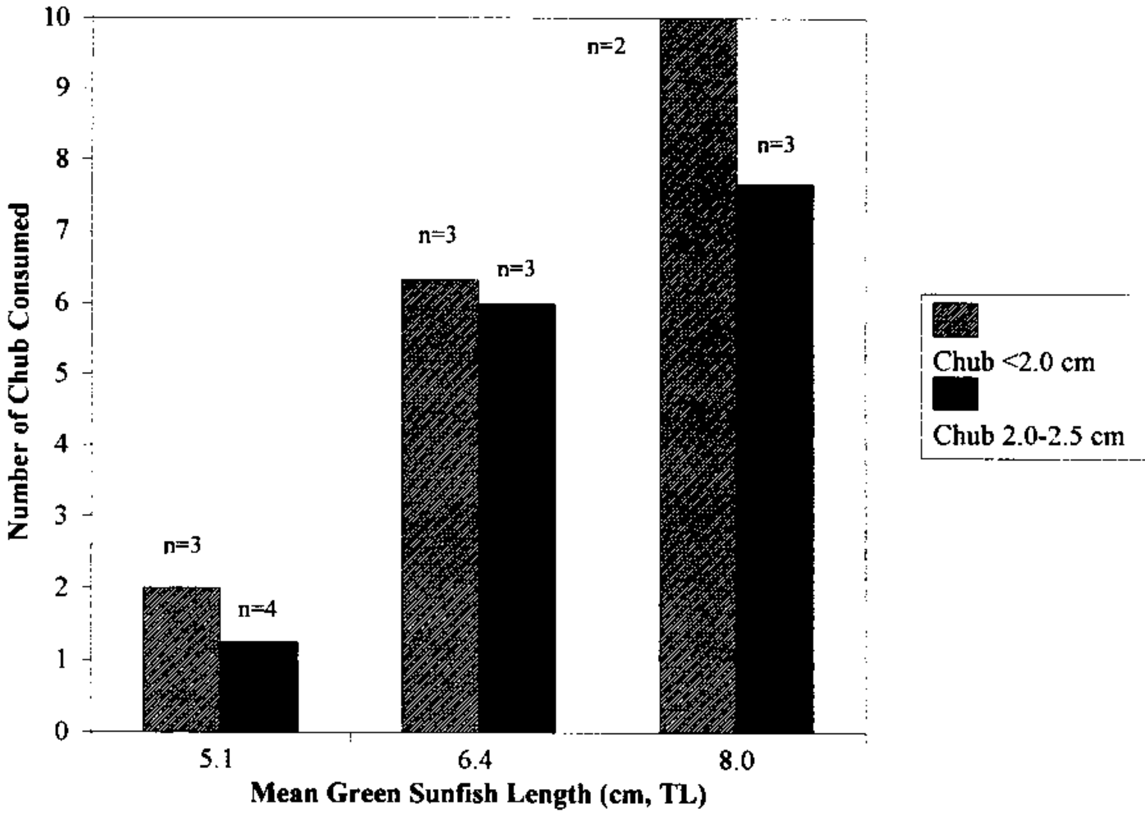


Table 1. Number of green sunfish removed from three pools (r1, r2 and r3) in Sabino Creek, Arizona in early summer (April to July 1994).

Date	Removal Pool 1	Removal Pool 2	Removal Pool 3
4/28/94	-	183	88
5/02/94	52	-	258
5/04/94	23	34	54
5/09/94	-	51	48
5/18/94	2	93	-
5/25/94	-	49	-
6/03/94	71	257	69
6/07/94	16	77	59
6/09/94	-	31	28
7/08/94	1	24	56
Total Removed	165	799	660

CHAPTER 3. EFFECTS OF GREEN SUNFISH ON HABITAT USE OF GILA CHUB IN SABINO CREEK, ARIZONA

ABSTRACT

I studied microhabitat use by Gila chub (*Gila intermedia*) in winter and summer in areas of Sabino Creek with and without green sunfish (*Lepomis cyanellus*) to determine if habitat used by chub differed by season, size-class or the presence of sunfish. In winter, Gila chub were highly reclusive. Sub-adult and adult chub were often found in areas with no measurable water velocity and in or close to cover provided by interstitial spaces between rocks and boulders. Adult chub used deeper water and were found over smaller substrates more than would be expected from the availability of these conditions.

In summer, microhabitat conditions differed at sites occupied by sub-adult and adult chub. Sub-adult chub often used sites in or near riffles so they were closer to cover, in faster currents, over larger substrates and at shallower depths than were adult chub. It is unclear whether sub-adult chub were found in different areas than adults because of their interactions with each other or because they preferred these areas. Both sub-adult and adult chub were more active and farther from cover in summer than in winter, probably because of warmer water temperatures. Areas of current and deeper water were used by sub-adult chub more in summer than in winter.

In winter, use of depth, velocity and substrate by chub did not differ in areas with and without sunfish, but sunfish and chub were rarely found together in the same "micro-sites". In summer, sub-adult and adult Gila chub used different conditions in the presence of green sunfish than when alone. Sub-adult and adult chub were in faster currents,

farther from cover and at shallower depths in areas with sunfish than in areas without sunfish. Adult chub were found over larger substrates in areas with sunfish than in areas without sunfish. In summer, it appears that the presence of green sunfish may have caused niche shifts in both sub-adult and adult Gila chub.

INTRODUCTION

Gila chub (*Gila intermedia*) are endemic to the streams and marshes of the upper Gila River basin including areas of Arizona, New Mexico and Sonora, Mexico (Rinne 1976). They have been reported to be most abundant in deep pools with extensive cover (Minckley 1973, Griffith and Tiersch 1989), and the loss of these conditions is correlated to decreases in their distribution and abundance (Hendrickson and Minckley 1984). The species may be extirpated in Mexico and New Mexico (Minckley 1991) and is presently listed as "threatened" by the Arizona Game and Fish Department. Gila chub are now abundant at fewer than 10 sites below the central Arizona highlands and Mogollon Rim (Minckley 1969, 1985) and are often restricted to the uppermost pools or springs (Rinne 1975, Minckley 1991).

Species Interactions

Increased distribution of non-native fish in streams of the desert Southwest has been correlated to extinction or declines in the distribution of many native fish (Williams and Sada 1985, Bestgen and Platania 1991, Minckley and Deacon 1991). The presence of non-natives also has been correlated to dramatic declines in the growth and recruitment of native fish (Meffe 1985, Tippie and Deacon 1991). Introduced species may impact native fish through predation (especially on early life stages), competition for resources, or harassment in small closed areas. Native fish may be rapidly eliminated because they evolved with different or few natural competitors and predators (Miller 1961, Meffe 1985, Miller 1989). The historic losses of aquatic habitat in Arizona have restricted many native fish, including Gila chub, to isolated pools (Meffe 1985, Minckley 1991) where negative interactions with introduced species may be accentuated (Naiman and Soltz 1981, Meffe 1985).

Green sunfish (*Lepomis cyanellus*) are habitat generalists (Layher and Maughan 1987) and are able to exploit and switch between a variety of conditions and food resources (Werner and Hall 1979). They are the most piscivorous of the lepomids (Werner 1977, Sigler and Sigler 1987) and their introduction has been associated with the decline of many native cyprinids (Moyle and Nichols 1973, Lemly 1985) especially in the desert Southwest (Marsh and Langhorst 1988, Fausch and Bramblett 1991).

Ecological systems can be studied at either a broad or fine scale depending on the question of interest (Weins 1989). In stream ecology, a broad scale is referred to as "macrohabitat" (e.g., pools, riffles, runs) and a fine scale as "microhabitat" (e.g., substrate, depth or velocity within a pool or riffle). Different species and size-classes of fish often co-occur in the same macrohabitat, but they generally differ in their use of microhabitat (Gorman 1988a).

Fish select microhabitat, in part, to minimize interactions with competitors and predators (Baltz et al. 1987). The presence of a large centrarchid predator can cause microhabitat shifts among smaller size-classes of prey (Werner et al. 1983) and may restrict juvenile cyprinids, normally abundant in pools, to refugia in shallow areas (Power et al. 1985) and areas of current (Schlosser 1987). Interactions with non-native fish have resulted in niche shifts in native southwestern cyprinids (Rinne 1991, Blinn et al. 1993, Douglas et al. 1994) and are associated with decreases in the distribution and abundance of native fish (Minckley and Carufel 1967, Minckley and Deacon 1968, Minckley 1973, Cross 1978, Blinn et al. 1993).

Objectives

The objectives of my study were to: 1) determine the microhabitat used by sub-adult and adult Gila chub, 2) document seasonal changes in microhabitat used by sub-adult and adult chub, and 3) determine differences in habitat conditions used by Gila chub in areas of Sabino Creek with sunfish compared to areas without sunfish.

METHODS

I studied microhabitat use by Gila chub in winter (January and February 1994) and in late summer (September and October 1994). I conducted the summer microhabitat study after pools became reconnected by surface water rather than when stream flow was at its minimum in June and July 1994. I reasoned that microhabitat selected by fish during periods when they were free to move across broad areas were more representative of optimal conditions than those selected during periods of low flow when fish were trapped in pools. Also, fish were easily disturbed by underwater observation during periods of greatest constriction in pool size and visibility in some isolated pools was poor due to algae growth.

I randomly chose sites to study microhabitat use from suitable perennial stretches of the creek. I located fish through underwater observations and with the aid of a diving light during winter. Underwater observation has been shown to be as accurate as electrofishing for estimating fish populations (Bozek and Rahel 1991) and has been used successfully to "sample" green sunfish (Werner 1977). Underwater observation may be more accurate than electrofishing or seining for studies of habitat use, because fish locations are based on observations of individual fish exhibiting normal behaviors rather than on the general site of capture (Goldstein 1978, Bozek and Rahel 1991). Habitat use data were not collected for fish disturbed (i.e., showing flight and hiding response) by the diver.

Several abiotic variables (water depth, water velocity, cover type, distance to cover and substrate size) were measured at the location where fish were observed. Cover and substrate were classified using a modified Wentworth particle size index (Table 1). Fish length was estimated to the nearest 2.5 cm by reference to an underwater measuring rod.

Microhabitat availability was estimated immediately after all measures of microhabitat use were taken within a particular site. Microhabitat availability was estimated by taking a series of depth, velocity and substrate measurements. For each area sampled, these measures were taken every 50 cm along at least four equally spaced transects which were perpendicular to flow and no more than 4 m apart. The gradient (m/km) of Sabino Creek in areas with and without sunfish was estimated from topographic maps of the U.S. Geological Survey (1975).

Data Analysis

Chi-square tests of independence were used to determine if the availability of depths, velocities and substrates differed in areas with and without sunfish. Sample sizes for observed and expected values were standardized to 100 for these comparisons, as recommended by Gorman (1988a), because chi-square tests calculated with large sample sizes (e.g., n=946 for available depths in winter) often result in Type I errors.

Chub were separated into two size-classes (sub-adult and adult) for data analysis. Sub-adults were between 40 and 70 mm, TL and adults were > 70 mm, TL. This distinction is based on the size at which chub in Sabino Creek began to show breeding coloration and behaviors (personal observation).

Chi-square tests of independence were used to determine whether habitat conditions used (depth, velocity, distance to cover, substrate size and cover type) by sub-adult and adult chub differed from each other or from availability along transects. Only data on chub occupying areas without sunfish were used in these tests because of possible habitat shifts by chub in areas with sunfish. Chi-square tests of independence were also used to determine whether chub used different conditions in areas with and without sunfish. Sample sizes for observed and expected values were standardized to 50 for all chi-square comparisons because of the sensitivity of chi-square tests to large sample sizes. A combined sample size of 100 makes these tests more conservative and less likely to result in Type I errors (Daniel 1978, Gorman 1988b). As a further precaution to avoid Type I errors, differences were reported as significant only when p-values were < 0.01. Bonferroni simultaneous confidence intervals (Byers et al. 1984) were calculated for chi-square tests of independence to determine if observed and expected values differed within a particular category. For example, if a chi-square test of independence indicated that depths of areas used by chub differed from the availability of depths, the Bonferroni procedure was used to determine which depth categories (e.g., 0-20 cm, 21-40 cm etc.) were "preferred" or "avoided".

RESULTS

Microhabitat Availability

The availability of microhabitat conditions may vary greatly between different locations or seasons. A measure of the availability of microhabitat conditions is necessary before unbiased comparisons of microhabitat selection can be made between different locations. The availability of different depths, velocities and substrates did not differ in areas with and without sunfish in either the winter or summer (Table 2). The gradient of Sabino Creek in areas with sunfish was 33.9 m/km and was 31.2 m/km in areas without sunfish.

Microhabitat Use vs. Availability

In winter, sub-adult and adult chub were found in or close to cover provided by interstitial spaces between rocks and boulders (Figure 1). Both sub-adult and adult chub used slower velocity water more frequently than would be expected based on its availability (Figure 2). Adult chub used smaller substrates and deeper water more than would be expected based on their availability (Figure 3). However, use of substrate and depth by sub-adult chub did not differ from the availability of these conditions.

In summer, sub-adults used shallower and adult chub used deeper areas more than would be expected based on their availability (Figure 4). While adult chub used slower velocity water more than would be expected based on its availability (Figure 5), sub-adults were used water velocity in proportion to its availability. Use of substrate by sub-adult and adult chub did not differ from its availability.

Both sub-adult and adult chub were found in areas farther from cover in summer than in winter (Figure 6). Also, sub-adult chub used faster velocity water and a narrower range of depths (between 20 and 40 cm) more frequently in summer than in winter (Figure 7). However, use of water velocity and depth by adult chub did not differ between winter and summer. Use of cover by sub-adult and adult chub was also independent of season.

Size-Class Effects

No comparisons between sub-adult and adult chub in winter were possible because of the small numbers of adult chub observed in areas without sunfish. In summer, sub-adult chub used shallower areas and higher velocity water more than adult chub (Figure 8). Also, adult chub were found over smaller substrates and were farther from cover than were sub-adult chub (Figure 9).

Microhabitat Shifts

In winter, Gila chub and sunfish were found in the same interstitial space in less than 5% of observations. The number of adult chub was not adequate to make comparisons of their use of habitat in areas with and without sunfish. However, sub-adult chub used the same depth, velocity, substrate, cover and distance to cover in areas with and without sunfish.

In summer, both sub-adult and adult chub were found in shallower water (Figure 10) and in faster velocity water in areas with sunfish (Figure 11). Similarly, both size-classes were found closer to cover in areas with sunfish (Figure 12). Finally, adult chub were found over larger substrates in areas with sunfish (Figure 13).

DISCUSSION

Microhabitat Availability

Gila chub generally used different areas in the presence and absence of green sunfish in the summer. Although the presence of sunfish appeared to be the main difference between the areas I surveyed, there may have been other differences in the amounts of abiotic (e.g., water quality) and biotic (e.g., aquatic invertebrates and algae) resources between areas (without regard to the presence or absence of sunfish). However, such differences seem unlikely considering the sites are in close proximity (< 1 km apart), are connected by surface flow throughout much of the year, and are of similar gradient.

Microhabitat Use vs. Availability

Gila chub were highly reclusive and inactive in winter in Sabino Creek. Chub were often found together in the same interstitial space, between boulders, with some individuals in partial contact with each other or with the cover. Gila chub were probably inactive in winter because of cold water (mean=5° C). Native fish in southwestern streams are difficult to locate during winter even when using underwater observation (Barrett 1992). I initially had difficulty finding fish, but was able to locate fish occupying dark interstitial spaces between rocks and boulders with the aid of an underwater light.

Sub-adult and adult chub were easier to locate in summer than in winter because they rarely used dark interstitial spaces and were more active. Chub were probably more active during summer because of warmer water temperatures (mean=29° C). Temperature is one of the most important factors influencing the choice of microhabitat by stream fishes (Baltz et al. 1987). Barrett (1992) found roundtail chub (*Gila robusta*) active year round in a stream with a constant temperature of 19° C, but could not locate roundtail chub, presumably because of their inactivity and use of dark cover areas, in a stream with a winter temperature of 7° C. In Sabino Creek, sub-adult and adult Gila chub were farther from cover, and sub-adult chub were found more frequently in shallow areas with measurable current as water temperatures increased. Both size-classes of chub were more active in summer and foraged on algae throughout most of the day.

Adult Gila chub were described by Minckley (1973) as being secretive and using deep water close to cover. I found adult chub in deeper water than would be expected from its availability but they often used areas away from cover. Adult chub were often found in water with no measurable velocity and over small substrates, common in still-water areas.

Sub-adult chub were described by Minckley (1973) as being active throughout the day and occupying areas of current. I found sub-adult chub in shallow water, close to cover and in areas with measurable velocity. Sub-adult chub were found over larger substrates and bedrock, which were common in areas of current, more than would be expected from the availability of these conditions. Sub-adult chub were very active throughout the day and were often seen foraging on filamentous algae.

<u>Size-Class Effects</u>

Different size-classes of cyprinids are often segregated from each other by their use of habitat (Minckley 1973, Gorman 1988b). Sub-adult chub in Sabino Creek commonly used areas in or near riffles and, therefore, were exposed to faster currents, larger substrates, shallower depths and were in closer proximity to cover than were adult chub. Sub-adult cyprinids often occupy shallow areas of current more than do adult cyprinids (Griffith and Tiersch 1989, Rinne 1991) perhaps to avoid competition or predation (Minckley 1983, Schlosser 1987). Griffith and Tiersch (1989) found that large Gila chub in Redfield Canyon, Arizona consumed speckled dace (*Rhinichthys osculus*) up to 73 mm, TL. Therefore, it is possible that sub-adult chub (40 - 70 mm, TL) in Sabino Creek were avoiding either competition or predation by adult chub by utilizing different habitats.

Microhabitat Shifts

Competitive interactions with non-native fish can result in changes in the microhabitat use of native southwestern cyprinids (Rinne 1991, Blinn et al. 1993). The degree of niche shifts caused by competition varies between taxa and location, but it is unlikely that fish normally found in pool areas would be restricted exclusively to shallow or riffle areas through these interactions alone (Mittlebach 1981, Schlosser 1987). Habitat utilization also is often affected by the risk of predation (Werner et al. 1983, Power et al. 1985, Schlosser 1987, Foster et al. 1988). Risk of predation is related to availability of areas where predator efficiency is reduced (Stein and Magnuson 1976, Crowder and Cooper 1982, Fraser and Cerri 1982, Cook and Streams 1984, East and Magnan 1991). The presence of a large centrarchid predator has resulted in habitat shifts of smaller prey (Werner et al. 1983) and restricted juvenile cyprinids, normally abundant in pools, to refugia in shallow areas (Power et al. 1985) and riffles (Schlosser 1987). Agonistic behavior of non-natives may negatively impact the growth, reproductive success and survival of adult cyprinids (Meffe 1985; Tippie 1991), especially in isolated habitats such as pools.

During the summer, sub-adult and adult chub used shallow riffles more in areas with sunfish than in areas without sunfish. Also, sub-adult and adult chub were closer to cover in areas with sunfish compared to areas without sunfish. Large green sunfish (> 10.0 cm, TL) known to be highly piscivorous (Carlander 1977) were present in all pools that I studied where chub and sunfish co-occurred. The threat of predation by sunfish probably existed for all but the largest Gila chub in these pools. The threat of predation may, in part, explain the observed niche shifts by chub in areas with sunfish.

Gila chub and sunfish were relatively inactive and highly reclusive in winter and there were no significant habitat shifts by chub in areas with and without sunfish. However, chub and sunfish rarely occurred together in the same interstitial space (< 5% of observations). Absence of co-occurrence suggests negative interactions may still be occurring but at a more subtle level than revealed by my analysis of microhabitat use.

Conclusions

Small chub (< 5.0 cm, TL) were virtually absent in areas of Sabino Creek with sunfish (see Chapter 1). Large green sunfish (> 10.0 cm, TL) are known to be highly piscivorous, but I also found small sunfish (< 7.5 cm, TL) to be predaceous on YOY chub (see Chapter 2). Predation by or competition with sunfish appears to have virtually eliminated small chub from downstream reaches of Sabino Creek.

Gila chub probably use preferred habitat in areas where there are no green sunfish. If chub use different conditions in areas with sunfish, chub probably are being displaced from preferred areas. The presence of sunfish appears to cause niche shifts in both sub-adult and adult Gila chub in downstream reaches of the creek. Agonistic behavior between green sunfish and Gila chub especially in isolated habitats such as pools may indirectly contribute to the absence of YOY and low numbers of juvenile chub in areas of Sabino Creek with sunfish.

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Figure 1. Distance to cover at sites used by sub-adult and adult Gila chub in Sabino Creek, Arizona in winter (January and February 1994).

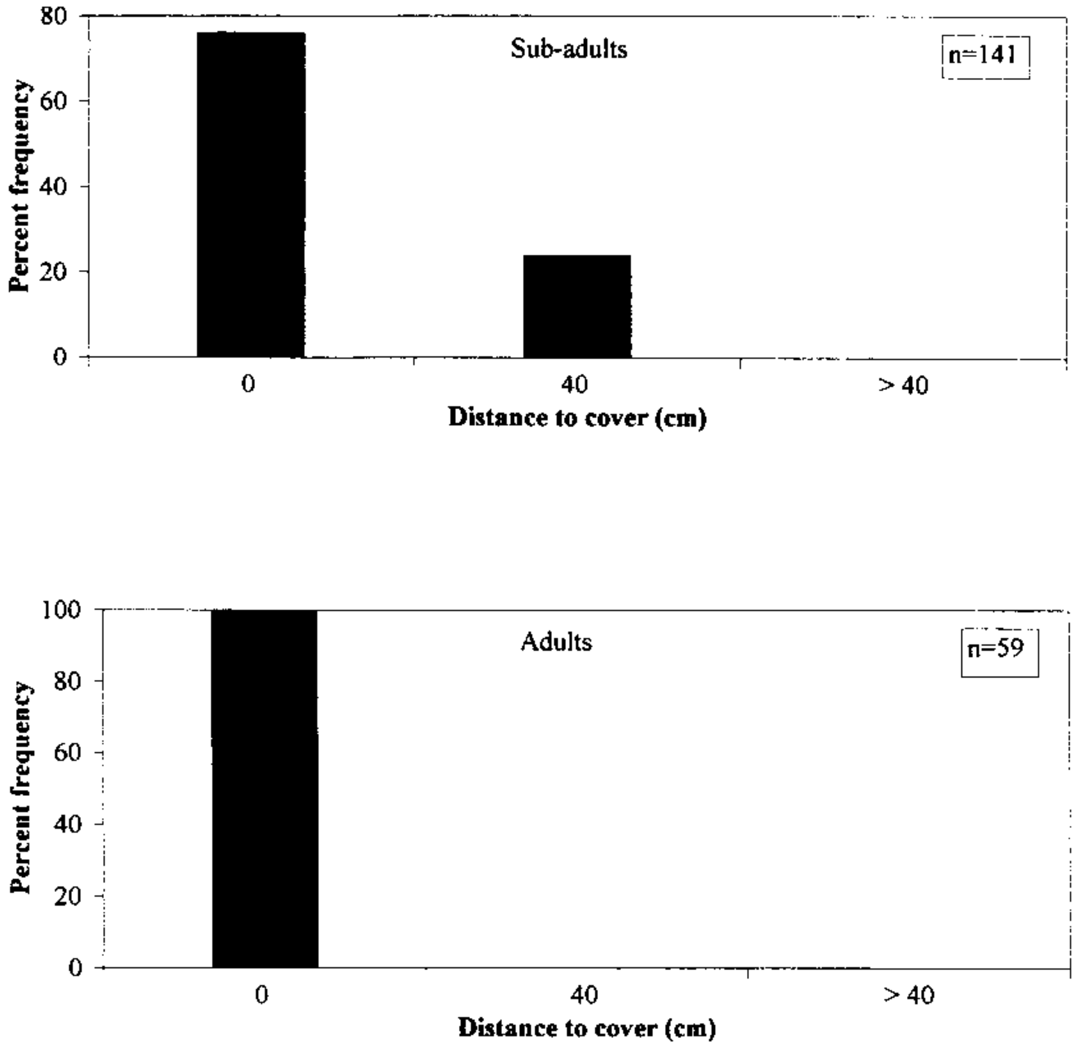


Figure 2. Water velocity at sites used by sub-adult and adult Gila chub compared to the availability of water velocities along transects in Sabino Creek in winter (January and February 1994) (± indicates preference/avoidance at $p < 0.05$).

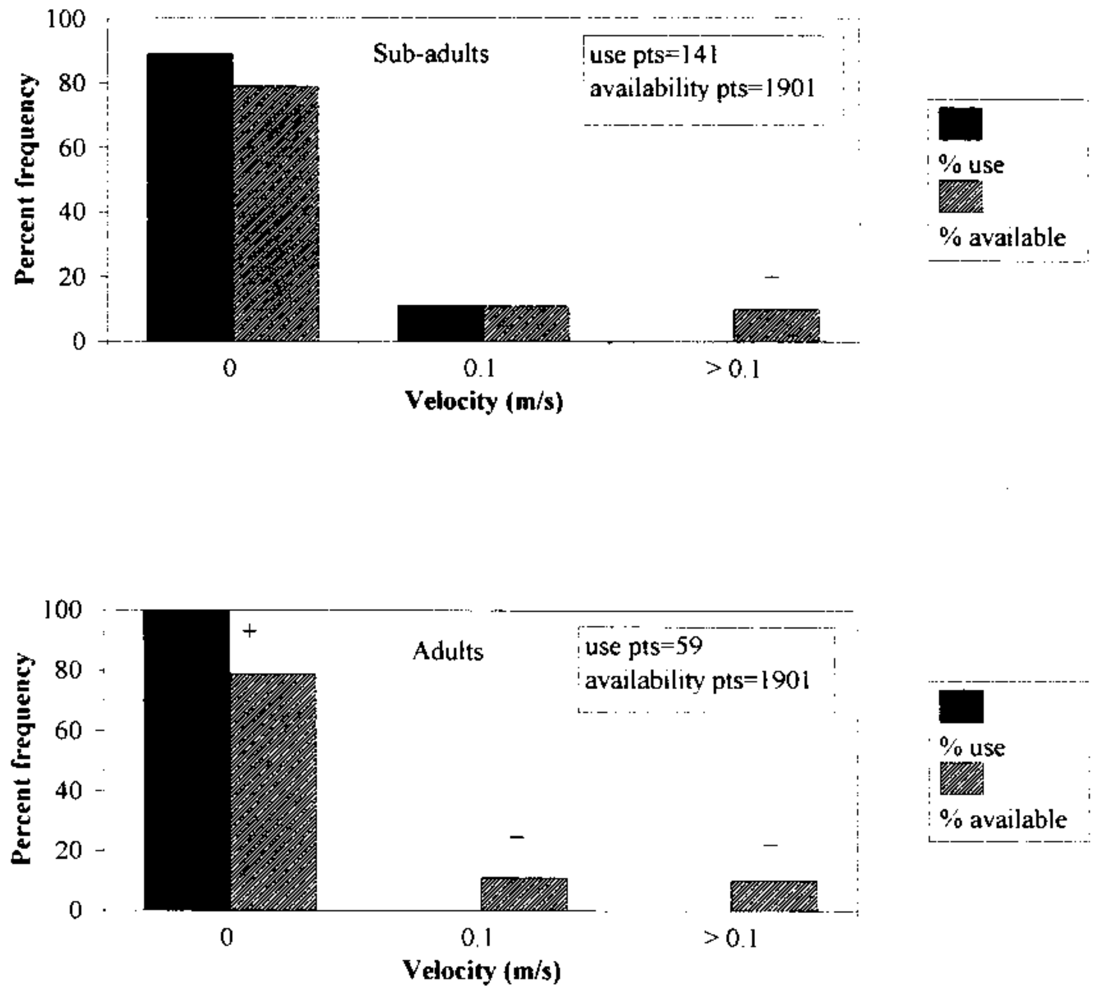
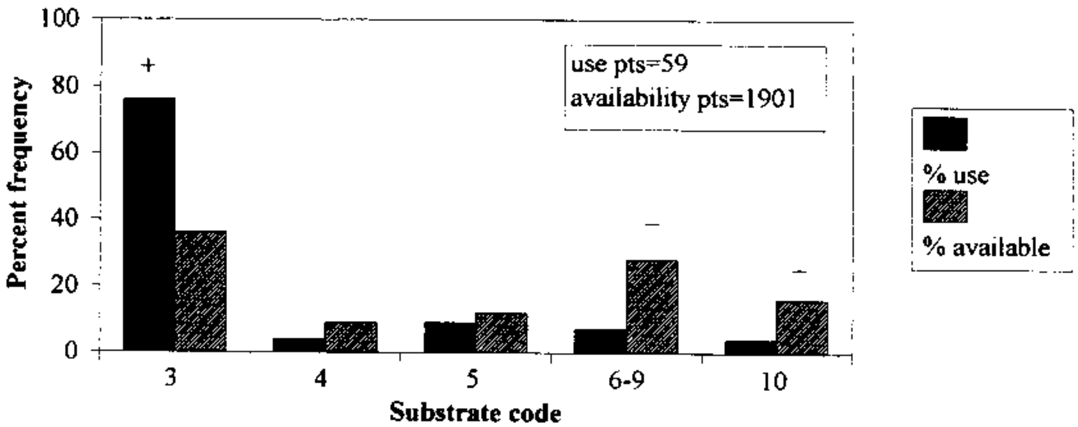


Figure 3. Substrate sizes and depths at sites used by sub-adult and adult Gila chub compared to the availability of substrates and depths along transects in Sabino Creek in winter (January and February 1994) (± indicates preference /avoidance at $p < 0.05$).



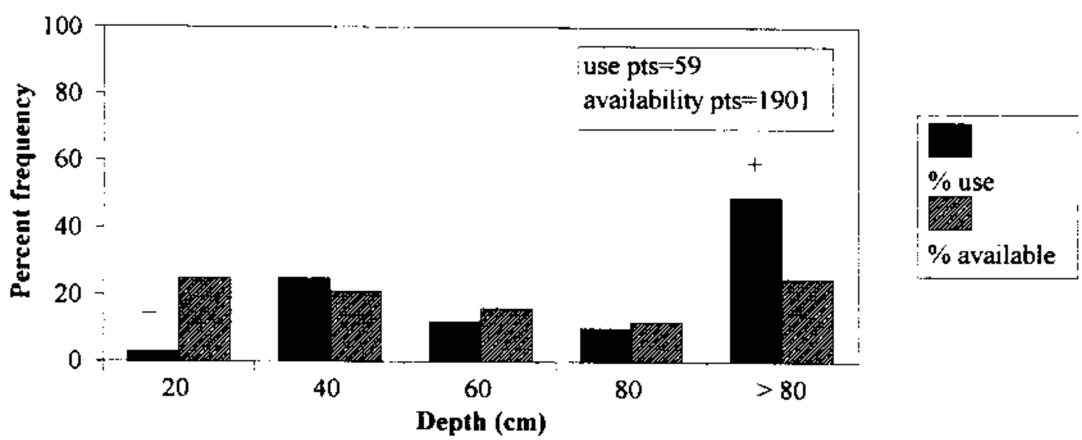
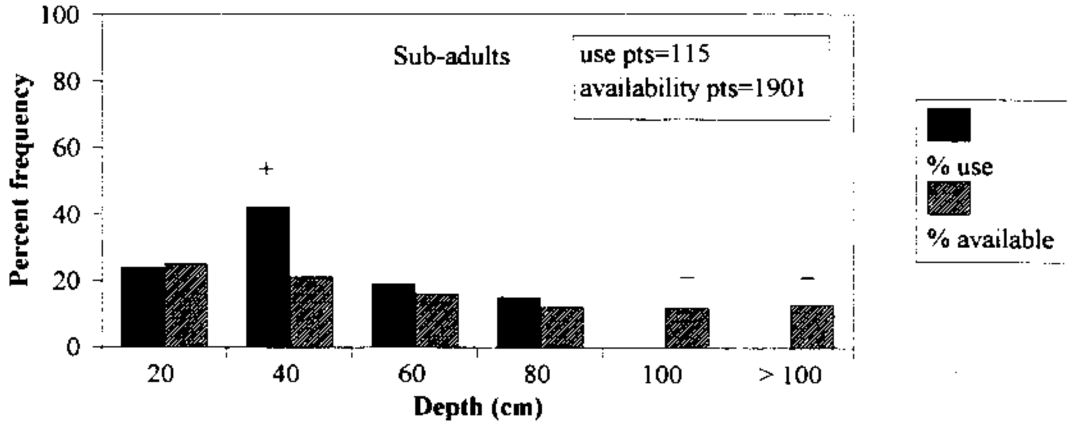


Figure 4. Depths at sites used by sub-adult and adult Gila chub compared to the availability of depths along transects in Sabino Creek in summer (September and October 1994) (± indicates preference /avoidance at $p < 0.05$).



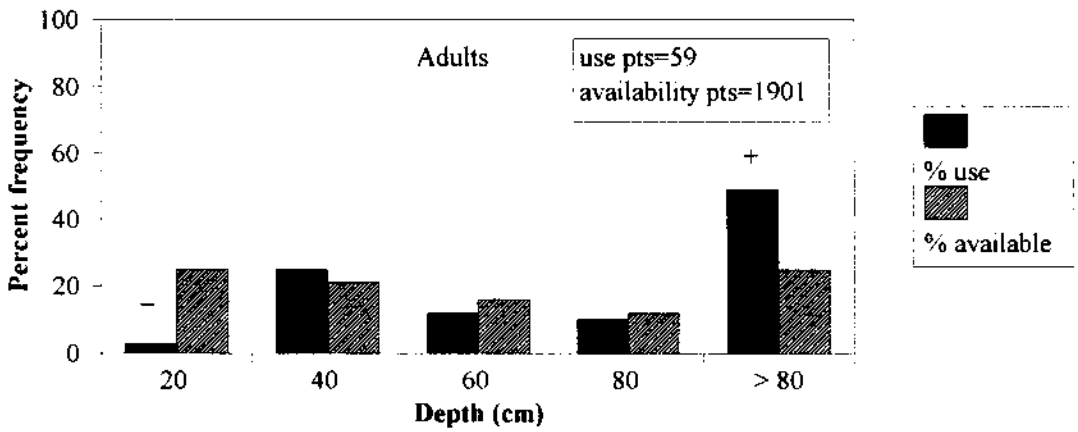


Figure 5. Water velocity at sites used by adult Gila chub compared to the availability of water velocities along transects in Sabino Creek in summer (January and February 1994) (± indicates preference /avoidance at $p < 0.05$).

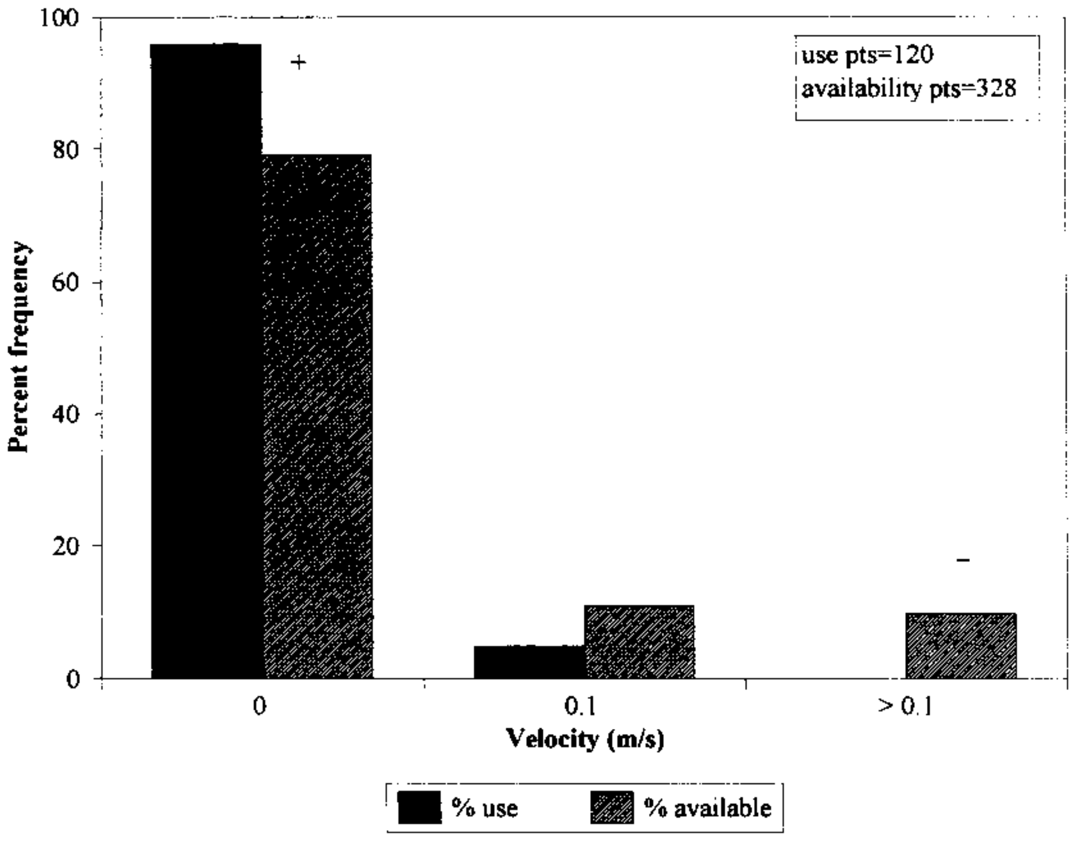
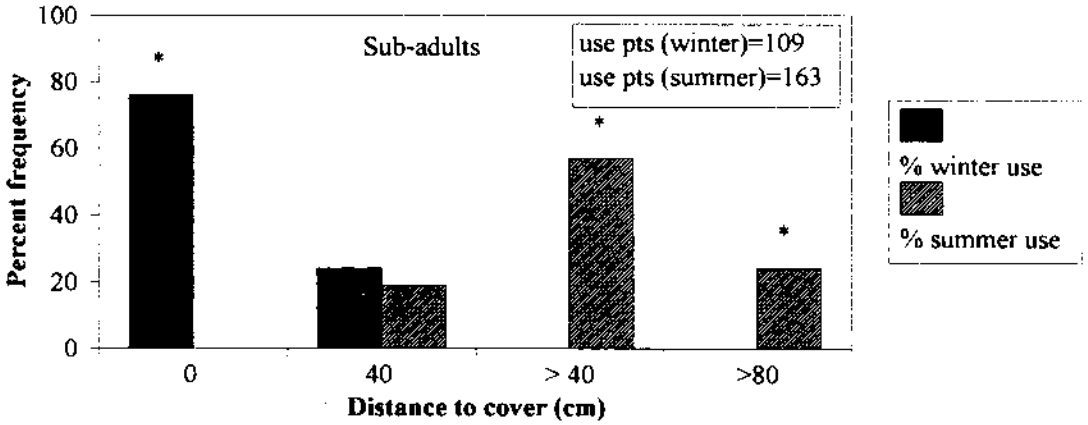


Figure 6. Distance to cover for sub-adult and adult Gila chub in winter (January and February 1994) and summer (September and October 1994) in Sabino Creek, Arizona (* indicates difference in use between seasons at $p < 0.05$).



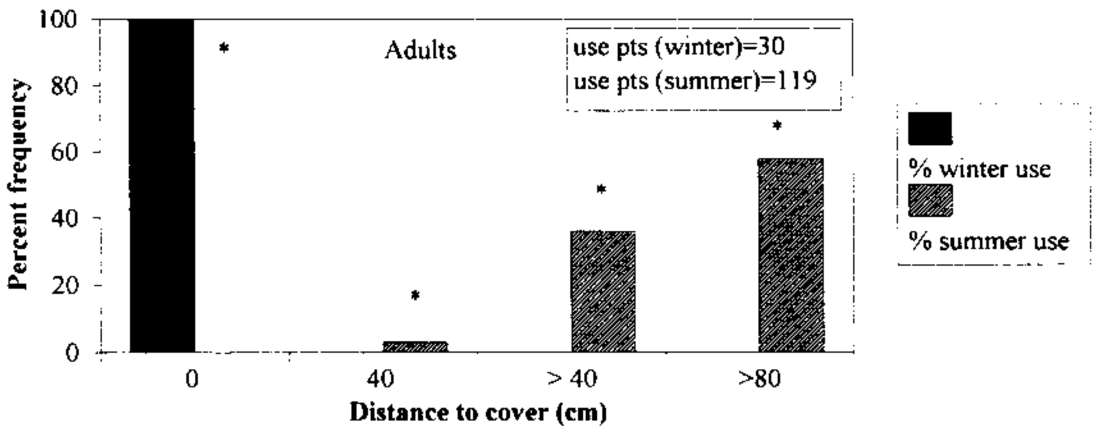
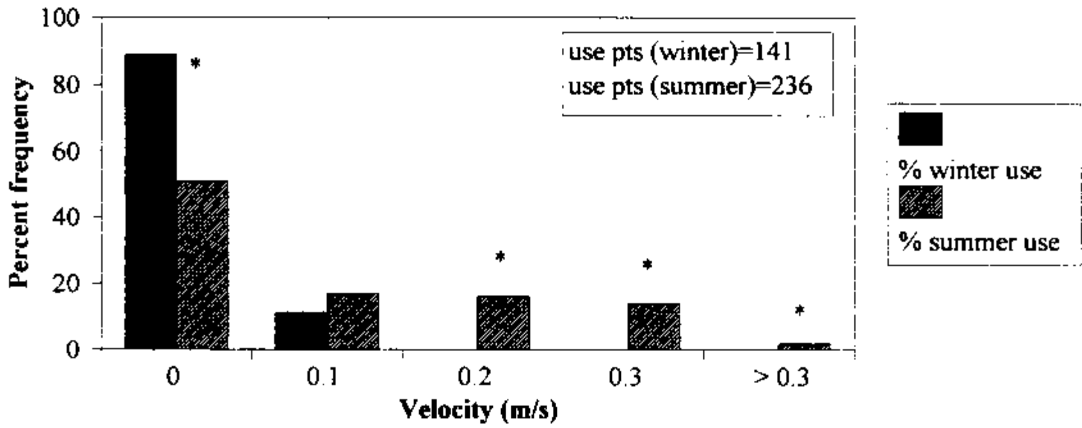


Figure 7. Water velocity and depth at sites used by sub-adult Gila chub in winter (January and February 1994) and in summer (September and October 1994) in Sabino Creek, Arizona (* indicates difference in use between seasons at $p < 0.05$).



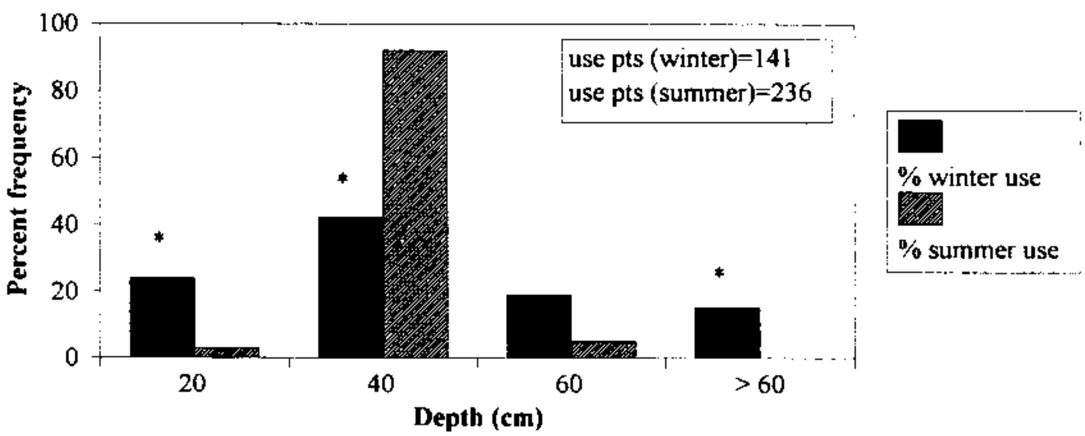
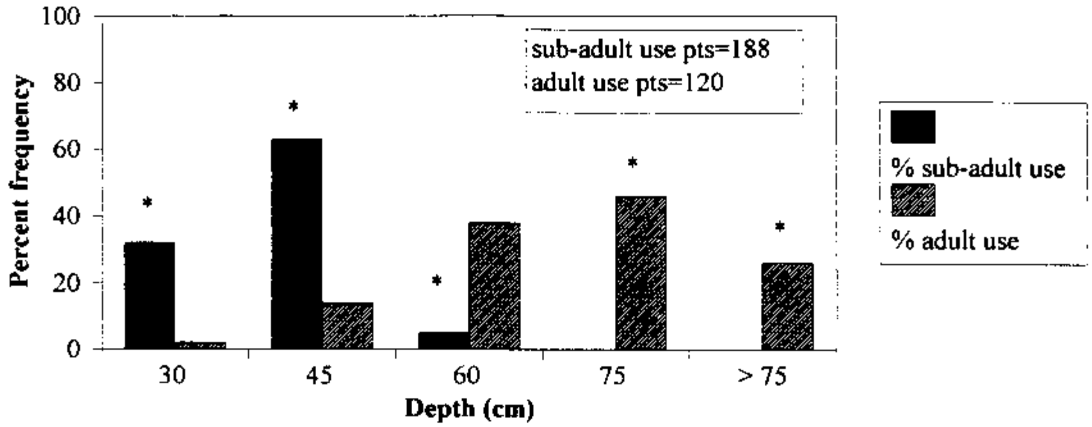


Figure 8. Water depth and velocity at sites used by sub-adult and adult Gila chub in summer (September and October 1994) in Sabino Creek, Arizona (* indicates a difference between size-classes of chub at $p < 0.05$).



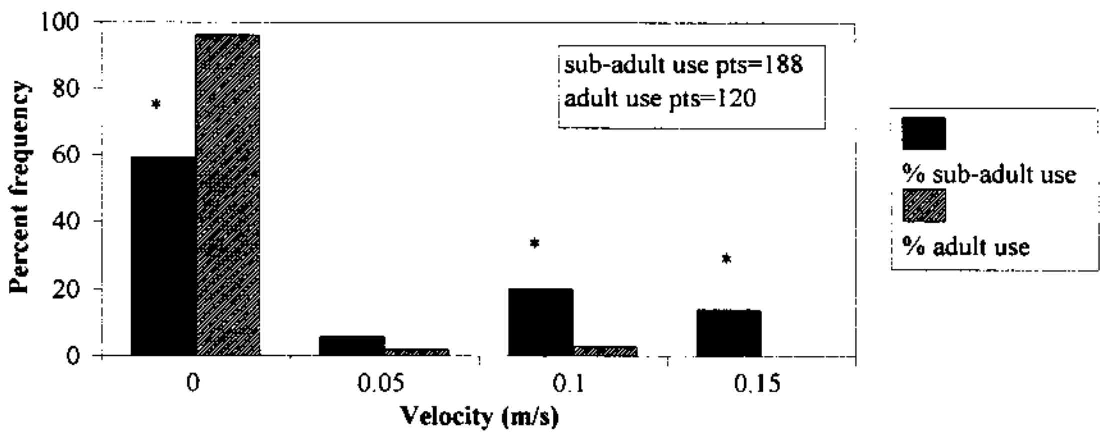
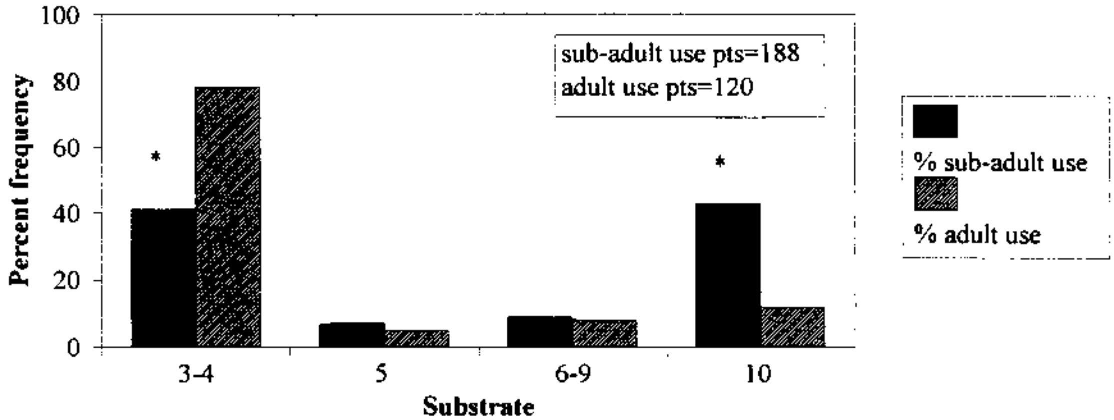


Figure 9. Substrate and distance to cover at sites used by sub-adult and adult Gila chub in summer (September and October 1994) in Sabino Creek, Arizona (* indicates a difference between size-classes of chub at $p < 0.05$).



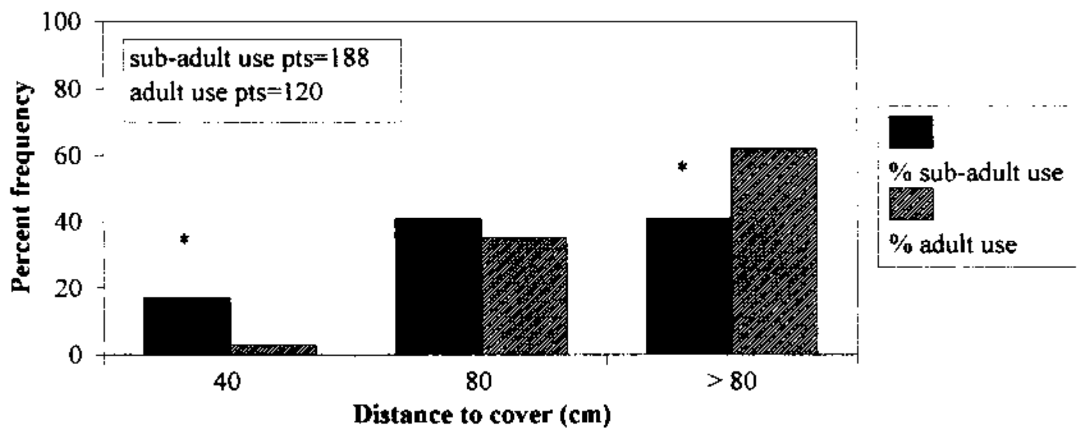


Figure 10. Water depth at sites used by sub-adult and adult Gila chub in areas with and without green sunfish in summer (September and October 1994) in Sabino Creek, Arizona (* indicates difference in use between areas with and without sunfish at $p < 0.05$).

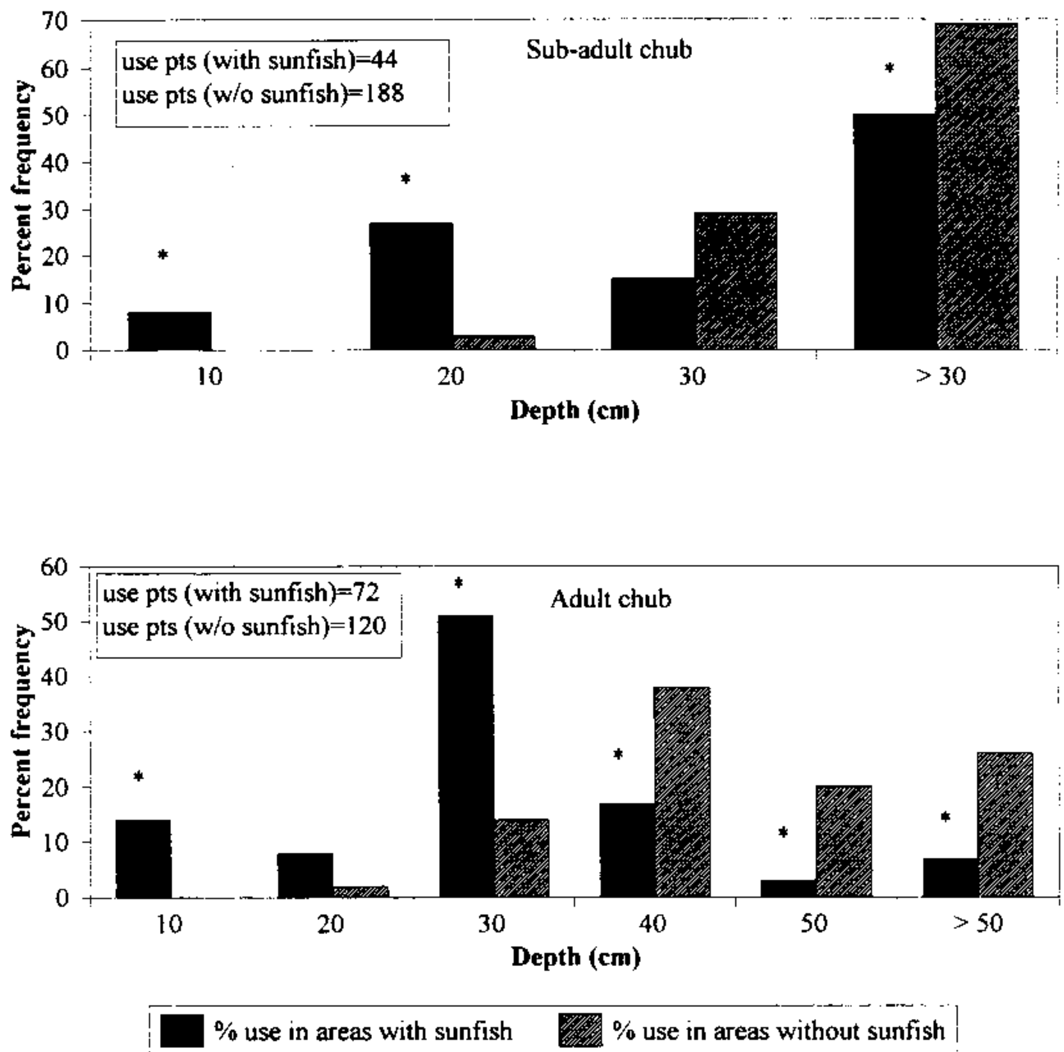


Figure 11. Water velocity at sites used by sub-adult and adult Gila chub in areas with and without green sunfish in summer (September and October 1994) in Sabino Creek, Arizona (* indicates difference in use between areas with and without sunfish at $p < 0.05$).

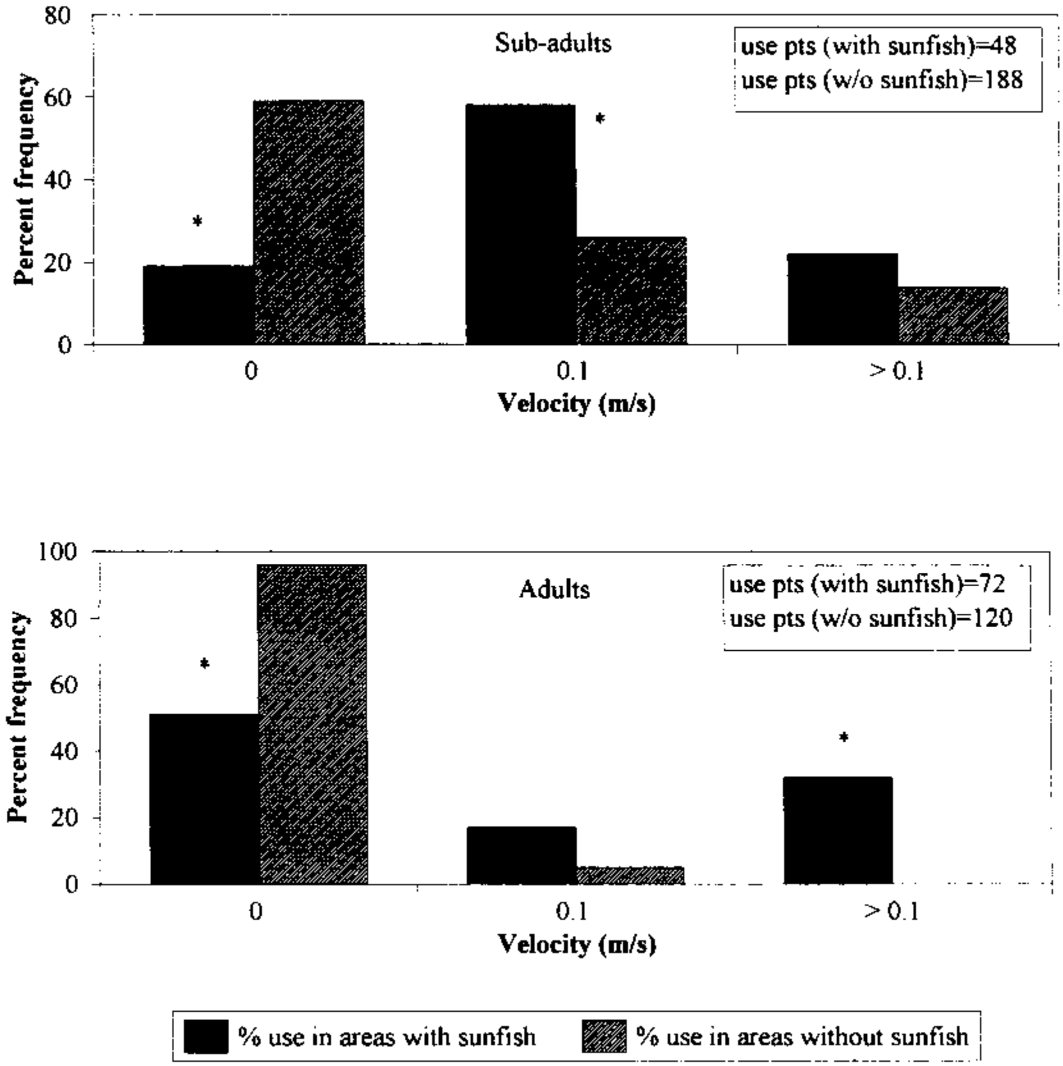


Figure 12. Distance to cover at sites used by sub-adult and adult Gila chub in areas with and without green sunfish in summer (September and October 1994) in Sabino Creek, Arizona (* indicates difference in use between areas with and without sunfish at $p < 0.05$).

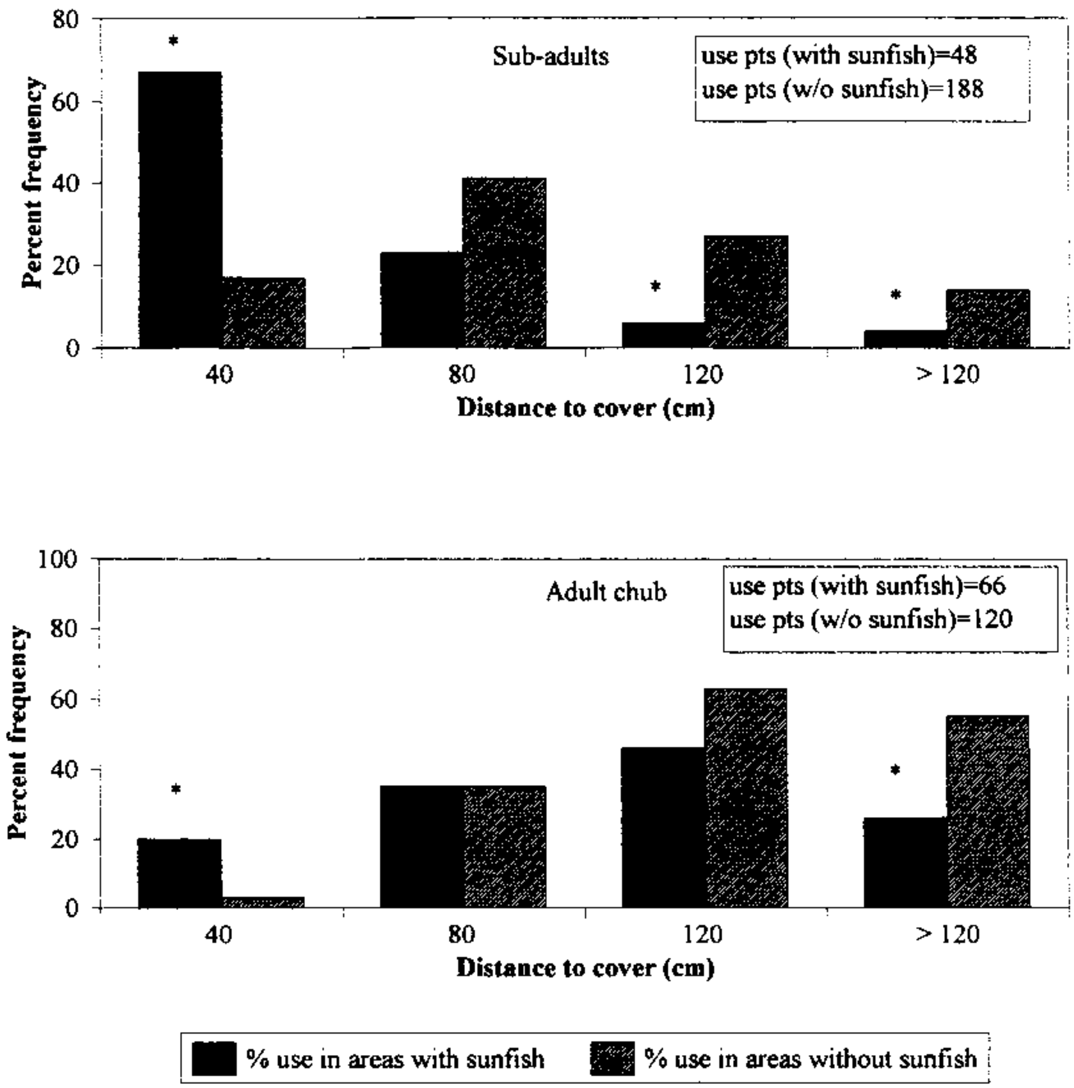


Figure 13. Substrate at sites used by adult Gila chub in areas with and without green sunfish in summer (September and October 1994) in Sabino Creek, Arizona (* indicates difference in use between areas with and without sunfish at $p < 0.05$).

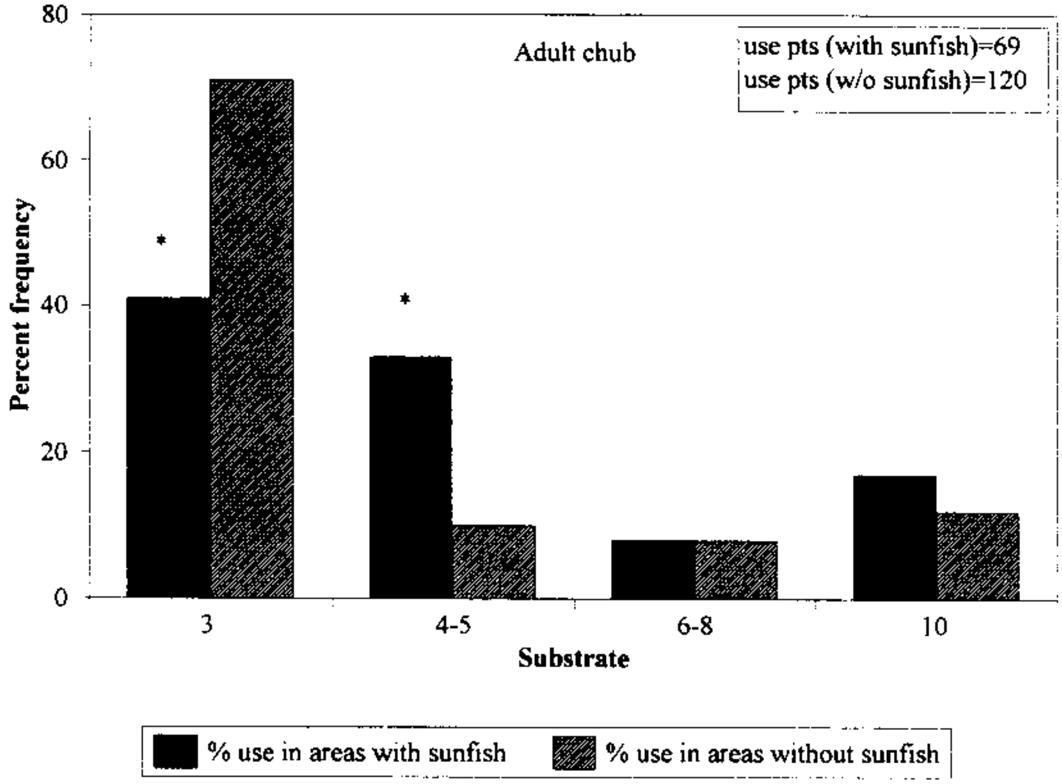


Table 1. Substrate and cover categories used for microhabitat studies in Sabino Creek.

Category	Description	Particle size (mm)
1	silt	<0.06
2	silty-sand	0.06-0.10
3	sand	0.10-2
4	gravel-pebble	2-32
5	rock	32-100
6	cobble	100-256
7	small boulder	256-1000
8	large boulder	1000-3000
9	mega boulder	>3000
10	bedrock	bedrock

Table 2. Chi-square tests of independence of available depth, velocity and substrate along habitat transects in areas with and without sunfish in winter (January and February 1994) and summer (September and October 1994) in Sabino Creek, Arizona.

Season	Variable	Location	N	Df	Chi-square value	P
Winter	Depth	with sunfish	667	6	5.23	0.26
		without sunfish	946			
	Velocity	with sunfish	644	4	0.70	0.95
		without sunfish	947			
	Substrate	with sunfish	669	5	9.01	0.25
		without sunfish	947			
Summer	Depth	with sunfish	328	9	16.04	0.07
		without sunfish	188			
	Velocity	with sunfish	319	4	3.35	0.50
		without sunfish	185			
	Substrate	with sunfish	328	4	4.74	0.32
		without sunfish	188			

CHAPTER 4. MANAGEMENT RECOMMENDATIONS

Green sunfish ≥ 10 cm, TL are known to be highly piscivorous and probably prey on Gila chub. My data appear to indicate that small green sunfish (< 7.5 cm, TL) are inhibiting the survival of YOY Gila chub. These results suggest that removal of sunfish would be desirable to ensure successful recruitment and survival of Gila chub in downstream reaches of Sabino Creek.

Sabino Creek becomes a series of isolated pools (area of surface water may decline by nearly 90%) during the summer (June and July). Restriction of the amount of surface water would facilitate removal of sunfish. However, complete removal of sunfish is not likely if minnow traps and electrofishing are used. I spent over 40 hours attempting to remove all sunfish from three pools using these techniques, but was unsuccessful. Small sunfish hide in interstitial spaces between rocks and boulders, making them difficult to capture.

Therefore, a chemical application may be required to increase the probability that sunfish are eliminated in a particular pool. Reduction of Sabino Creek to a series of isolated pools without surface flow will facilitate chemical renovation and minimize chances for transport of toxicant to downstream areas not targeted for treatment. The abundance of aquatic insects and amphibians in these pools at their summer minimum should be measured to help assess the impact of chemical treatments on other biota. Treatment of only one or two areas (from bridge to bridge) in any 1 year would minimize loss of nontarget organisms and enhance their recolonization. The majority of Gila chub could be removed from pools using minnow traps or an electrofisher prior to chemical treatment. These chub could be transferred to perennial reaches upstream or held for a period of time and then reintroduced. Any fish transferred to upstream reaches without sunfish or reintroduced to areas where sunfish are eliminated should be positively identified by an experienced fish biologist to prevent any sunfish from accidently being introduced.

I recommend that a trial sunfish removal effort be attempted from the uppermost distribution of sunfish downstream to bridge 8. More than one treatment may be necessary to achieve complete removal. If sunfish are successfully eliminated from this reach, similar efforts should be applied to each of the areas between successive bridges (from upstream to downstream) because bridges act as temporary barriers to upstream recolonization by sunfish. Such efforts over several years might push the distribution of sunfish downstream to below bridge 1. A large effort would be required to remove sunfish from between bridge 1 and Sabino Dam, and from the perennial stretch of the creek below Sabino Dam. However, recolonization of the stretch below Sabino Dam by sunfish would be possible during periods of high flow when Sabino Creek and Bear Creek (which contains sunfish) are connected by surface flow.

Removal of sunfish in Sabino Creek (at least downstream to Sabino Dam) could facilitate the restoration of Gila chub to areas of Sabino Creek they occupied a few decades ago. In addition, since the current "core" population of Gila chub in Sabino Creek occupies a relatively short reach of stream and is separated from sunfish by only a few remaining temporary barriers, failure to attempt to control green sunfish could result in the loss of Gila chub from Sabino Creek.

There is no guarantee that complete removal of sunfish in select areas of Sabino Creek will occur even if all recommendations are followed. Additionally, it may be necessary to treat the area of interest several times with the chemical application if all sunfish are not eliminated on the first attempt.

These recommendations will only succeed with the cooperation of the public. A program to educate visitors to avoid transport of fish should be considered.

APPENDIX I. A COMPARISON OF CONDITIONS SELECTED BY GREEN SUNFISH IN SABINO CREEK, ARIZONA TO HABITAT SUITABILITY INDEX MODELS

INTRODUCTION

Green sunfish are found in streams, lakes and reservoirs throughout the United States (Carlander 1977). The presence of green sunfish in such a wide variety of climates and water bodies may, in part, be explained by their broad habitat tolerances (Layher and Maughan 1987). Habitat suitability curves have been developed for green sunfish (Stuber et al. 1982) and they reflect the wide range of conditions that support green sunfish. The low predictability of habitat models for green sunfish may be due to confounding interactions between different physical or biological factors (Layher and Maughan 1987).

Objective

My objective was to determine if abiotic conditions selected by green sunfish in Sabino Creek are within the range of habitat occupied by green sunfish in streams outside of the desert Southwest.

METHODS

Fourteen abiotic variables were measured at sites in Sabino Creek containing green sunfish in summer (June and July) of 1994. These values were compared to habitat suitability curves developed by Stuber et al. (1982) and assigned a suitability index (SI) values from 0 (unsuitable) to 1 (optimal). SI values for areas of Sabino Creek containing green sunfish were then used to determine the four components (food and cover, water quality, reproduction and other) of the habitat suitability index (HSI) and the total HSI value.

RESULTS

Many of the abiotic conditions in areas of Sabino Creek occupied by green sunfish during the summer of 1994 were close to or matched "optimal" suitability index values (i.e., SI=1.0; Table 1) determined for green sunfish by Stuber et al. (1982). However, the maximum temperature in pools for embryos was 29° C (SI=0.3) and stream gradient was 33.9 m/km (SI=0.0) in areas of Sabino Creek containing sunfish. I did not measure turbidity in summer and did not include it in the equation for water quality. The dissolved oxygen and Ph values are estimates based on values from similar streams in Arizona during summer (USGS 1991). Suitability index values were relatively high (Table 2) for all four components (food and cover, water quality, reproduction and other) of the HSI model developed for green sunfish by Stuber et al. (1982).

DISCUSSION

HSI models were designed to predict the standing crop of a particular species based on the physical habitat factors present in a particular area (Orth and Maughan 1982). However, HSI models may yield inaccurate predictions when applied to species with broad habitat tolerances (Layher and Maughan 1987) because of the difficulty in identifying and quantifying abiotic factors that consistently limit populations of fish occupying different geographical areas. Layher and Maughan (1987) suggest that other factors, such as the presence of other fish species (e.g., in the genus *Lepomis*, may be equally or more important in predicting standing crop as are physical factors.

Green sunfish are habitat generalists (Werner and Hall 1979) and this is reflected in the HSI model developed by Stuber et al. (1982) by the broad range of values for many environmental conditions that yield high suitability index values. Areas of Sabino Creek occupied by green sunfish fall well within the bounds of this HSI model developed by Stuber et al. (1982). Therefore, it is not surprising that suitability index values for many areas in Sabino Creek were high despite differences between this stream and those outside of the desert Southwest upon which the models were based. However, because I did not measure the standing crop of green sunfish, I do not know how accurate this model would be in predicting the carrying capacity of green sunfish in Sabino Creek based on SI values from streams outside of the desert Southwest.

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Table 1. Variables used in determining suitability index values (SI) for abiotic conditions in areas of Sabino Creek (SC) containing green sunfish in summer (June and July) of 1994 using models developed by Stuber et al. (1982). (ND= no data)

$Var_{\#}$	Description of Variable	Value in Sabino Creek	Value of SI
V_1	Percent of the bottom of pools or littoral areas covered with vegetation, rocks etc. in summer	SC=42.56	SI=1.0
V_2	Percent pool areas during average summer flow	SC=100	SI=1.0
V_3	Stream gradient within representative reach	SC=33.9 m/km	SI=0.0
V_4	Usual minimum dissolved oxygen levels during summer	SC > 5 mg/l	SI=1.0
V_5	Maximum monthly average turbidity in pools or littoral areas during summer (JTU)	SC= ND	SI=ND
V_6	Ph range during the summer growing season	SC=6.5-8.5	SI=1.0
V_7	Maximum midsummer temperature in pools or littoral areas for adult and juvenile fish	SC=29° C	SI=1.0
V_8	Maximum midsummer temperature in pools or littoral areas for fry	SC=29° C	SI=0.8
V_9	Maximum temperature in pools or littoral areas during spawning (June-July) for embryos	SC=29° C	SI=0.3
V_{10}	Predominant substrate in pools or littoral areas during spawning for embryos	SC ≤ 0.2 cm	SI=0.8

Table 1. (continued) Variables used in determining suitability index values (SI) for abiotic conditions in areas of Sabino Creek (SC) containing green sunfish in summer (June and July) of 1994 using models developed by Stuber et al. (1982). (ND= no data)

$Var_{\#}$	Description of Variable	Value in Sabino Creek	Value of SI
V_{11}	Average current velocity in pools during average summer flow for adult and juvenile fish	SC= 0.7 cm/sec	SI= 1.0
V_{12}	Average current velocity in pools during spawning (June-July) for embryos	SC= 0.7 cm/sec	SI= 1.0
V_{13}	Average current velocity in pools during average summer flow for fry	SC= 0.7 cm/sec	SI= 1.0
V_{14}	Average stream width within representative reach	SC= 8.29 m	SI= 1.0

Table 2. Values of four components of the HSI and the total HSI value for conditions in areas of Sabino Creek containing green sunfish in summer (June and July) of 1994 using models developed by Stuber et al. (1982).

Four components of HSI	Equation	Values for Sabino Creek
Food and Cover	$C_{F/C} = (V_1 \times V_2)^{1/2}$	$C_{F/C} = 1.0$
Water Quality	$C_{WQ} = (2V_4 + V_5 + V_6 + V_7 + V_8) \div 6$	$C_{WQ} = 0.96^{*}$
Reproduction	$C_R = (V_9 \times V_{10} \times V_{12})^{1/3}$	$C_R = 0.62$
Other	$C_{OT} = (V_3 + [(V_{11} + V_{13}) \div 2] + 1/2V_{14}) \div 2.5$	$C_{OT} = 0.6$
HSI determination	$HSI = (C_{F/C} \times C_{WQ} \times C_R \times C_{OT})^{1/4}$	HSI = 0.77

*Note: The value of (C_{WQ}) was estimated without a value for V_5 so that the new equation was $C_{WQ} = (2V_4 + V_6 + V_7 + V_8) \div 5$