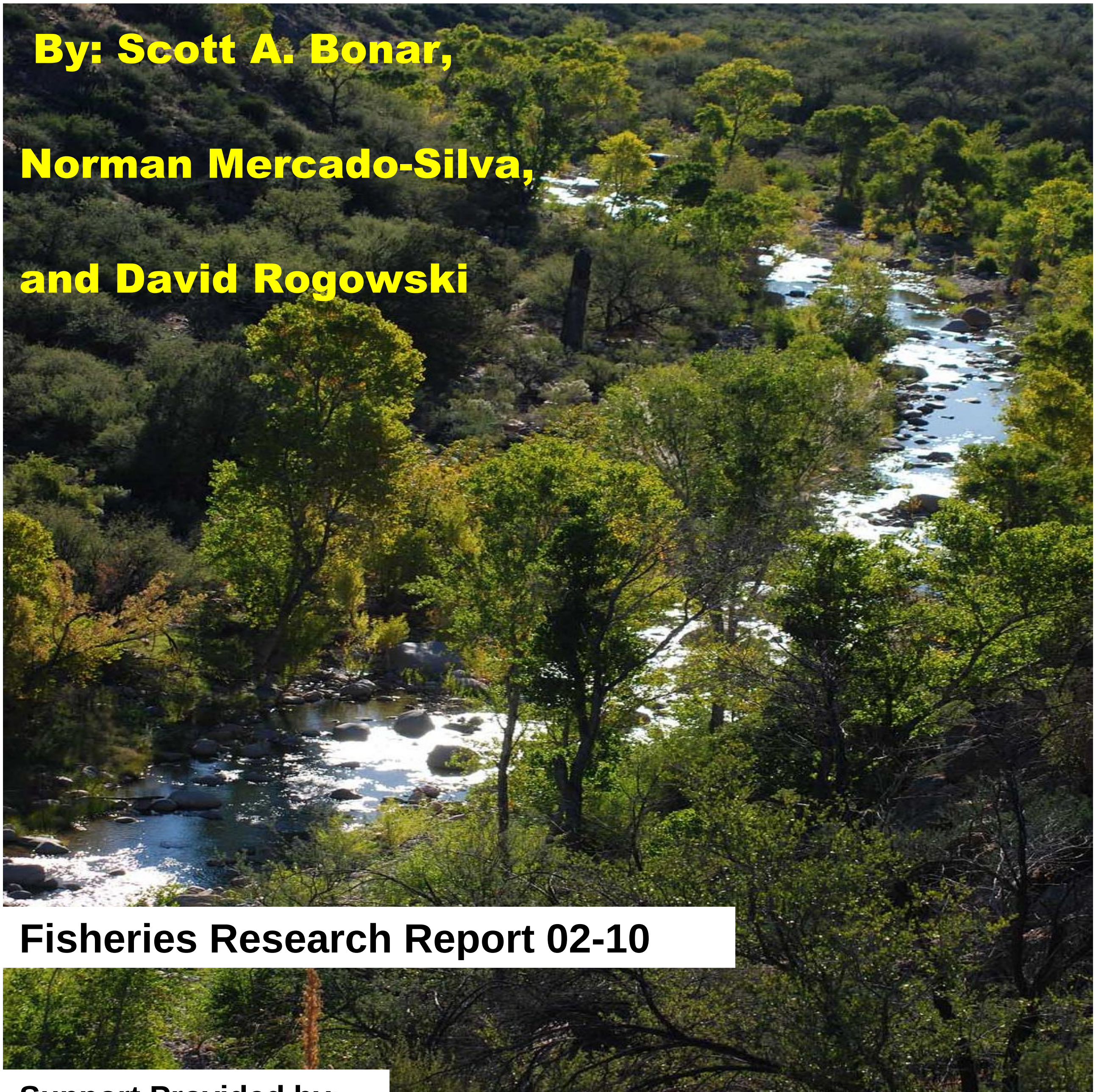
ARIZONA COOPERATIVE FISH AND WILDLIFE RESEARCH UNIT SEPTEMBER 2010

Habitat use by the fishes of a southwestern desert stream: Cherry Creek, Arizona



By: Scott A. Bonar,

Norman Mercado-Silva,

and David Rogowski

Fisheries Research Report 02-10

Support Provided by:

Habitat use by the fishes of a southwestern desert stream: Cherry Creek, Arizona

By

Scott A. Bonar, Norman Mercado-Silva, and David Rogowski

USGS Arizona Cooperative Fish and Wildlife Research Unit
School of Natural Resources and the Environment
325 Biological Sciences East
University of Arizona
Tucson AZ 85721

USGS Arizona Cooperative Fish and Wildlife Unit
Fisheries Research Report 02-10

Funding provided by:

United States Department of Agriculture Forest Service

With additional support from:

School of Natural Resources and the Environment, University of Arizona

Arizona Department of Game and Fish

United States Geological Survey

Executive Summary

- Fish communities in the Southwest U.S. face numerous threats of anthropogenic origin. Most importantly, declining instream flows have impacted southwestern stream fish assemblages.
- Maintenance of water flows that sustain viable fish communities is key in maintaining the ecological function of river ecosystems in arid regions. Efforts to calculate the optimal amount of water that will ensure long-term viability of species in a stream community require that the specific habitat requirements for all species in the community be known.
- Habitat suitability criteria (HSC) are used to translate structural and hydraulic characteristics of streams into indices of habitat quality for fishes. Habitat suitability criteria summarize the preference of fishes for numerous habitat variables.
- We estimated HSC for water depth, water velocity, substrate, and water temperature for the fishes of Cherry Creek, Arizona, a perennial desert stream.
- Native longfin dace *Agosia chrysogaster*, and nonnative red shiners *Cyprinella lutrensis* were habitat generalists. Nonnative fathead minnows *Pimephales promelas* selected slow, shallow areas with soft sediments, but native speckled dace *Rhinichthys osculus* were found mostly in fast, relatively deep waters with coarse sediments. Native catostomids were usually found in swift-running waters over gravel- to boulder-sized substrates; however, Sonora suckers *Catostomus insignis* were typically found in warmer waters than desert suckers *Catostomus clarki*. Native roundtail chub *Gila robusta* occupied a variety of conditions, but selected for water temperatures between 16 and 19 ºC. Habitat suitability criteria for nonnative yellow bullhead *Ameiurus natalis* and green sunfish

Lepomis cyanellus included deep pools with little flow, a variety of substrate types and relatively high water temperatures (>18 ºC).

- The HSC we calculated can be used to estimate the total habitat available for a species under various water flow scenarios.

Introduction

Fish communities in the southwestern United States face numerous threats from anthropogenic activities. Pollution, habitat modifications, nonnative species, and perhaps most importantly, declining instream flows all have impacted southwestern stream fish assemblages (Miller et al. 1989, Minckley and Deacon 1991, Propst et al. 2008). Conservation and management strategies for these fish assemblages require that species' ecology and habitat requirements be known.

Habitat suitability criteria (HSC) are used to translate structural and hydraulic characteristics of streams into indices of habitat quality for fishes (Bovee 1982, Thomas and Bovee 1993). Habitat suitability criteria summarize the preference of fishes for numerous habitat variables. Habitat suitability criteria have been developed for numerous fish species and applied in many instream flow studies (e.g., Barrett and Maughan 1995, Jowett 2002, Strakosh et al. 2003). Species-specific HSC can be obtained via professional judgement and the use of published literature, the use of microhabitat data collected at locations where target organisms are observed or collected (utilization functions), and correction of utilization functions for environmental availability (preference criteria) (Bovee 1986). Evaluation of the developed HSC by comparison with criteria developed by other investigators, convergence studies in a variety of streams, or other methods discussed in Bovee (1986) further add to the credibility of the HSC.

In relatively diverse and highly variable systems such as desert streams, species-specific habitat segregation is common. However, several species may have similar habitat requirements or may be forced to use the same areas and resources during periods of low or high flow. The characterization of habitat use and overlap among species in desert streams can provide important information to assess effects of ecosystem management strategies, anthropogenic impacts, or interspecific interactions (e.g., non-native – native interactions; Gido and Propst 1999). With increasing water use, habitat modifications, and non-native aquatic species introductions occurring throughout the Southwest, it is imperative that the basic habitat requirements for native fishes, which are often threatened or endangered, be known for management and conservation strategies to succeed. Thus, our objectives were to describe habitat use for the fishes of a perennial desert stream in central Arizona.

Methods

Study site

Cherry Creek is a perennial stream with an annual daily mean discharge of 0.10-3.67 $m^{3} \cdot s^{-1}$ that flows from the Mogollon Rim to the Salt River north of Globe, Arizona (Fig. 1). The creek runs through the Tonto National Forest from 16 km north of Paradise Valley, Arizona (34°06’04” N, 110°58’15” W) to its confluence with the Salt River (33°40’22” N, 110°45’57” W). Most of the Cherry Creek watershed is remote and undeveloped, and Cherry Creek is accessible at points only by unimproved dirt roads. Furthermore, most of the northern half of Cherry Creek is located in a deep inaccessible canyon. Three kilometers before the end of the canyon, near the southern extreme of a narrow bedrock controlled valley, is a US Geological Survey (USGS) stream gage (USGS 09497980 Cherry Creek near Globe, Arizona [33°49'40" N, 110°51'20" W]). Within 3 km downstream from the gage, the narrow valley transitions to a broader, braided alluvial valley that persists for approximately 20 km to the Salt River. The majority of Cherry Creek is wadable, but deep pools (>1.2 m) exist throughout the channel. The fish community of Cherry Creek is a mixture of native and non-native species. Native species previously captured in Cherry creek include: longfin dace *Agosia chrysogaster*, speckled dace *Rhinichthys osculus*, Sonora sucker *Catostomus insignis*, desert sucker *C. clarki*, roundtail chub

Gila robusta, headwater chub *G. nigra*, razorback sucker *Xyrauchen texanus*, Colorado pikeminnow *Ptychocheilus lucius* and Gila topminnow *Poeciliopsis occidentalis* (USDA 2001). Nonnative species include: yellow bullhead *Ameiurus natalis*, green sunfish *Lepomis cyanellus*, red shiner *Cyprinella lutrensis*, common carp *Cyprinus carpio*, flathead catfish *Pylodyctis olivaris* (USDA 2001) and channel catfish *Ictalurus punctatus* (first reported in this study). Some native species (e.g., razorback sucker, Colorado pikeminnow) were stocked in Cherry Creek during the 1980s (USDA 2001).

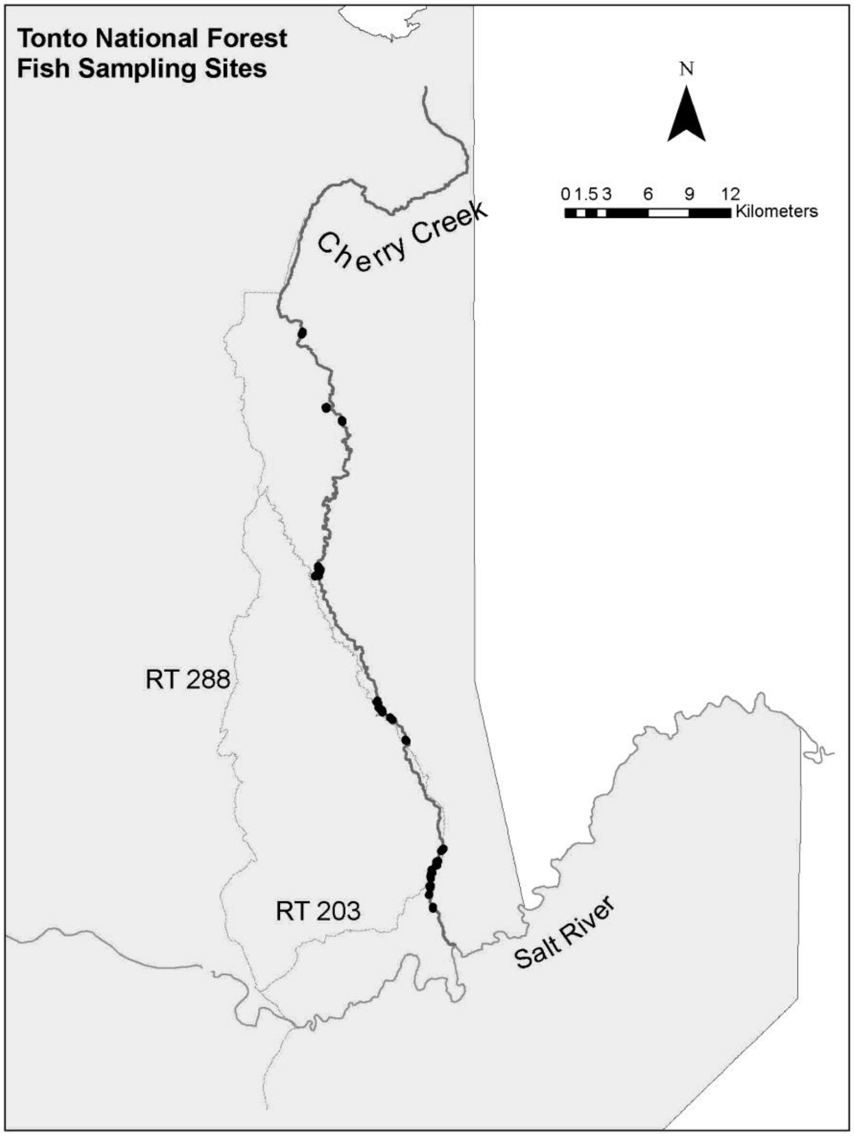


Figure 1. Sampling sites (black points) in Cherry Creek, Arizona. Roads (RT) are indicated as reference. Each point is a sampling site. Some points overlap at the scale of this map. Shaded area marks the boundaries of the Tonto National Forest.

Sampling

Between August and October 2008, we sampled fish and habitat variables in 257 sites from 22 reaches of Cherry Creek. Mean monthly discharge for these months was between 0.25 $m^3 \cdot s^{-1}$ (August) and 0.16 $m^3 \cdot s^{-1}$ (October). All sites were in wadable areas of the creek and sampled during daylight hours. Sample reaches were necessarily restricted to those near vehicular access points to the creek. Each 100 to 200-m long reach was divided into 10-m sections. Sampling sites were randomly placed in 6-12 of these sections. Sampling sites were 1 x 1.5 m each (the size of the electrofishing array described below). Placement of the array in the stream depended on stream morphology. If the array covered the entire width of the stream, the center of the array was placed in the middle of the stream. If the stream was wider than the array, width of stream was subdivided based on the number of array widths. Then the location of the array along an axis perpendicular to the stream flow was randomly selected.

At each site, unaltered AC current was used to sample fish. We used prepositioned areal electrofishing devices (PAEDs) to deliver current. Fish in streams and rivers have been successfully sampled by PAEDs to avoid fright bias in habitat suitability studies (Bain et al. 1985, Larimore and Garrels 1985, Fisher and Brown 1993, Kinsolving and Bain 1993, Schwartz and Herricks 2004). Additionally, PAEDs have lower differential capture efficiency related to fish size, species, and habitat sampled than other electrofishing techniques (Bain et al. 1985, Bowen and Freeman 1998). For our study, PAEDs consisted of two, parallel 1.5-m long by 1.27-cm diameter aluminum pipes, which served as the electrodes. Electrodes were separated by 1.0 m, and each was connected to a cable in a split extension cord, which in turn was plugged in to a 1,850-2,000-watt generator. The generator was placed on shore in a hidden location and the extension cord ran into the water where the rods were placed. The array (pipes and extension cord) was placed in the stream a minimum of 15 minutes before current application, during which time personnel were out of the water and away from the site so as not to disturb fishes; because fishes require about 11 minutes after electrode placement to reposition (Bain et al. 1985). To apply current, one person turned on the generator for 15-20 seconds, and another one or two personnel were positioned downstream with dip nets or a seine to capture all stunned fish. Then netters walked through the site, carefully searching and overturning stones to collect any fish that remained on the bottom. Fish were identified to species, counted, and measured (total length, mm).

Following sampling of fishes at each site, we measured depth (cm) at each of the four corners of the array. We sampled water velocity ($cm \cdot s^{-1}$) at three randomly selected points within the site. We used a Marsh-McBurney flow meter (Global Water Flow Probe, Gold River, California) to measure water velocity. We used the modified Wentworth scale (Table 1, Bain 1999) to classify substrate within the site. Substrate size was estimated using a chain marked in ten equally-spaced increments placed across the center of the sampling array. Size of substrate at each marked increment was recorded and averaged for an overall value for the array site.

Table 1. Wentworth scale for the classification of instream substrate types (from Bain 1999).

Substrate type	Particle Diameter Range (mm)	Sample Code
Boulder	>256	5
Cobble	64-256	4
Pebble	16-63	3
Gravel	2-15	2
Sand	0.06-1	1
Silt & clay	<0.059	0

A spherical densiometer was used to measure overhead cover (% shaded; Lemon 1956). We quantified instream large woody debris (% of site covered by woody debris) by visual observation. We visually divided the sampling site into 10 equal sections, counted the number of these sections occupied by woody debris in the site, and expressed the result as a percentage of site covered. Water temperature (ºC) was measured at each site using an ISO calibrated mercury thermometer. Specific conductivity was measured at each site using a EC400 ExStik II conductivity meter (Extech Instruments, Massachusetts, USA). Geographic coordinates (Universal Transverse Mercator and Latitude-Longitude) were measured at each site using a Model 300 Magellan (MiTAC International Corporation, California, USA) global positioning unit. A digital photograph of each site was also taken.

Analysis

We calculated HSC for substrate, water depth, water velocity, and water temperature for all but two (flathead and channel catfishes) species (due to low numbers) captured in the creek. We report the HSC for substrate, depth, and water velocity separately from temperature because the first three are the parameters used most commonly for instream habitat suitability criteria development. Following Bovee (1986) habitat suitability is defined here as the range of habitat variable values that are preferentially used by a species. We used plot analyses and χ^2 tests to calculate HSC for individual species (Bovee 1986, Thomas and Bovee 1993). For each variable and species, occurrence limits were established by analyzing the distribution of occupied (species present) and unoccupied (species absent) sites in comparative plots. We compared the distribution of occupied and unoccupied sites to the distribution of values found for a given variable in all samples. Specifically, we noted when the proportion of occupied sites (dark lines in plots in figures 2-5) for a given variable range was lower or higher than the proportion of sites present in all (occupied and unoccupied) samples (lighter lines in figures 2-5). We used nonparametric analyses (one-sided χ^2) to define the preferred range for a variable as the interval containing the lowest number of occupied locations (intervals for each variable) that would produce a significant ($\alpha \leq 0.05$) *t*-statistic. The test hypothesis was that preferred sites (for each variable) would be occupied in greater proportion than not-preferred sites. Results from the plot analysis were used as a guide in carrying out the χ^2 analyses. Both, occupation (via plot-analysis) and preference (via the χ^2 analysis) allowed an initial estimation of habitat suitability criteria for a given variable and species. These criteria were compared to published habitat preference descriptions from literature. When literature indicated that a species had suitable conditions beyond the range we found in Cherry Creek, we widened the range of suitability for a given variable (Bovee 1986). Final habitat suitability criteria reflect results obtained from our data (via plot analysis and χ^2 tests) modified by literature values (Table 3).

Results

We captured 1,739 fish of 11 species (5 native and 6 non-native) at 257 sampling sites (Table 3). No fish were captured at 60 (~23%) of 257 sampling sites. A maximum of 69 fish were captured in a single sample. Maximum species richness in a sampling site was 5. Longfin dace had the greatest distribution of any species. They were present at 96 sites (37.5% of all sites). The percentage of sites occupied by other species was as follows: desert sucker (23.0%), red shiner (23.0%), Sonora sucker (19.0%), speckled dace (15.0%), fathead minnow (12.5%), yellow bullhead (8.0%), roundtail chub (6.0%), green sunfish (5.0%), flathead catfish (0.7%), and channel catfish (0.4%).

Cherry Creek had a mean channel wetted width of 7.9 m, and an average depth of 24.4 cm. Values for other selected habitat characteristics found in Cherry Creek are included in Table 2.

Table 2. Selected habitat characteristics of sampling sites (*n* = 257) in Cherry Creek, Arizona. SE is standard error.

Characteristic	Mean	SE	Maximum	Minimum
Channel width (m)	7.9	26.5	29.3	1.1
Temperature (^{o} C)	18.7	0.3	28.0	11.1
Conductivity (µS)	620.0	16.0	1551.0	8.3
Depth (cm)	24.4	0.8	81.5	3.0
Shade (%)	37.0	1.9	100.0	0
Substrate (modified Wentworth scale)	3.0	-	5.0	0
Water velocity ($cm \cdot s^{-1}$)	6.7	0.4	36.5	0
Woody debris (% coverage)*	-	-	50	0

* We found very few sites (n=6) with more than 10% woody debris cover; most sites had zero to <10% cover.

Table 3. Total number (*N*) of individuals captured and relative abundance (R.A., % of all fishes captured) for fishes in Cherry Creek, Arizona, and associated habitat suitability criteria for three variables: depth (cm), water velocity ($cm \cdot s^{-1}$), and substrate size (Modified Wentworth scale [Bain 1999]).

Family Species	*N*	R.A.	Depth		Velocity		Substrate	
			Min	Max	Min	Max	Min	Max
Cyprinidae								
Agosia chrysogaster [a] (Longfin dace)	524	30.0	8	55	0	30	0	4
Cyprinella lutrensis [b] (Red shiner)	261	15.0	11	45	0	35	0	3
Gila robusta [a] (Roundtail chub)	60	3.4	14	65	0	30	2	5
Pimephales promelas [b] (Fathead minnow)	180	10.3	16	65	0	20	0	4
Rhinichthys osculus [a] (Speckled dace)	106	6.0	9	30	2.2	50	2	5
Catostomidae								
Catostomus clarki [a] (Desert sucker)	206	11.8	15	60	0	50	3	5
Catostomus insignis [a]	341	19.6	13	60	3.1	50	1	5

(Sonora sucker)								
Ictaluridae								
Ameiurus natalis [b] (Yellow bullhead)	31	1.7	10	81.5*	0	30	0	5
Pylodictys olivaris [b,c] (Flathead catfish)	2	0.1						
Ictalurus punctatus [b,c] (Channel catfish)	2	0.1						
Centrarchidae								
Lepomis cyanellus [b] (Green sunfish)	26	1.4	18	81.5*	0	20	0	5

[a] Native species

[b] Nonnative species

[c] Habitat suitability criteria not calculated for these species

*Maximum depth can extend to the deepest areas in Cherry Creek.

Plot analyses for depth, water velocity, and substrate (Figures 2-4), HSCs (Table 3), and *t*-values for the HSC χ^2 tests (Table 4) revealed different habitat use by different species. Longfin dace occurred at all depths, except for the shallowest sites (0-5.0 cm), and sites between 55.1 and 70.0 cm. They occurred in water flows of 2.25 – 26.8 $cm \cdot s^{-1}$, and were found over all substrates. However, preferred habitat for longfin dace were relatively shallow depths (minimum depth 8 cm - maximum depth 55 cm), with slow to moderate water velocities (min. 2.2 $cm \cdot s^{-1}$ - max. 20.1 $cm \cdot s^{-1}$), and any substrate type. We used information found in literature to obtain final HSC for longfin dace (Table 3); specifically, maximum substrate suitability was considered to be cobble, minimum water velocity included conditions of no flow, and maximum water velocity was increased to 30 $cm \cdot s^{-1}$ (see discussion section for details).

Table 4. *t*-values for χ^2 tests of habitat suitability criteria for three variables and nine species in Cherry Creek, Arizona. Significance level is as follows: a) $p < 0.01$, b) $p < 0.05$, c) $0.1 < p > 0.05$. N.S indicates $p > 0.1$).

Species	*t*		
	Depth	Velocity	Substrate
Agosia chrysogaster (Longfin dace)	2.77[a]	1.98[b]	2.76[a]
Cyprinella lutrensis (Red shiner)	2.74[a]	1.45[c]	3.22[a]
Gila robusta (Roundtail chub)	1.81[b]	1.81[b]	2.44[a]
Pimephales promelas (Fathead minnow)	2.11[b]	3.44[a]	1.35[c]
Rhinichthys osculus (Speckled dace)	3.14[a]	2.74[a]	2.58[a]
Catostomus clarkii (Desert sucker)	1.57[c]	1.98[b]	3.41[a]
Catostomus insignis (Sonora sucker)	1.94[b]	2.03[b]	0.58 (N.S.)
Ameiurus natalis (Yellow bullhead)	2.32[a]	1.57[c]	0.50 (N.S.)
Lepomis cyanellus (Green sunfish)	2.30[b]	2.24[b]	0.92 (N.S.)

Results of plot analyses showed red shiners occurred at depths of up to 50 cm, water velocities ranging from 0 -22.3 cm•s^{-1}, and over all substrate types. However, relatively shallow sites (11.0 – 35.0 cm), with low velocities (0.0 - 15.6 cm•s^{-1}), and substrates comprised of silt to pebbles were preferred by red shiners. We used information found in literature to obtain final HSC (Table 3); specifically, maximum depth was increased to 45 cm and maximum velocity was increased to 35 cm•s^{-1} (see details in discussion section).

Roundtail chub occurred at depths from 10-65 cm, at water velocities of 0 – 22.3 cm•s^{-1} and over substrates ranging from gravel to boulders. Roundtail chub preferred relatively shallow (14.0 – 50.0 cm) depths with moderate water velocity (4.4 – 22.3 cm•s^{-1}), and substrates from sand to boulders. We used information found in literature to obtain final HSC for roundtail (Table 3) chubs; specifically, areas with no flow are suitable for the species, and maximum suitable velocity was slightly increased (see discussion section for details).

Fathead minnows occurred from depths of 5 to 65 cm; water velocities of 0 – 11.1 cm•s^{-1} and over all substrate types. However, sites preferred by fathead minnows were relatively deep (16.0 – 65.0 cm), with slow water velocity (0.0 – 7.5 cm·s^{-1}), and substrates ranging from silt to pebbles. We used information found in literature to obtain final HSC for fathead minnows (Table 3); specifically, they can also be found in cobble and their maximum suitable velocity is 20 cm•s^{-1} (see discussion section for details).

Speckled dace occurred at depths from 5 – 45 cm, velocities from 0 - >33.5 cm•s^{-1} and over all substrate types. Sites preferred by speckled dace were relatively shallow (9.0 – 30.0 cm), with fast flowing waters (2.2 – 26.8 cm·s^{-1}) and relatively coarse substrates (gravel – boulders). We used information found in literature to obtain final HSC for speckled dace; specifically, their maximum suitable velocity was 50 cm•s^{-1} (see discussion section for details).

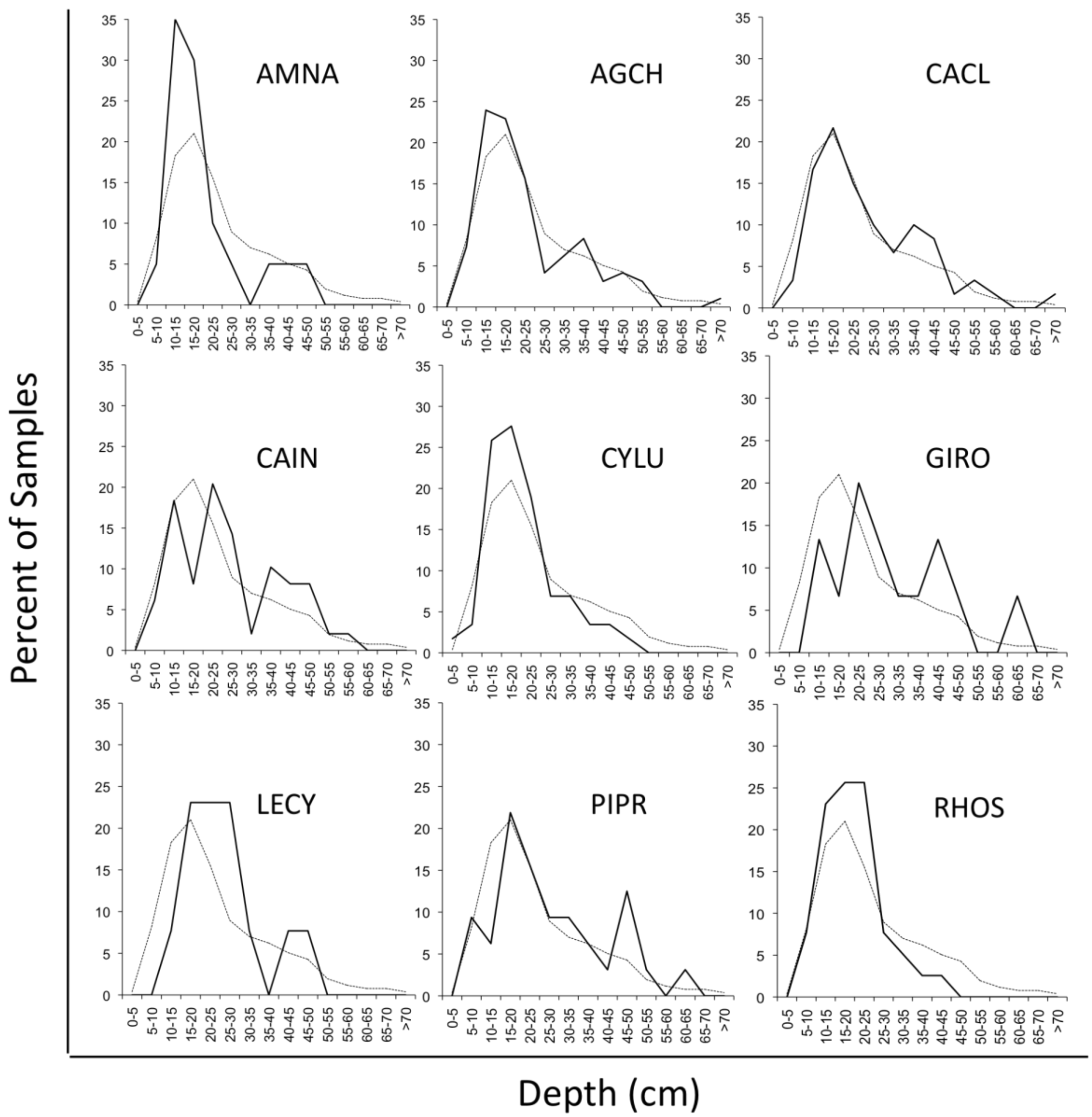


Figure 2. Distribution by depth of 9 fish species in Cherry Creek, Arizona. Dotted line indicates the percent of Cherry Creek sampling sites at each depth interval. Dark lines indicate the percent of sites occupied by a species that were found in each depth interval. *Ameiurus natalis*, yellow bullhead (AMNA); *Agosia chrysogaster*, longfin dace (AGCH); *Catostomus clarki*, desert sucker (CACL); *Catostomus insignis*, Sonora sucker (CAIN); *Cyprinella lutrensis*, red shiner (CYLU); *Gila robusta*, roundtail chub (GIRO); *Lepomis cyanellus*, green sunfish (LECY); *Pimephales promelas*, fathead minnow (PIPR), *Rhinichthys osculus*, speckled dace (RHOS).

Desert suckers were found at depths ranging from 5 - >70 cm, water velocities of 0 – >33.5 $cm \cdot s^{-1}$ and over all substrate types. Preferred sites for desert suckers were generally deep (15.0 – 60.0 cm), with moderate water velocity (0.0 – 26.8 $cm \cdot s^{-1}$), and relatively coarse sediments (pebbles to boulders). We used information found in literature to obtain final HSC (Table 3) for desert suckers; specifically, the maximum velocity was increased to 50 $cm \cdot s^{-1}$ (see discussion section for details).

Sonora suckers occurred at depths ranging from 5 – 60 cm, water velocities of 0 – 26.8 $cm \cdot s^{-1}$, and over all substrate types. Compared to desert suckers, Sonora suckers preferred sites with similar depths (13.0 – 60.0 cm), and velocities (3.1 – 26.8 $cm \cdot s^{-1}$), but Sonora suckers preferred a wider variety of substrates. We used information found in literature to obtain final HSC for Sonora suckers (Table 3); specifically, the maximum velocity was increased to 50 $cm \cdot s^{-1}$ (see discussion section for details).

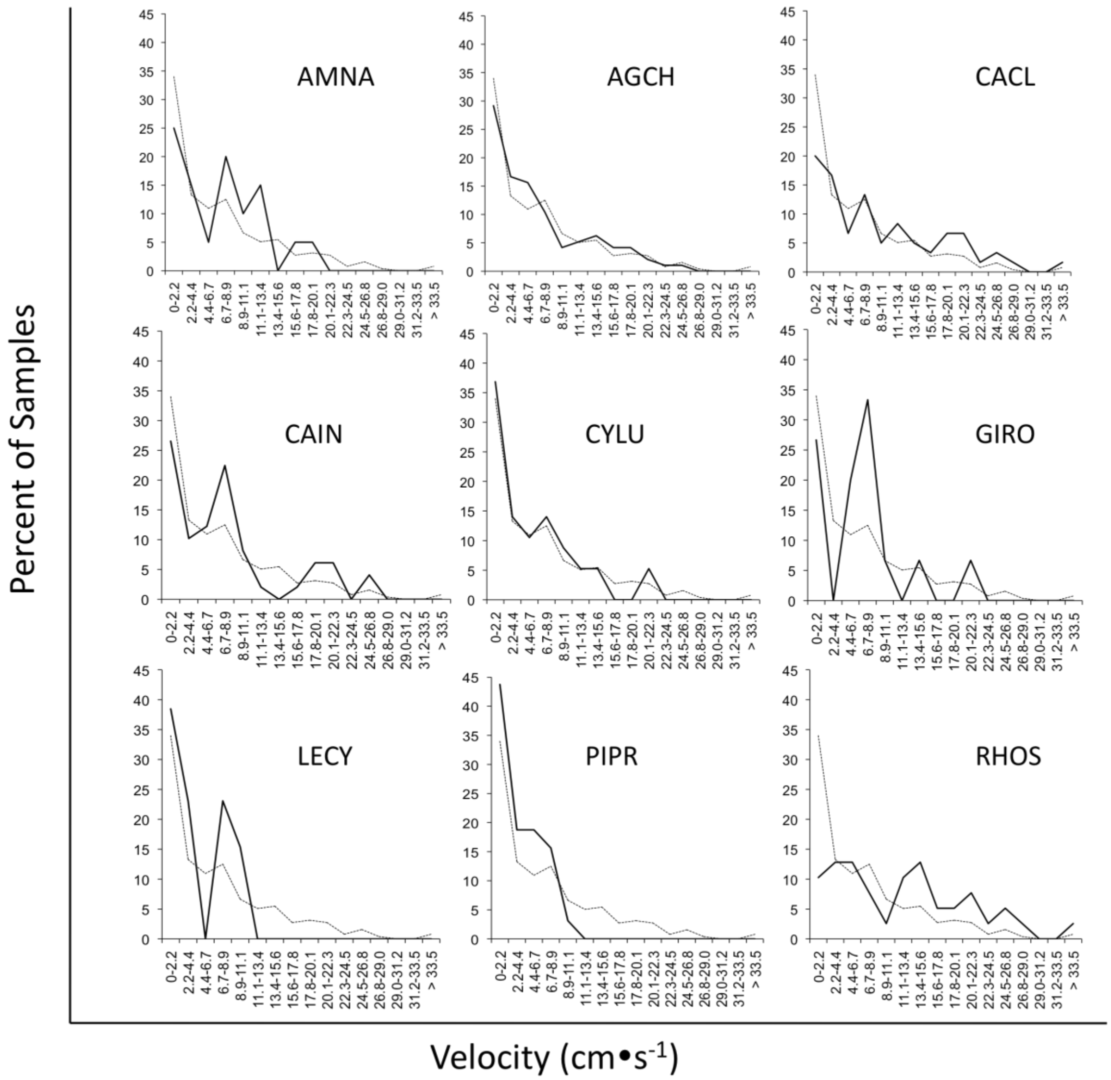


Figure 3. Distribution by water velocity of 9 fish species in Cherry Creek, Arizona. Dotted lines indicate the percent of Cherry Creek sampling sites at each water velocity interval. Dark lines indicate the percent of samples occupied by a species at each water velocity interval. *Ameiurus natalis*, yellow bullhead (AMNA); *Agosia chrysogaster*, longfin dace (AGCH); *Catostomus clarki*, desert sucker (CACL); *Catostomus insignis*, Sonora sucker (CAIN); *Cyprinella lutrensis*, red shiner (CYLU); *Gila robusta*, roundtail chub (GIRO); *Lepomis cyanellus*, green sunfish

(LECY); *Pimephales promelas,* fathead minnow (PIPR), *Rhinichthys osculus,* speckled dace (RHOS).

Yellow bullhead occurred at depths from 5 – 50 cm, water velocities from 0 – 20.1 cm•s^{-1} and over all substrate types. They preferred sites that were relatively shallow (10.0 – 20.0 cm), with moderate velocities (2.7 – 20.1 cm·s^{-1}), and a variety of substrates. Yellow bullhead HSC for Cherry Creek were modified by values found in literature; specifically, the depth at which they could occur, and the maximum suitable velocity were increased (Table 3) (see other details in the discussion section).

Green sunfish occurred at depths of 10 – 50 cm, velocities of 0 – 11.1 cm•s^{-1} and over all substrate types. Sites preferred by green sunfish had moderate depths (18.0 – 35.0 cm), and velocities (0.0 – 10.2 cm·s^{-1}), and no specific substrate type. Green sunfish HSC values were modified by values found in literature; their suitable depth and maximum water velocity were increased (Table 3) (see details in the discussion section).

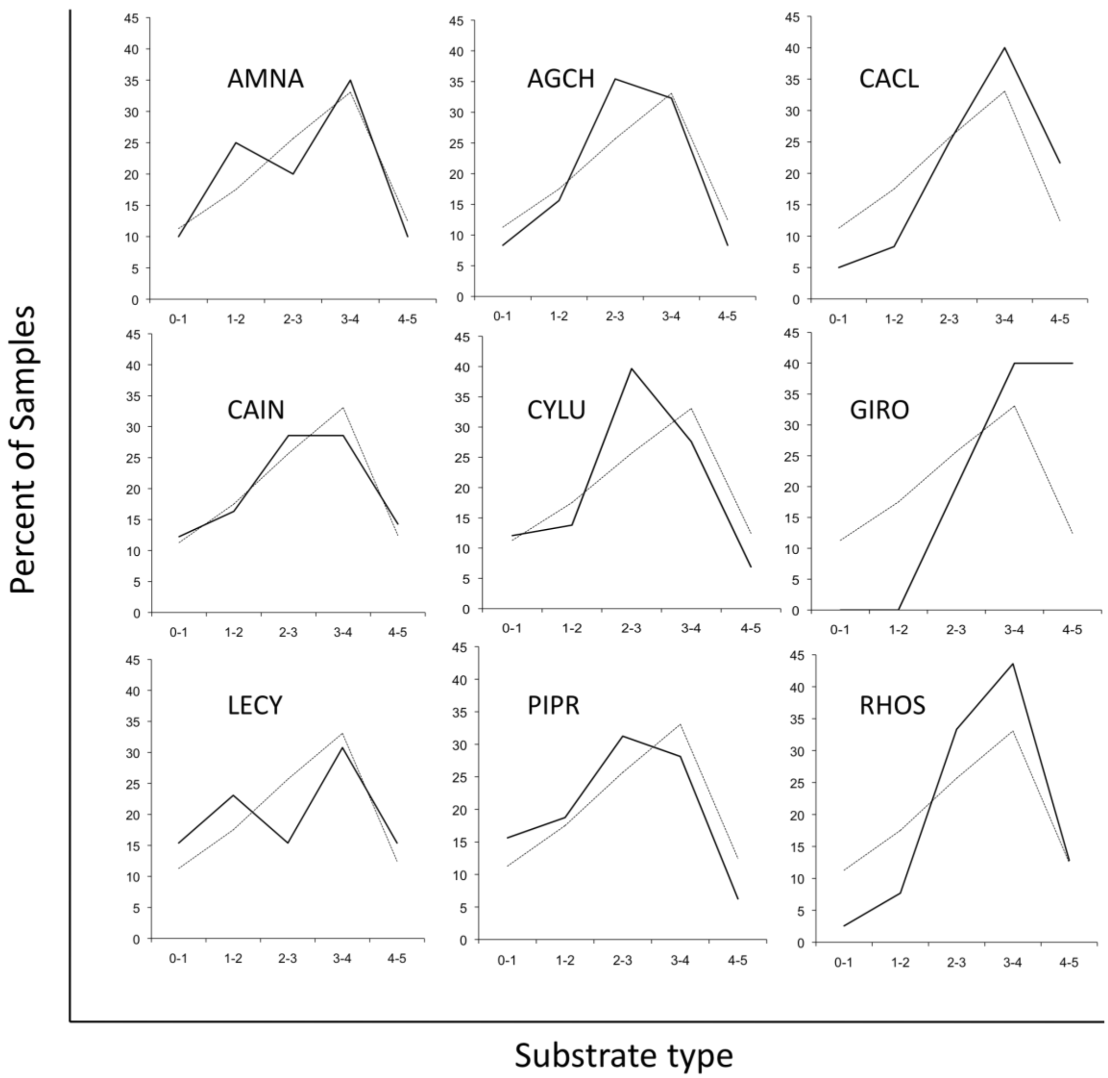


Figure 4. Distribution by substrate type for 9 species in Cherry Creek, Arizona. Dotted lines indicate the percent of Cherry Creek sampling sites with mean modified Wentworth scale (Bain 1999) value within specific intervals. Dark lines indicate the percent of samples occupied by a species in each substrate type. Qualitative descriptions for each substrate type are included in Table 1. *Ameiurus natalis,* yellow bullhead (AMNA); *Agosia chrysogaster*, longfin dace (AGCH); *Catostomus clarki*, desert sucker (CACL); *Catostomus insignis*, Sonora sucker (CAIN); *Cyprinella lutrensis,* red shiner (CYLU); *Gila robusta*, roundtail chub (GIRO); *Lepomis*

cyanellus, green sunfish (LECY); *Pimephales promelas*, fathead minnow (PIPR), *Rhinichthys osculus*, speckled dace (RHOS).

Temperature preferences also varied by species (Table 5, Figure 5). Longfin dace, desert suckers, and speckled dace were the only species found in the coldest sites (11-13 ºC). Yellow bullhead, longfin dace, Sonora sucker, red shiner, fathead minnows, speckled dace, and green sunfish were found in the warmest sites (26 - 28 ºC). Longfin dace were present in all temperature intervals (11-28 ºC), but roundtail chub were found only in sites with temperatures between 14-22 ºC. In Cherry Creek, roundtail chub were not collected from sites with the lowest (11 – 13 ºC) or highest (>23ºC) temperatures. Preferred temperatures for red shiner, Sonora sucker, fathead minnow, and yellow bullhead were the warmest (20-28 ºC) in the creek, whereas preferred temperatures for speckled dace, desert suckers and roundtail chub were relatively cooler (11 - 21 ºC). Temperature preference for green sunfish and longfin dace were between 15 - 25 ºC (Table 5).

Table 5. Range of preferred water temperatures for fishes in Cherry Creek, Arizona. Minimum and maximum water temperatures and the *t*-values for χ^2 tests are presented. All *t*-values were significant at α = 0.05.

Species	Temperature (^{o}C)		
	Min.	Max.	*t*
Agosia chrysogaster (Longfin dace)	15	25	3.02
Cyprinella lutrensis (Red shiner)	21	26	2.56
Gila robusta (Roundtail chub)	16	19	2.82
Pimephales promelas (Fathead minnow)	20	26	3.74
Rhinichthys osculus (Speckled dace)	11	21	1.89
Catostomus clarkii (Desert sucker)	14	19	1.64
Catostomus insignis (Sonora sucker)	20	28	5.93
Ameiurus natalis (Yellow bullhead)	21	26	2.56
Lepomis cyanellus (Green sunfish)	18	22	2.36

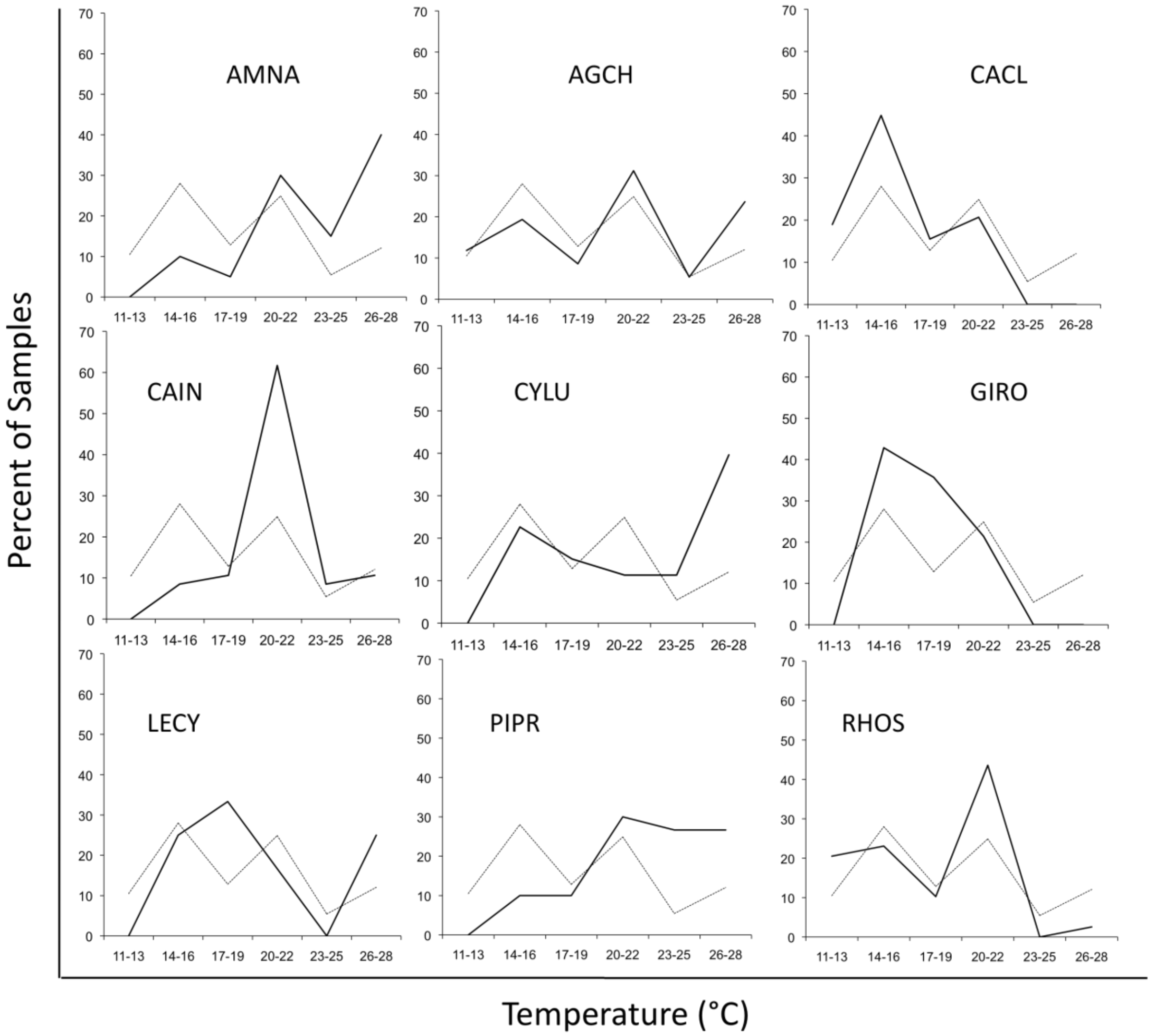


Figure 5. Distribution by temperature of 9 fish species in Cherry Creek, Arizona. Dotted lines indicate the percent of Cherry Creek sampling sites found at each temperature interval. Dark lines indicate the percent of sites occupied by a species in each temperature interval. *Ameiurus natalis*, yellow bullhead (AMNA); *Agosia chrysogaster*, longfin dace (AGCH); *Catostomus clarki*, desert sucker (CACL); *Catostomus insignis*, Sonora sucker (CAIN); *Cyprinella lutrensis*, red shiner (CYLU); *Gila robusta*, roundtail chub (GIRO); *Lepomis cyanellus*, green sunfish (LECY); *Pimephales promelas*, fathead minnow (PIPR), *Rhinichthys osculus*, speckled dace (RHOS).

Our literature review provided additional data that were used to calibrate results from the plot analysis and χ^2 tests for some species (Table 3). These calibrations are presented in the discussion section.

Discussion

Definition of habitat suitability for freshwater fishes in streams subject to diverse anthropogenic stressors is useful for managers to define possible outcomes of multiple management scenarios. Flow regulation, implementation of minimum ecological water flows, habitat restoration practices, and individual species conservation efforts have relied on species specific habitat selection data to define management needs and strategies (Rinne 1992, Barrett and Maughan 1995, Gido and Propst 1999).

We identified several differences in habitat use and preference among fish species in Cherry Creek. Compared to other species in Cherry Creek, longfin dace were habitat generalists and were found over multiple depths, water velocities, and substrates. Further, they were found at all temperatures in the creek. These results are generally supported by existing literature. Although longfin dace are known to prefer water of 20.0 cm in depth when spawning (Minckley and Barber 1971, Sublette et al. 1990), they are often found in deeper or shallower waters (Lewis 1978, AGFD 2006). Like other fishes, longfin dace may avoid deeper water when predators are present (Power 1987, Gelwick et al. 1997). In Aravaipa Creek, Arizona, Rinne (1992) found longfin dace occupying relatively shallow (12.0 – 22.0 cm) waters with water velocities of up to 40 $cm \cdot s^{-1}$ over pebble substrate. Longfin dace can swim against water velocities of up to 73.5 $cm \cdot s^{-1}$ (Ward et al. 2003). Minckley (1973) referred to longfin dace as the ‘most successful, highly adaptable, cyprinid fish native to the deserts of the American Southwest’. During low flows, they sometimes take refuge in moist detritus and algal mats until flow increases (Sublette et al. 1990). Longfin dace prefer gravel, sand, and pebble substrate, but can also be found among boulders (especially if finer substrates are found in the interstices of boulders; Barber and Minckley 1966, Lewis 1978, Meffee and Minckley 1987, Grimm et al. 1988). Thus, suitable habitat for longfin dace includes water velocities between 0.0 - 30 $cm \cdot s^{-1}$, depths between 8.0 – 55.0 cm, and substrates from silt to cobble. Longfin dace are generally found in water less than 24° C, but are tolerant of high temperatures and low dissolved oxygen (AGFD 2006).

The red shiner, nonnative to Cherry Creek, also has great plasticity in terms of habitat suitability. In lotic systems, they have been found up to 350 cm deep (Chappell and Fisher 2005), although most occupy waters between 3 and 100 cm deep (Matthews and Hill 1979 a,b, Gido and Propst 1999). Although red shiners have been reported in waters with velocities as high as 56.77 $cm \cdot s^{-1}$ (Matthews and Hill 1979a) and can swim in water as fast as 77.0 $cm \cdot s^{-1}$ (Ward et al. 2003), they mostly occupy habitats with slower water velocities (11.2 $cm \cdot s^{-1}$; Gido and Propst 1999). Red shiners live over a variety of substrates including silt, gravel, and fine sands (Matthews and Hill 1979 a, b, Becker 1983, Platania 1991, Gido et al. 1997, Gido and Propst 1999, Fischer and Paukert 2008). We concluded that suitable depth for red shiner ranged from 11.0 – 45.0 cm, water velocity from 0.0 - 35 $cm \cdot s^{-1}$ and substrate between 0 (silt) - 3 (pebbles). The temperature preference of red shiner in Cherry Creek was between 21-26 ºC, but they are known to live in waters with higher (30 ºC) and lower temperatures (10 ºC) (Deacon et al. 1987).

Roundtail chub is a native species that has been collected from depths from 20 to 200 cm over generally coarse substrates (e.g., cobble, pebbles, boulders), but occasionally over sand and gravel (Barber and Minckley 1966, Griffith and Tiersch 1989, Sublette et al. 1990, Rinne 1992, Barrett and Maughan 1995, Brouder et al. 2006). They select for relatively swift waters but also require calm deep pools, and have been collected at water velocities of 0.0 – 96 $cm \cdot s^{-1}$ (Barrett and Maughan 1995). In Cherry Creek they were often found in pools adjacent to riffle or run areas. Thus, their suitable velocity maximum was set at 30 $cm \bullet s^{-1}$. Habitat suitability criteria for roundtail chub in Cherry Creek are in agreement with those reported in literature. Temperature tolerance of roundtail chub has been reported up to 39°C (Deacon et al. 1987), but preferred temperature reported between 22 °C and 24 °C (Weitzel 2002). In Cherry Creek we found them occupying sites with lower temperatures (14-22 °C).

Slow water velocities, shallow depths, and small sediments are suitable for fathead minnows (Becker 1983). They have been collected at depths of up to 440.0 cm in lentic systems (Chappel and Fisher 2005), but in rivers they often occupy shallow areas close to shore. They prefer water velocities slower than 15 $cm \cdot s^{-1}$ (Sublette et al. 1990), but have been collected at 31.3 $cm \cdot s^{-1}$ (Gido and Propst 1999) and can swim against water velocities of up to 69.1 $cm \cdot s^{-1}$ (Ward et al. 2003). Fathead minnow occur over many substrate types, but prefer silt, sand, and gravel (Becker 1983, Sublette et al. 1990, Gido and Propst 1990, Gido et al. 1997, Fischer and Paukert 2008). Our HSC criteria for fathead minnow in Cherry Creek fall within these intervals. Fathead minnows prefer temperatures between 23-29ºC, and avoid water > 32ºC and lower than 23ºC (Coutant 1977). This species was most commonly found at temperatures between 23-28ºC in Cherry Creek.

Speckled dace usually live in clear, well-oxygenated water with abundant deep cover and moving water, most often occupying water less than 60.0 cm deep in riffles and runs (Valdez et al. 2001, Moyle 2002). Rinne (1992), Mullen and Burton (1995), Gido and Propst (1999), and Moyle and Baltz (1985) collected them from waters shallower than 32.0 cm and reported that water velocities preferred by speckled dace are relatively fast. Mullen and Burton (1995) found that speckled dace avoided velocities slower than 10 $cm \cdot s^{-1}$ and selected for velocities faster than 50 $cm \cdot s^{-1}$. Speckled dace cannot swim against water currents with velocities greater than 70.4 $cm \cdot s^{-1}$ (Ward et al. 2003). For Cherry Creek their maximum suitable velocity was established at 50 $cm \cdot s^{-1}$, which is consistent with available literature. Speckled dace are often found among boulders and cobble, although they can also be occasionally found in soft substrates (Gido and Propst 1999). Speckled dace usually inhabit relatively cold waters in desert streams and have been collected at temperatures between 9 and 27ºC (Deacon et al. 1987). This interval encompasses the temperatures at which they were found in Cherry Creek (11-28 ºC).

Catostomids are benthic, found in pools, slow runs or deep riffles of desert streams over gravel to boulder-sized substrate (Barber and Minckley 1966, Griffith and Tiersch 1989, Bonar et al. 2004). Sonora suckers occur at depths of 30 cm in water with a velocity of up to 25 $cm \cdot s^{-1}$ (Rinne 1992). The highest water velocity they can swim against is 55.9 $cm \cdot s^{-1}$ (Ward et al. 2003). Desert suckers have similar habitat requirements to Sonora suckers, but can swim against water with velocities of up to 93.1 $cm \cdot s^{-1}$ (Ward et al. 2003). They have been collected at depths of up to 65 cm (Fisher et al. 1981) in waters with velocities of up to 38 $cm \cdot s^{-1}$, but most often 22-30 $cm \cdot s^{-1}$. Thus, we report a maximum suitable water velocity of 50 $cm \cdot s^{-1}$ for both Catostomids. These depth and substrate suitable criteria fall within the intervals reported in literature. Desert suckers are thermally labile, but will usually select for temperatures between 13 and 22ºC depending on the time of acclimation (Deacon et al. 1987). Sonora suckers are tolerant of temperatures as low as 10ºC, and up to 30ºC for short periods (Rinne et al. 2001). In Cherry Creek, Sonora suckers were mostly collected where midday water temperatures rose to 28ºC, whereas desert suckers were not collected in waters this warm. Thus our suitable temperature intervals were narrower for desert suckers than Sonora suckers.

Yellow bullhead commonly live in pools and glides but can occur in riffles (Bonar 2004, Schade and Bonar 2005). They can occur at depths of up to 500 cm in lentic areas (Moyle 2002), but are most often found at depths of 60.0 – 150.0 cm (Becker 1983). In the San Juan River black bullhead, a species with very similar habitat requirements to yellow bullhead, were found in waters deeper than 30 cm, with velocities of 1.6 $cm \cdot s^{-1}$, and generally soft sediments (Gido and Propst 1999). Black bullhead have also been reported from habitats with water velocities of 100 $cm \bullet s^{-1}$ (Schade and Bonar 1995). In general, yellow bullhead occupy areas with gravel, sand, and silt (Sigler and Sigler 1996, Fisher and Paukert 2008). In Cherry Creek, yellow bullhead we captured were relatively small— mean TL 105mm — compared to the maximum size (465 mm TL) recorded for the species (Becker 1983). Thus, the habitat criteria collected from Cherry Creek reflect habitats that relatively small yellow bullhead use. We adjusted yellow bullhead HSC to be consistent with habitat requirements suitable for larger individuals: maximum suitable depth was established as the deepest section of Cherry Creek, and their maximum suitable velocity was 30 $cm \bullet s^{-1}$. Yellow bullhead have a temperature preference of 28.3ºC (Coutant 1977), but can be found at lower and higher temperatures in a variety of ecosystems. In Cherry Creek, yellow bullhead were primarily found at the warmest sites.

Green sunfish inhabit areas with varied substrates in shallow (<1.5m) quiet pools. They require considerable habitat structure (i.e., trees, macrophytes) (Becker 1983, Platania 1991). Green sunfish cannot swim against currents with velocities higher than 46.2 $cm \cdot s^{-1}$ (Ward et al. 2003). The suitable depth for green sunfish in Cherry Creek extends from 18.0 cm to the deepest sections of the Creek. Their suitable water velocities include a maxima of 20 $cm \cdot s^{-1}$. They have no substrate preference. These results coincide with literature findings. Green sunfish prefer temperatures of 27-30 ºC, and usually avoid temperatures lower than 23ºC (Coutant 1977). In

Cherry Creek, green sunfish were collected at temperatures as low as 14ºC, but most preferred temperatures between 17-19ºC and above 26ºC. We thus consider them as restricted to stream areas that reach relatively high temperatures.

Our study was focused on habitat suitability criteria and temperature preferences for adult fishes in Cherry Creek. However, larval fish generally have different habitat requirements than adults (Childs et al. 1998). To further investigate the habitat requirements for larval fishes in Cherry Creek, we carried out intensive sampling between March and June 2009. We took 275 samples located randomly throughout the creek. Forty eight percent of these had no larval fish. Using two-sample-*t*-tests, we found that samples with at least one larva were taken from shallower sites (mean depth = 14.6 cm, SE = 1.01) than those without larvae (mean depth = 20.7 cm, SE = 1.16) ($t = 3.95$, $p < 0.001$). Further, we found samples with larvae in sites with slower (1.28 $cm \cdot s^{-1}$) water velocities than samples without larvae (5.97 $cm \cdot s^{-1}$) ($t = 7.71$, $p < 0.001$); sites with larvae had smaller mean substrate size (Wentworth Scale = 2 [gravel]) than sites without larvae (3 [pebble]; $t = 3.84$, $p < 0.001$); sites with larvae had higher average water temperature (20.0ºC) than sites without larvae (18.8ºC; $t = 3.44$, $p < 0.001$). Finally, sites with larvae were closer (0.94 m) to shore than sites without larvae (mean distance =1.55 m; $t = 2.58$, $p = 0.011$). Although we have not carried out a species-specific analysis of these data, it is clear that larvae in Cherry Creek are concentrated in shallow, quiet areas of the creek, that have relatively high temperatures, soft substrates, and are located near the near the shore.

Development of habitat suitability criteria is subject to several difficulties (Hudson et al. 2003). Ideally, data for development of HSC should be obtained from unexploited streams at carrying capacity (Bovee 1992, Mathur et al. 1985). Failure to do so, will introduce bias into HSC calculations. Additionally, presence of nonnative species and other anthropogenic impacts (e.g., cattle use portions of stream) could modify fish behavior and distribution, thus possibly affecting HSC. Also, there is no way to eliminate all bias from habitat preference data (Bovee 1986). By using PAEDs, we attempted to reduce some of the bias resulting from the use of alternative sampling methods such as backpack electrofishing which can herd fish into sites they do not usually occupy. However, it is possible that PAEDs were selective for fishes of a certain size, and less effective at greater depths or in fast waters. Also, the effects of timing and seasonality of sampling on HSC values calculations should also be considered. Fishes may make different use of habitats at different times of day or in different seasons. Our sampling occurred diurnally during summer and fall, and it is possible that habitat preference for fishes in these seasons and times may not reflect their preference during times of high water flows in early spring or during the night. Finally, our selection of sampling sites was limited by access to the creek, which left remote areas unsampled. All these considerations may have affected our values for HSC criteria; however, we feel that the relatively high number of sites (n = 257) we sampled, along with our use of a relatively unbiased sampling method, and corroboration of HSC values with those found in literature, support the HSC values we report here.

Acknowledgements

We thank Amy Unthank, Robert Diebel, David M. Merritt and Shannon Torrence from the USDA Forest Service; Kenneth Bovee and Terry Waddle from the USGS Fort Collins Science Center; Dave Weedman from the Arizona Game and Fish Department; and Edgar Solis Cordero, Lisa Trestik, Olin Feuerbacher, and Matt Recsetar from the USGS Arizona Cooperative Fish and Wildlife Research Unit for their assistance with field collections and overall project coordination. The Tonto Basin Ranger District (Roosevelt, Arizona) and the Pleasant Valley Ranger District (Young, Arizona) in the Tonto National Forest, and The School of Natural

Resources & the Environment of the University of Arizona, provided assistance to complete this research. Funding for this project was provided by the USDA Forest Service. Cover image by Olin Feuerbacher.

Literature cited

(AGFD), Arizona Game and Fish Department. 2006. *Agosia chrysogaster chrysogaster*, unpublished abstract compiled and edited by the Heritage Data Management System. Page 6. Arizona Game and Fish Department, Phoenix.

Bain, M. B. 1999. Substrate. Pages 95-103 *in* M. B. Bain, and N. J. Stevenson, editors. Common Methods: Aquatic Habitat Assessment. American Fisheries Society, Bethesda, Maryland.

Bain, M. B., J. T. Finn, and H. E. Bookem. 1985. A quantitative method for sampling riverine microhabitats by electrofishing. North American Journal of Fisheries Management 5:489-493.

Barber, W. E., and W. L. Minckley. 1966. Fishes of Aravaipa Creek, Graham and Pinal Counties, Arizona. The Southwestern Naturalist 11:313-324.

Barrett, P. J., and O. E. Maughan. 1995. Spatial habitat selection of Roundtail chub (*Gila robusta*) in two central Arizona streams. The Southwestern Naturalist 40:301-307.

Becker, G. C. 1983. Fishes of Wisconsin. University of Wisconsin Press, Madison, WI.

Bonar, S., L. L. Leslie, and C. E. Velez. 2004. Influence of species, size class, environment, and season on introduced fish predation on native fishes in the Verde River system, Arizona. USGS Arizona Cooperative Fish and Wildlife Research Unit Research Report 04-01, Tucson.

Bovee, K.D. 1982: A guide to stream habitat analysis using the instream flow incremental methodology. Instream Flow Information Paper 12, United States Fish and Wildlife Service, Fort Collins, Colorado.

Bovee, K. D. 1986. Development and evaluation of habitat suitability criteria for use in the instream flow incremental methodology. US. Fish Wildlife Service Biological Report 86(7). U.S. Fish and Wildlife Service, Washington D.C.

Bovee, K.D.; Lamb, B.L.; Bartholow, J.M.; Stalnaker, C.B.; Taylor, J.; Henriksen, J. 1998: Stream habitat analysis using the instream flow incremental methodology. Biological Resources Division Information and Technology Report USGS/BRD-1998-0004. United States Geological Survey, Fort Collins, Colorado.

Bowen, Z. H., and M. C. Freeman. 1998. Sampling effort and estimates of species richness based on prepositioned area electrofisher samples. North American Journal of Fisheries Management 18:144-153.

Brouder, M. J., D. D. Rogers, and L. D. Avenetti. 2006. Observations on the reproductive biology of roundtail chub, *Gila robusta*, in the upper Verde River, Arizona. Western North American Naturalist 66:260-262.

Chappell, W. S., and W. L. Fisher. 2005. Fish assemblage and aquatic habitat relationships at the Tishomingo National Wildlife Refuge, Oklahoma. Proceedings of the Oklahoma Academy of Science 85:19-31.

Childs, M. R., R. W. Clarkson, and A. T. Robinson. 1998. Resource use by larval and early juvenile native fishes in the Little Colorado River, Grand Canyon, Arizona. Transactions of the American Fisheries Society 127:620-629.

Coutant, C. C. 1977. Compilation of temperature preference data. Journal of the Fisheries Research Board of Canada 34:739-745.

Deacon, J. E., P. B. Schumann, and E. L. Stuenkel. 1987. Thermal tolerances and preferences of fishes of the Virgin River system (Utah, Arizona, Nevada). Great Basin Naturalist 47:538-546.

Fischer, J. R., and C. P. Paukert. 2008. Habitat relationships with fish assemblages in minimally disturbed Great Plains regions. Ecology of Freshwater Fish 17:597-609.

Fisher, W. L., and M. E. Brown. 1993. A prepositioned electrofishing apparatus for sampling stream habitats. North American Journal of Fisheries Management 13:807-816.

Fisher, S. G., D. E. Busch, and N. B. Grimm. 1981. Diel feeding chronologies in two Sonoran Desert stream fishes, *Agosia chrysogaster* (Cyprinidae) and *Panteosteus clarki* (Catostomidae). The Southwestern Naturalist 26:31-36.

Gelwick, F. P., M. S. Stock, and W. J. Matthews. 1997. Effects of fish water depth and predation risk on patch dynamics in a north temperate river ecosystem. Oikos 80:382-398.

Gido, K. B., and D. L. Propst. 1999. Habitat use and association of native and nonnative fishes in the San Juan River, New Mexico and Utah. Copeia 1999(2):321-332.

Gido, K. B., D. L. Propst, and M. C. Molles. 1997. Spatial and temporal variation of fish communities in secondary channels of the San Juan River, New Mexico and Utah. Environmental Biology of Fishes 49:417-434.

Griffith, J. S., and T. R. Tiersch. 1989. Ecology of fishes in Redfield Canyon, Arizona, with emphasis on *Gila robusta intermedia*. The Southwestern Naturalist 31:131-134.

Grimm, N. B. 1988. Feeding dynamics, nitrogen budgets, and ecosystem role of a desert stream omnivore, *Agosia chrysogaster* (Pisces: Cyprinidae). Environmental Biology of Fishes 21:143-152.

Hudson, H. R., A. E. Byrom, and W. L. Chadderton. 2003. A critique of IFIM—instream habitat simulation in the New Zealand context. Science for Conservation 231, Wellington, New Zealand.

Jowett, I. G. 2002. In-stream habitat suitability criteria for feeding inanga (*Galaxias maculatus*). New Zealand Journal of Marine and Freshwater Research 36:399-407.

Kinsolving, A. D., and M. B. Bain. 1993. Fish assemblage recovery along a riverine disturbance gradient. Ecological Applications 3:534-544.

Larrimore, R. W., and D. D. Garrels. 1985. Assessing habitats used by warmwater stream fishes. Fisheries 10:10-16.

Lemon, P. E. 1956. A spherical densiometer for estimating forest overstory density. Forest Science 2: 314-320.

Lewis, M. A. 1978. Notes on the natural history of the Longfin dace, *Agosia chrysogaster*, in a desert rheocrene. Copeia 4:703-705.

Mathur, D.; W. H. Bason, E. J. Purdy Jr; C. A. Silver. 1985: A critique of the instream flow incremental methodology. Canadian Journal of Fisheries and Aquatic Sciences 42: 825–831.

Matthews, W. J., and L. G. Hill. 1979a. Age specific differences in the distribution of red shiners, *Notropis lutrensis*, over physicochemical ranges. American Midland Naturalist 101:366-372.

Matthews, W. J., and L. G. Hill. 1979b. Influence of physicochemical factors on habitat selection by red shiners, *Notropis lutrensis* (Pisces: Cyprinidae). Copeia 1979:70-81.

Meffee, G. K., and W. L. Minckley. 1987. Persistence and stability of fish an invertebrate assemblages in a repeatedly disturbed Sonoran Desert stream. American Midland Naturalist 117:177-191.

Miller, R. R., J. D. Williams, and J. E. Williams. 1989. Extinction in North American fishes during the past century. Fisheries 14:22-38.

Minckley, W. L. 1973. Fishes of Arizona. Arizona Game and Fish Department, Phoenix.

Minckley, W. L., and W. E. Barber. 1971. Some aspects of biology of the longfin dace, a cyprinid fish characteristic of streams in the Sonoran Desert. The Southwestern Naturalist 15:459-464.

Minckley, W. L., and J. E. Deacon, editors. 1991. Battle against extinction: Native fish management in the American West. University of Arizona Press, Tucson

Moyle, P. B. 2002. Inland fishes of California. University of California Press, Berkeley.

Moyle, P. B., and D. M. Baltz. 1985. Microhabitat use by an assemblage of California stream fishes: developing criteria for instream flow determinations. Transactions of the American Fisheries Society 114:695-704.

Mullen, D. M., and T. M. Burton. 1995. Size related habitat use by longnose dace (*Rhinichthys cataractae*). American Midland Naturalist 133:177-183.

Platania, S. P. 1991. Fishes of the Rio Chama and Upper Rio Grande, New Mexico, with preliminary comments on their longitudinal distribution. The Southwestern Naturalist 36:186-193.

Power, M. 1987. Predator avoidance by grazing fishes in temperate and tropical streams: importance of stream depth and prey size. Pages 333-351 *in* W. C. Kerfood, and A. Sih, editors. Predation: direct and indirect impacts on aquatic communities. University Press of New England, Hanover, New Hampshire.

Prenda, J., P. D. Armitage, and A. Grayston. 1997. Habitat use by the fish assemblages of two chalk streams. Journal of Fish Biology 51:64-79.

Propst, D. L., K. B. Gido, and J. A. Stefferud. 2008. Natural flow regimes, nonnative fishes, and native fish persistence in arid-land river systems. Ecological Applications 18:1236-1252.

Rinne, J. N. 1992. Physical habitat utilization of fish in a Sonoran desert stream, Arizona, southwestern United States. Ecology of Freshwater Fish 1:35-41.

Rinne, J. N., B. Holland, and G. Sundnes. 2001. Comparison of heart rate in fishes: cold, temperate sea water versus warm, desert rivers. Pages 13-26 *in* K. Gamperl, T. Ferrel, and D. MacKinlay, editors. Proceedings of the International Congress on the Biology of Fish. University of British Columbia, Vancouver, British Columbia, Canada.

Schade, C. B., and S. A. Bonar. 2005. Distribution and abundance of nonnative fishes in streams of the western United States. North American Journal of Fisheries Management 25:1386-1394.

Schwartz, J. S., and E. E. Herricks. 2004. Use of prepositioned areal electrofishing devices with rod electrodes in small streams. North American Journal of Fisheries Management 21:1330-1340.

Sigler, J. W., and W. F. Sigler 1996. Fishes of Utah. University of Utah Press, Salt Lake City.

Strakosh, T. R., R. M. Neumann, and R. A. Jacobson. 2003. Development and assessment of habitat suitability criteria for adult brown trout in southern New England rivers. Ecology of Freshwater Fish 12:265-274.

Sublette, J. E., M. D. Hatch, and M. Sublette 1990. The Fishes of New Mexico. University of New Mexico Press, Albuquerque.

Thomas, J. A., and K. D. Bovee. 1993. Application and testing of a procedure to evaluate transferability of habitat suitability criteria. Regulated Rivers: Research and Management 8:285-294.

(USDA) United States Department of Agriculture - Forest Service, 2001, Biological assessment and evaluation for the Cherry Creek ecosystem analysis area. Tonto National Forest, Pleasant Valley Ranger District.

Valdez, R. A., T. L. Hoffnagle, C. C. McIvor, T. McKinney, and W. C. Leibfried. 2001. Effects of a test flood on fishes of the Colorado River in Grand Canyon, Arizona. Ecological Applications 11:686-700.

Ward, D. L., A. A. Schultz, and P. G. Matson. 2003. Differences in swimming ability and behavior in response to high water velocities among native and nonnative fishes. Environmental Biology of Fishes 68:87-92.

Weitzel, D. L. 2002. Conservation and status assessments for the bluehead sucker (*Catostomus discobolus*), flannelmouth sucker (*Catostomus latipinnis*), roundtail chub (*Gila robusta*), and leatherside chub (*Gila copei*): rare fishes west of the Continental Divide, Wyoming. Research Report. Wyoming Fish and Game Department, Laramie, WY.